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HYDROGENATION OF CO₂ INTO METHANOL AND DIMETHYL ETHER OVER HYBRID CATALYSTS

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ABSTRACT

The development of technology for utilization of CO₂ is of importance in recent years due to the greenhouse effect. The catalytic hydrogenation of CO₂ into methanol and dimethyl ether was carried out over a hybrid-catalytic system. Different ratios of Cu/ZnO/Al₂O₃:zeolite catalysts have been formulated and characterized. The methanol-synthesis catalyst, Cu/ZnO/Al₂O₃ (CuO:ZnO:Al₂O₃ 50:45:5), was prepared by a co-precipitation method. The copper catalyst was physically mixed with ZSM-5 zeolite at ratios of 1:1, 1:2 and 2:1. The hybrid catalysts were characterized using the x-ray diffraction method (XRD), temperature-programmed reduction (TPR), temperature-programmed desorption (TPD) of ammonia, nitrogen adsorption, scanning electron microscopy (SEM) and reactive frontal chromatography (RFC). The hydrogenation reaction was carried out in a tubular micro reactor at 250 °C and 40 bar using H₂/CO₂ feed ratios of 3 and 7. Products detected include methanol, dimethyl ether, carbon monoxide and water. Selectivity of products was depending upon the amount of copper-zeolite constituent and H₂/CO₂ feed ratio. The Cu/ZnO/Al₂O₃:zeolite hybrid catalysts showed over 30% CO₂ conversion.

Keywords: CO₂; methanol; dimethyl ether; hydrogenation; hybrid catalyst; copper catalyst; zeolite

INTRODUCTION

Efficient utilization of CO₂ has attained great importance in recent years due to global warming issues. Hydrogenation of CO₂ into methanol is one of the most promising methods of CO₂ utilization. However, thermodynamic constraint and equilibrium limitation of this process led to low conversion of CO₂ due to the water–gas shift reaction. In order to overcome the equilibrium limitation, a third reaction can be added to shift the equilibrium and favor the methanol synthesis reaction [1]. By combining methanol–synthesis (MS) catalyst (Cu-based) with a solid acid (zeolite), which facilitates methanol dehydration (MD) in the form of a hybrid–catalytic system, dimethyl ether (DME) and hydrocarbons were formed with improved conversion of CO₂ (more than 20%) due to the consecutive conversions of methanol and CO. Moreover, the CO₂ conversion to clean liquid fuel such as methanol and dimethyl ether (DME) could provide a way to produce a secondary energy carrier for using renewable energy more efficiently. At present, DME is produced by methanol dehydration (MD) over solid acid catalysts such as γ-alumina and HZSM-5 zeolite, whereas methanol is synthesized from syngas over Cu/ZnO/Al₂O₃ catalysts [2]. The development of a hybrid-catalytic system in concurrent production is perhaps not only to increase.

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the activity but also to facilitate the consecutive reactions of the primarily formed products from the diminution of CO selectivity [3].

Currently, methanol is produced industrially using ternary catalyst system comprising Cu/Zn/Al oxide at 5-10 MPa and 473-523 K with syngas feedstock. However, the catalyst system that is active for CO-rich feedstock is not so active for the CO2-rich sources under operating conditions of interest. Utilizing CO2 as an alternative feedstock replacing CO in the methanol production is regarded as an effective way of reducing CO2 in the atmosphere.[4].

This paper reports the results of the physical and chemical characterizations of the hybrid catalysts as well as the performance of the hybrid catalytic systems in the direct hydrogenation of CO2 into methanol and dimethyl ether (DME).

**EXPERIMENTAL DETAILS**

The methanol-synthesis (MS) catalyst was prepared by a co-precipitation method. The CuO/ZnO/Al2O3 catalyst precursor with 50/45/5 weight percent ratio was prepared by mixing an appropriate amount of aqueous solutions of copper, zinc and aluminum nitrate (Sigma Aldrich 99.8%) and sodium carbonate (Merck 99.8%). Temperature and pH were maintained at 40 °C and 7.0, respectively, during the precipitation. The precipitate was dried at 120 °C overnight and calcined in air at 280 °C for 12 hours. Zeolite HZSM-5 (Si/Al=140) was designated as the methanol dehydration (MD) catalyst. In the preparation of hybrid catalysts, the calcined CuO/ZnO/Al2O3 powder was physically mixed with zeolite H-ZSM-5 at weight ratios of 2:1, 1:1 and 1:2 [5].

XRD analyses were performed using a Bruker D8 Advanced diffractometer instrument equipped with a CuKα radiation source, operated at 40 kV and 30 mA. The temperature-programmed reduction (TPR), temperature-programmed desorption of ammonia (TPD-NH3) and reactive frontal chromatography (RFC) analyses were carried out using a Thermo Electron TPDRO 1100 instrument equipped with a mass spectrometer (Balzers). TPR profiles were scanned from room temperature to 600 °C at 10 °C/min with 5% H2/He gas flowing at 20 mL/min [5]. Temperature-programmed desorption (TPD) of ammonia was used to examine acid sites of the catalyst. Catalyst sample was initially heated under He flow at 400 °C for 1 hour, then it was cooled to 100 °C, where He flow was replaced by NH3. The NH3 flow was maintained for 3 hours to allow for adsorption of NH3 on the catalyst and then NH3 was replaced by helium. The temperature was then increased to 800 °C at a rate of 7.6 K/min where He flow was maintained for another hour. Copper dispersion and metal area were determined via reactive frontal chromatography (RFC) method [6]. As N2O molecules encountered copper on the catalyst, it decomposed totally to N2. The sample was reduced with 5% H2 in He stream flowing at 25 mL/min and 250 °C for 16 hours and subsequently flushed with He for another 1 hour. The temperature was then lowered to 60 °C under the flow of He. Then the reactive gas (2% N2O in He) was introduced continuously to the catalyst sample at 25mL/min and the eluted N2O and N2 (mass of 44 and 28, respectively) were monitored on-line using the mass spectrometer. The BET surface area and pore size distributions were determined by a Micromeritics ASAP 2000 instrument. The SEM/EDX analyses were performed on an Oxford Instrument INCA-sight (model LEO 1430 VP). The particle size distribution was obtained from the Malvern 2000 particle size analyzer.

The CO2 hydrogenation was carried out in a microtubular fixed–bed reactor, shown in Figure 1. One gram of the catalyst powder was loaded in the microreactor and reduced in a flow of 10% H2 in He at 250 °C for 1 hour. A H2/CO2 gas mixture (H2:CO2 = 7:1 and 3:1) was fed into the microreactor and the experiment was performed at 250 °C and 40 bar for five hours. Output from the reactor was analyzed by an on-line gas chromatograph equipped with TCD and FID detectors.
RESULTS AND DISCUSSION

Table 1 shows the characteristics of the catalysts. The pure Cu/ZnO/Al₂O₃ (CZA) catalyst had the lowest surface area and the pure H-ZSM5 catalyst showed the largest surface area whilst the surface area of the hybrid catalysts ranged between those of the CZA and the H-ZSM-5. The 1:1 hybrid ratio exhibited the highest % Cu dispersion whereas the 1:2 hybrid ratio displayed the lowest % Cu dispersion. The area for copper metal was found to be proportional to the copper content in the hybrid catalyst.

The SEM results revealed spherically-shaped, uniform-sized particles and the EDX results indicated that elements were evenly dispersed within the catalyst matrix. XRD analyses depicted the presence of Al₂O₃·5SiO₂, CuO, ZnO as well as CuZnCuO species in the catalyst hybrids. The TPR profiles revealed reduction temperature of 190-230 °C and the highest amount of H₂ adsorbed per gram sample was achieved by the 1:1 hybrid catalyst ratio.

Figure 2 shows the TPD-NH₃ spectra of the hybrid catalysts. Each profile shows two distinct regions. The peak at 285-295 °C (L) represents a weak acid sites whereas the peak which appeared at higher temperature around 500-515 °C (H) was attributed to the Brønsted strong acid sites [7]. The Brønsted acid sites are known to catalyze the dehydration of methanol to DME [8]. Increasing the amount of H-ZSM-5 in the hybrid did not modify the strength of

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Mean Particle Size (μm)</th>
<th>BET Surface Area (m²/g)</th>
<th>Mean Pore Diameter (Å)</th>
<th>Cu Metal Area (m²/g)</th>
<th>Cu Dispersion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZA</td>
<td>179</td>
<td>70.6</td>
<td>207.9</td>
<td>49.1</td>
<td>20.3</td>
</tr>
<tr>
<td>Hybrid 2:1</td>
<td>276</td>
<td>167.8</td>
<td>76.8</td>
<td>46.5</td>
<td>16.6</td>
</tr>
<tr>
<td>Hybrid 1:1</td>
<td>382</td>
<td>226.3</td>
<td>50.2</td>
<td>34.1</td>
<td>20.8</td>
</tr>
<tr>
<td>Hybrid 1:2</td>
<td>248</td>
<td>284.3</td>
<td>38.1</td>
<td>18.6</td>
<td>14.6</td>
</tr>
<tr>
<td>H-ZSM-5</td>
<td>26</td>
<td>380.2</td>
<td>21.6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of catalysts.
the acid sites but changed the number of the acid sites. The hybrid catalyst with a 1:1 ratio exhibited the highest total number of acid sites followed by the hybrid catalysts of 2:1 and 1:2 ratios. Although the hybrid catalyst with 1:2 ratio has higher percentage of zeolite compared to the other two compositions, the amount of acid site was found to be lower compared to those of the other two compositions. This trend suggested that the amount of acid site was not directly related to the zeolite content but it was influenced by the interaction between the MS and the MD parts of the hybrid catalysts. There seemed to be a stronger interaction between the MS and the MD parts of the 1:1 catalyst hybrid compared to those of the 2:1 or the 1:2 hybrids.

Table 2 summarized the performance of Cu/ZnO/Al2O3, H-ZSM-5 and catalyst hybrids in the catalytic hydrogenation of CO2. The Cu/ZnO/Al2O3 catalyst resulted in 35.7% CO2 conversion and 61% methanol selectivity. The pure H-ZSM-5, on the other hand, did not show any activity towards CO2 conversion. The highest CO2 conversion and methanol yield was obtained over the hybrid catalyst with 2:1 ratio. However, the catalyst hybrid having 1:1 ratio produced relatively high yields of methanol and DME as well as the lowest yield of undesired products (CO and H2O). Hence, the 1:1 ratio was concluded as the best hybrid catalyst amongst the catalysts tested in this study.

Figure 3 shows the plot for CO2 conversion as a function of time for various catalysts at H2/CO2 feed ratio of 3:1. Steady state was reached after two hours of reaction. The highest CO2 conversion achieved was 38% and it was obtained using the hybrid catalyst of 2:1 ratio. The performance of the copper catalyst was similar to those of the 1:1 hybrid, in which 35.6% CO2 conversion was attained at steady state. The CO2 hydrogenation reaction produced oxygenates, namely methanol and DME, together with CO and H2O. Product distributions obtained over the 3:1 and 7:1 H2/CO2 feed ratios, are shown in Figures 4 and 5, respectively. The selectivity for the oxygenates (methanol + DME) ranged between 46% to 64% for the 3:1 feed ratio. The values of oxygenates selectivity decreased slightly when the feed ratio was increased to 7:1.
The performance of the catalysts from this work was slightly better than those reported by others, as depicted in Table 2. Park and co-workers [3] reported oxygenates yield of 10.70% using the Cu/ZnO/Al₂O₃-H-ZSM-5 (1:1) at temperature of 250 °C and pressure of 2.0 MPa. Other workers [9] have investigated the CO₂ hydrogenation in a traditional catalytic packed bed reactor and a membrane reactor at a temperature of 206 °C and a pressure of 20 bar. The membrane reactor was found to perform better than the packed bed reactor. Using the membrane reactor, they obtained CO₂ conversion of 11.6% and methanol selectivity of 75% whereas using the traditional packed bed reactor, the values obtained were 5% and 48%, respectively. Other researchers [10] have investigated the CO₂ hydrogenation reaction at relatively high temperature of 400 °C and 28 atm using the CuZnO/ZrO₂ + H-ZSM-5 (ion-exchanged) hybrid catalysts as well as CuZnO/ZrO₂ + SAPO zeolites and CO₂ conversion was reported as 38.9% and 38.3%, respectively. However, the presence of ZrO₂ in SAPO-34 zeolite catalyst hybrid only resulted in 2.0% and 0.1%, methanol and DME yields, respectively.

**CONCLUSION**

Three MS: MD hybrid catalysts at weight ratios of 1:1, 1:2 and 2:1 were prepared by mixing copper-based catalyst (MS) and zeolite H-ZSM-5 (MD) catalyst. The hybrid catalysts were characterized by various methods such as XRD, TPR, TPD-NH₃, RFC, SEM/EDX, particle size analysis and N2 adsorption. The hybrid catalyst with weight ratio of MS:MD at 1:1 adsorbed the highest amount of hydrogen, had the highest Cu dispersion and exhibited the highest number of acid sites amongst the samples tested. The 1:1 hybrid catalyst also appears to be the most promising catalyst amongst the three hybrid catalysts tested for the hydrogenation of CO₂ to methanol and DME. The highest CO₂ conversion obtained was 38%. The highest yields of methanol and DME achieved over the hybrid catalyst were 23.9% and 0.52%, respectively.

**Table 2.** Catalyst performance for CO₂ hydrogenation reaction.

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Cu loading (wt %)</th>
<th>Cu dispersion (%)</th>
<th>CO₂ conversion (%)</th>
<th>CH₃OH yield (%)</th>
<th>DME Yield (%)</th>
<th>CO+H₂O Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu/ZnO/Al₂O₃</td>
<td>45</td>
<td>14.6</td>
<td>35.7</td>
<td>21.9</td>
<td>0</td>
<td>13.7</td>
</tr>
<tr>
<td>Hybrid (2:1)</td>
<td>33.3</td>
<td>20.3</td>
<td>38.0</td>
<td>23.9</td>
<td>0.46</td>
<td>13.6</td>
</tr>
<tr>
<td>Hybrid (1:1)</td>
<td>25.0</td>
<td>20.8</td>
<td>36.0</td>
<td>22.0</td>
<td>0.52</td>
<td>13.5</td>
</tr>
<tr>
<td>Hybrid (1:2)</td>
<td>16.7</td>
<td>16.6</td>
<td>33.5</td>
<td>15.1</td>
<td>0.50</td>
<td>18.0</td>
</tr>
<tr>
<td>H-ZSM-5</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cu/ZnO/Al₂O₃/ H-ZSM-5 [3]</td>
<td>24</td>
<td>-</td>
<td>21.7</td>
<td>8.3</td>
<td>2.3</td>
<td>10.9 (CO)</td>
</tr>
<tr>
<td>Cu/ZnO/Al₂O₃ [9]</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu/ZnO/ZrO₂ + H-ZSM-5 [10]</td>
<td>60</td>
<td>-</td>
<td>38.9</td>
<td>0.9</td>
<td>-</td>
<td>36.4 (CO)</td>
</tr>
<tr>
<td>Cu/ZnO/ZrO₂ + SAPO-34 [10]</td>
<td>60</td>
<td>-</td>
<td>38.3</td>
<td>2.0</td>
<td>0.1</td>
<td>33.3 (CO)</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

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ABSTRACT

The steam reforming process used for syngas production is always accompanied by coke deposition and metal sintering leading to catalyst deactivation. The common practice at the moment on catalyst disposal is the responsibility of the catalyst supplier of the plant without undergoing any regeneration process. The objectives of this project include identifying the cause of deactivation and developing a suitable regeneration process for recovery of active sites on the spent reforming catalyst. First, the spent catalyst was characterized via temperature-programmed reduction technique to identify the deactivation criteria of the catalyst. This was followed by subsequent reduction-oxidation treatments on the spent catalyst and the effects monitored by temperature-programmed reduction technique. The reduction profile of the spent catalyst indicated the presence of sintered nickel particles and also loss of nickel. No coke deposition was detected. The reduction profile of the spent catalyst with subsequent reduction-oxidation cycles showed evidence of redispersion for both the inactive NiAl2O4 species and also the sintered Ni particles.

Key words: Ni, steam reforming, spent catalyst, regeneration, temperature-programmed reduction

INTRODUCTION

The steam reforming process for syngas production gave higher H2:CO ratio as shown by the following reaction:

\[
\text{CH}_4 + \text{H}_2\text{O} \rightarrow 3\text{H}_2 + \text{CO} \quad \Delta H^\circ_{298K} = 206 \text{ kJ mol}^{-1}
\]

However, this process is always accompanied by coke deposition and metal sintering leading to catalyst deactivation [1,2]. Since coking has always been associated with larger Ni particles, coke deposition and metal sintering are interrelated. Catalysts based on noble metals are reported to be less sensitive to coking than Ni-based catalysts, but Ni is available at low price and highly active for this reaction [1]. Recently, there has been proposal that NiAl2O3 catalysts promoted with MgO are more resistant to carbon formation [3,4]. This may be associated to the presence of more dispersed Ni particles on the magnesium aluminate (MgAl2O4) spinel support, which inhibits coking. In addition, the presence of Mg could also prevent the formation of non reactive NiAl2O4 [5]. Therefore, MgAl2O4 could offer desirable properties as catalyst support for steam reforming of methane due to its low acidity and resistance to sintering [6].

Currently, spent Ni/MgAl2O4 steam reforming catalysts are disposed by the catalyst suppliers of the plant without undergoing any regeneration procedure. This project is focused on identifying the cause of deactivation and developing a suitable regeneration process for recovery of active sites on the spent catalyst.
EXPERIMENTAL

The fresh and spent catalysts in this project were obtained from a chemical plant in Malaysia.

A series of oxidation or reduction followed by oxidation (reduction-oxidation) treatments were conducted on the spent catalyst to identify the optimum conditions for regeneration process. Figure 1 shows the flow diagram for the treatments and also the treated samples designation. Spent catalyst which has undergone oxidation at 600 °C for 120 min was designated as Ox6_120. On the other hand, reduction at 300 °C for 30 min followed by oxidation at 400 °C for 60 min was designated as R3_30/Ox4_60. Properties of the fresh and spent catalysts and also the treated samples were analyzed using a temperature programmed reduction (TPR) method where Thermo Finnigan TPDRO 1100 instrument was used. The TPR analyses were carried out in a mixture of 5% H2/N2 at a flow of 20 ml/min and the temperature was raised to 800 °C at a ramp of 10 °C/min. Temperature programmed oxidation (TPO) was also carried out on the fresh and spent catalysts. The analyses method was similar to the TPR method but 5% O2/He was used instead. A Shimadzu FTIR-8400S spectrometer with 4 cm⁻¹ resolution was used to determine the presence of carbonaceous materials on the spent catalyst.

RESULTS AND DISCUSSION

Figure 2 compares the TPR profiles of the fresh and spent catalysts. The fresh catalyst displayed peaks at 260 °C, 495 °C, 615 °C and a shoulder around 400 °C. Similar reduction profile was also observed by some researchers [7,8]. Reduction peaks below 280°C are associated with unbounded free NiO [7, 8] while those in the range from 420-500 °C are associated with surface NiO interacting with MgAl₂O₄ spinel support [4]. Higher reduction temperature of this species is related to stronger metal-support interaction displayed by smaller size particles. The reduction peak at 615 °C may be attributed to reduction of NiO particles having strong interaction with MgAl₂O₄ spinel support. The shoulder at 400 °C may be associated with some segregated Ni particles having low interaction with the support [9].
The drastic reduction in the peak intensities (Figure 2) and also the amount of hydrogen consumption (Table 1) for the spent catalyst compared to for the fresh catalyst strongly indicate loss of Ni content for the spent catalyst. This indication is further supported by the TPO results (no signals detected) which suggest that the Ni species are mainly in the oxidized form.

**Table 1**: Reduction peaks and the total hydrogen consumption of the fresh and spent catalysts

<table>
<thead>
<tr>
<th>Sample</th>
<th>Reduction peak, °C</th>
<th>Total H₂ consumed (mmol/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>260, 495, 615</td>
<td>1,466.58</td>
</tr>
<tr>
<td>Spent</td>
<td>200, 450, 520, 800</td>
<td>79.20</td>
</tr>
</tbody>
</table>

Figure 3 shows the reduction profile of the spent catalyst. The reduction profile displayed peaks at 200 °C, 450 °C, 520 °C, 800 °C and a shoulder around 400 °C. The peak at 200 °C may be associated with minute amount of unbounded free NiO [8] while the peak at 450 °C may represent the presence of surface NiO interacting with MgAl₂O₄ spinel support [4]. The shift to lower reduction temperature compared to for the fresh catalyst indicates formation of larger Ni particles (with less metal-support interaction) due to sintering. Partially oxidized NiOₓ species could be present in the spent catalyst associated with a reduction peak at 520 °C [10]. Any reduction peaks observed at higher temperatures are associated with NiAl₂O₄ species [4,10,11]. A similar shoulder as for the fresh catalyst is observed at 400 °C which may be associated with some segregated Ni particles having low interaction with the support [9].

The FTIR spectrum of the spent catalyst in Figure 4 displays the presence of –OH functional group only: –OH stretching (3600-3200 cm⁻¹) and bending (1650-1600 cm⁻¹). The analysis did not show any sign of coke deposition.

Figure 5 provides the comparison of the reduction profiles of the spent catalyst and the treated spent catalysts; Ox4_120 and R3_60/Ox4_60. Oxidation treatment at 400 °C, Ox4_120, displayed two reduction peaks at 460 °C and 520 °C indicating the presence of surface NiO interacting with MgAl₂O₄ spinel support [4] and partially oxidized NiOₓ species [10], respectively.
After regeneration via reduction-oxidation treatment, the sample (R3_60/Ox4_60) begins to reduce at 260 °C with a maxim at 314 °C. This indicates that segregation of the nickel particles on the support has occurred. The low reduction temperature is associated with the low interaction of the segregated Ni particles with the support [9]. Another reduction peak at 461 °C was observed for R3_60/Ox4_60 which is associated with surface NiO interacting with MgAl₂O₄ spinel support [4].

**CONCLUSION**

In conclusion, the best regeneration process conducted on the spent catalyst is by subjecting it to a treatment cycle comprising of reduction in H₂ at 300 °C for 1 h followed by oxidation in O₂ at 400 °C for another hour. The reduction profile of the spent catalyst indicated the presence of small amount of inactive NiAl₂O₄ and also some sintered Ni particles. These species could be redispersed into smaller and more active species via reduction-oxidation treatments that displayed reduction peaks at lower temperature range. No coke deposition was detected on the spent catalyst. The possible causes for deactivation of the steam reforming catalyst are sintering, loss of Ni content and also formation of inactive Ni/Al₂O₄.

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**REFERENCES**


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DRILLING MUD MATERIAL COST SAVING THROUGH UTILIZATION OF TREATED MALAYSIAN LOCAL BENTONITE

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ABSTRACT

Based on the results of the investigation of the Malaysian Geological Survey Department, bentonite resources in Sabah are large. In order to reduce the overall cost in oilwell drilling and completion, the development of Sabah bentonite as drilling mud material has been initiated. Mineralogically, the samples were characterized as low grade Ca-Mg smectite. The dominant gangue mineral is ferrous ion with small amounts of kaolinite, quartz, illite, muscovite and hematite. Iron is present as magnetite and as amorphous oxides and hydroxides. Characterization of these samples indicated that the bentonite response for Na-exchange was poor while their hydration, plastic and rheological properties were inferior to those of commercial bentonite (WY-BEN). The sample was processed by crushing followed by aero cyclone to give pre-concentrates, which were then extracted with diluted oxalic acid and activated with sodium carbonate. Application of such simple flow sheet effectively removed the majority of the associated ferrous ion. These concentrates were further refined by a series of organic acid and alkaline treatment prior to their evaluation as industrial bentonite. The mineralogy, chemical analysis and physical properties of final concentrates and their activated products successfully match the required specifications for drilling mud industrial processes. Utilization of bentonite after their extraction and activation, adds value to the Sabah economy by minimizing imported bentonite used by oil and gas industry.

Keywords: Bentonite, mineralogy, extraction, organic acid, activation, drilling mud

INTRODUCTION

Bentonite (Al\textsubscript{0.2693}Fe\textsuperscript{2+}0.7212Mg\textsubscript{0.1374})(Si\textsubscript{3.5808}Al\textsubscript{0.4192})X\textsubscript{0.5855}nH\textsubscript{2}O is by far the most abundant of the smectite clay minerals. In the drilling industry, bentonite is generally classified as sodium (Na) or calcium (Ca) types, depending on dominant exchangeable ion. The major problems facing the utilization of Sabah bentonite are their low concentration of smectite, high level of iron contaminant and inconsistent composition. Previous studies on some Sabah bentonite suggest that, without upgrading, they were unsuitable as drilling mud material. Response of this bentonite to Na-exchange was poor and their hydration, plastic and rheological properties were inferior to that reference bentonite [1]. Several attempts were made to upgrade to meet OCMA/API specification for drilling fluid and other industrial uses. [2,3,4]. This paper presents the utilization of treated Malaysian local bentonite for drilling mud material cost saving. The tests were conducted on run-of-mine (ROM) and chemically activated samples. Chemical methods involve extraction of the minerals with organic acid and cation exchange capacity measurement.
EXPERIMENTAL WORK

BENTONITE SAMPLE

In this study, two groups of local bentonite samples were collected, namely SA5-1, SA5-3, SA5-4 and SA5-7 (N 4°18.97’- E 117°57.37’) from Andrassy area in Tawau district and M4 (N 5°7.35’- E 118°12.03’) from Mansuli area in Lahad Datu district. The SA5-1 and SA5-3 samples were collected exactly at 0.5 m depths. SA5-4 and SA5-7 samples were collected at 1.0 – 1.5 m depths and M4 at 0.3 m depths. The field sampling from Mansuli area were taken mainly from the area underlain by the Ayer Formation, which is collectively from the Segama Group and is interpreted to be Miocene in age. The Andrassy area is underlain mainly by the high level of alluvium and volcanic rock, and occur in a bed underlying of Pleistocene to Holocene in age [1].

EXPERIMENTAL PROCEDURE

Utilization Process

Bentonite samples from the field were dried in the oven at 35 °C for four hours until it reached moisture content less than 10%. Then the sample were then crushed using a Jaw crusher to 100% below 75 μm in size. This was followed by aero cyclone model EPC100P [5], to separate the smectite from its associating gangue minerals. Both the aero cyclone underflow (coarser than 75 μm) and the overflow fractions (finer than 75 μm) were filter dried at 55 °C and weighed. Underflow fractions, which were heavily contaminated with iron and free-silicon impurities, were discarded. Meanwhile, the overflow fractions were used as bentonite pre-concentrates. The latter products were further upgraded by extracting their residual iron impurities, with 7.1 kg m⁻³ oxalic acid solutions for 2h at 80 °C temperature. The bentonite was beneficiated to improve its smectite content by removing the associated gangue minerals (mainly iron and free-silicon).

PHYSICAL AND CHEMICAL PROPERTIES DETERMINATION

The common chemical property of bentonite is pH, cation exchange capacity (CEC) and specific surface area (SSA). pH values were measured by pH meter Model Hanna HI8424, which adapted generally from the BS1377: Part3: 1900: 9 [6]. SSA was measured using the methylene blue spot test [7]. In addition, the physical properties determinations include the Atterberg limit such as liquid limit (LL), plastic limit (PL) and plasticity index (PI), moisture absorption (MA), moisture content (MC) and ignition loss (IL). Methylene Blue Test (MBT) is used to estimate the CEC. A sodium-based bentonite should have a CEC value same as that of bentonite (80 – 10 meq/100 grams). Approximately 1 gram of bentonite sample will be tested in 50 ml of distilled water with about 0.5 ml of SN sulfuric acid added. The bentonite solution will be boiled gently for 10 minutes. The CEC is measured by conductomercial titration after cation exchange, in meq/100 grams. The standard testing method for liquid and plastic limit is according to ASTM D4318-84 [8]. Liquid limit and plastic limit also referred to as Atterberg limit, depends on the moisture content of the sample. The liquid limit provides the moisture content at which the clay changes from plastic to the liquid state. The plastic limit is simply the moisture content at which a ball of clay when rolled to a diameter of 1/8 inch. On the other hand, plasticity index is the difference between liquid limit and plastic limit. In addition, the moisture adsorption (MA), moisture content (MC) and ignition loss (IL) of sample will also be determined since the qualitative mineral content of sample can be studied. Moisture adsorption (MA) is defined as the percentage of water lost when clay from saturated atmosphere (around 20 °C) is dried in an oven at 105 °C. The analysis of moisture adsorption followed the ASTM. Committee D4318-00. Moisture adsorption (MA) value can be used to predict the mineralogy nature for clay. Moisture content (MC) is the percentage of water lost when clay from normal room temperature atmosphere (at around 20 °C) is dried at 105 °C. The ignition loss is the percentage of weight lost when a dried clay (at 105 °C) is fired to 1000 °C in the furnace.
MUD RHEOLOGICAL TESTS

In testing the rheological properties of the activated products, the suspension was re-agitated for 5 min, using a mixer, and then transferred to the viscometer at a rotor speed of 600 rpm. The readings of the viscometer were recorded at 5 min intervals until a stable reading was attained. This procedure was repeated at a rotor speed of 300 rpm. The reading of the viscometer at 600 rpm is taken as the apparent viscosity (A.V.) while the difference between the readings taken at 600 and 300 rpm represents the plastic viscosity (P.V.). The yield point (Y.P.) is calculated from the difference between the reading of viscometer at 300 rpm and plastic viscosity. Fig. 1 shows a simplified flow sheet for the beneficiation scheme. Testing of the samples as a raw material for drilling fluid was carried out according to Section 11 of the API specifications 13A. [10].

RESULTS AND DISCUSSION

THE MINERALOGY

From qualitative analysis (Table 1), after organic acid beneficiation, the mineral composition of the Andrassy samples changed with minor improvement (SA5-4 and SA5-7). From quantitative analysis (Table 2), the overall montmorillonite composition in the bentonite slightly changed. It is clear that the beneficiation by using oxalic acid had successfully removed iron content as impurities in the sample and the quantity of the montmorillonite in all samples have increased.

Table 1. Semi-quantitative analysis of beneficiated Andrassy and Mansuli samples

<table>
<thead>
<tr>
<th>Mineral Composition</th>
<th>Commercial Bentonite</th>
<th>Beneficiated Bentonite Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SA5-1</td>
<td>SA5-3</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>Quartz (SiO₂)</td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Kaolinite Al₂Si₂O₅(OH₄)</td>
<td>nd</td>
<td>*</td>
</tr>
<tr>
<td>Illite (K, H₂O) Al, Mg, (Si, Al)₂O₁₀</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Others</td>
<td>Feldspar KAlSi₃O₈</td>
<td>*</td>
</tr>
</tbody>
</table>

Keys:
**** = dominant  *** = major  ** = minor,
* = appreciable  tr = trace  nd = not detect

Table 2. Quantitative analysis of beneficiated Andrassy and Mansuli samples

<table>
<thead>
<tr>
<th>Montmorillonite content (%Volume)</th>
<th>SA5-1</th>
<th>SA5-3</th>
<th>SA5-4</th>
<th>SA5-7</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43.78</td>
<td>47.74</td>
<td>53.76</td>
<td>53.89</td>
<td>44.83</td>
</tr>
</tbody>
</table>

| Percentage of change after beneficiation process (%) | 186 | 226 | 47 | 54 | 258 |
MC, MA, IL

The MC, MA and IL results of beneficiated Andrassy and Mansuli are as shown in Table 3. It is observed that the MC for the beneficiated sample had been increased in the range of 9.92% to 63.33% of the original values. The beneficiated M4 sample from Mansuli area, had been dramatically increased i.e., 63.33% of the original value because of reduced free-silicon content. It is indicated that the beneficiated SA5-3 sample has a very low MC as compared to other bentonite samples due to low water adsorption and cation exchange since its closer to plastic kaolin region. The water in the lattice of bentonite mineral is important as an agent of chemical reaction such as ion exchange and adsorption into the mineral. The mineral moisture distribution is important for the sorption characteristics because mineral with higher specific gravity are transported in the solution. The reference bentonite sample shows higher moisture content and plasticity index compared to beneficiated Andrassy and Mansuli samples. The low moisture content in Andrassy and Mansuli samples was due to the low percentage of montmorillonite mineral as shown in Table 1 & Table 2. There are some improvements in MA values as shown in Table 3 due to reducing iron and free-silicon content in the samples, i.e. increment of 3.42% to 79.26% which is still not as good as the reference bentonite. The IL values Andrassy and Mansuli samples are higher than raw bentonite samples, except for the SA5-3 sample, since the water molecules in SA5-3 sample is located within the tetrahedral and octahedral sheets of bentonite crystal structure.

Atterberg Limit

Generally after beneficiation, Andrassy samples showed improvement in liquid limit with increment varying from 89.82% to 229.63% of the original values, as shown in Table 3. These samples also showed improvement in plastic limits, with increment varying from 0.40% to 37.13%. This again proved that the montmorillonite mineral plays an important role that influences the plasticity of a sample. These results show that the iron and free-silicon content as impurities in the raw bentonite decreased, but the improvement is still not as good as reference bentonite. As shown in Table 3, after beneficiation, the plasticity index of beneficiated Andrassy and Mansuli samples had also been improved with increment varying from 181.78% and 582.57%. This means that the water absorption capabilities of these samples are better than the raw ones. The low percentage of bentonite mineral in the sample has resulted in lower moisture content and plasticity index.

CHEMICAL PROPERTIES

Cation Exchange Capacity (CEC)

From Table 4, we can see that the CEC of beneficiated Andrassy and Mansuli samples have improved. This will have a positive impact on hydration and swelling capability when used as a material in drilling mud. However, their CEC values are still much less than the reference bentonite (CEC of 80 meq/100 g).

Table 3. MC, MA and IL values and Atterberg Limit of beneficiated Andrassy and Mansuli samples

<table>
<thead>
<tr>
<th>Bentonite Sample</th>
<th>MC</th>
<th>% of change</th>
<th>MA</th>
<th>% of change</th>
<th>IL</th>
<th>% of change</th>
<th>LL (%)</th>
<th>% of change</th>
<th>PL (%)</th>
<th>% of change</th>
<th>PI (%)</th>
<th>% of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Bentonite</td>
<td>16.732</td>
<td>-</td>
<td>24.51</td>
<td>-</td>
<td>5.43</td>
<td>-</td>
<td>700</td>
<td>-</td>
<td>65</td>
<td>-</td>
<td>635</td>
<td>-</td>
</tr>
<tr>
<td>SA5-1</td>
<td>12.58</td>
<td>33.97</td>
<td>21.35</td>
<td>79.26</td>
<td>11.45</td>
<td>10.95</td>
<td>259.8</td>
<td>165.62</td>
<td>55.75</td>
<td>6.17</td>
<td>204.05</td>
<td>266.01</td>
</tr>
<tr>
<td>SA5-3</td>
<td>11.99</td>
<td>0.42</td>
<td>17.62</td>
<td>0.46</td>
<td>11.25</td>
<td>-0.18</td>
<td>120.25</td>
<td>89.82</td>
<td>32.25</td>
<td>0.40</td>
<td>88</td>
<td>181.78</td>
</tr>
<tr>
<td>SA5-4</td>
<td>12.65</td>
<td>33.3</td>
<td>22.85</td>
<td>6.13</td>
<td>11.45</td>
<td>1.24</td>
<td>278.5</td>
<td>126.72</td>
<td>49.25</td>
<td>5.57</td>
<td>229.25</td>
<td>365.48</td>
</tr>
<tr>
<td>SA5-7</td>
<td>14.85</td>
<td>9.92</td>
<td>22.98</td>
<td>3.42</td>
<td>7.52</td>
<td>3.72</td>
<td>458.98</td>
<td>134.05</td>
<td>58.65</td>
<td>15</td>
<td>400.33</td>
<td>582.57</td>
</tr>
<tr>
<td>M4</td>
<td>12.07</td>
<td>63.33</td>
<td>16.4</td>
<td>72.45</td>
<td>10.287</td>
<td>10.49</td>
<td>267</td>
<td>229.63</td>
<td>40.85</td>
<td>37.13</td>
<td>226</td>
<td>341.32</td>
</tr>
</tbody>
</table>
Specific Surface Area

Specific surface area is shown in Table 4. It is clearly seen that the beneficiated Andrassy samples showed some improvement in specific surface area. The treatment with oxalic acid had successfully removed iron in the samples, therefore the specific surface area of all samples improved. This proves that the SA5-4 sample (640 m²/g) is the most satisfactory sample that has a specific surface area closest to the reference bentonite (660.37 m²/g). However, it still has insufficient absorption capability due to the low content of montmorillonite mineral in the local sample. The SA5-1, SA5-7 and M4 samples also exhibited increments in specific surface area. Since there is only limited or small amounts of montmorillonite mineral, these beneficiated samples still failed to reach the specific surface area of reference bentonite (660.37 m²/g). As for SA5-3 sample, due to its low content of montmorillonite mineral, an increment of specific surface area to 17% is considered encouraging.

DRILLING MUD PERFORMANCE

As shown in Table 5, the beneficiated Andrassy and Mansuli sample still failed to meet the API specification 13A except for YP/PV ratio and moisture content. However, it is clearly seen that the beneficiated samples show improvement in two important parameters; viscometer 600 rpm dial reading and filtrate loss, i.e. around 380% to 700% of viscometer 600 rpm dial reading and, 60% to 85% of fluid loss reduction. This was generally caused by the presence of impurities and low amount of montmorillonite content of the

<table>
<thead>
<tr>
<th>Bentonite Sample</th>
<th>CEC (meq / 100 g)</th>
<th>Specific Surface (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original</td>
<td>Beneficiated</td>
</tr>
<tr>
<td>Reference Bentonite</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>SA5-1</td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>SA5-3</td>
<td>39.5</td>
<td>60</td>
</tr>
<tr>
<td>SA5-4</td>
<td>27</td>
<td>72</td>
</tr>
<tr>
<td>SA5-7</td>
<td>41</td>
<td>68</td>
</tr>
<tr>
<td>M4</td>
<td>25.24</td>
<td>36.05</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Suspension properties</th>
<th>API Spec. 13A, 1995 requirements</th>
<th>Reference Bentonite</th>
<th>SA5-1</th>
<th>SA5-3</th>
<th>SA5-4</th>
<th>SA5-7</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% of change</td>
<td>% of change</td>
<td>% of change</td>
<td>% of change</td>
<td>% of change</td>
<td>% of change</td>
</tr>
<tr>
<td>Viscometer Dial Reading at 600 rpm</td>
<td>30, min</td>
<td>28</td>
<td>14</td>
<td>600</td>
<td>10</td>
<td>400</td>
<td>24</td>
</tr>
<tr>
<td>Yield Point/Plastic Viscosity Ratio</td>
<td>3, max</td>
<td>1.2</td>
<td>1.00</td>
<td>203</td>
<td>0.525</td>
<td>0.00</td>
<td>1.10</td>
</tr>
<tr>
<td>Filtrate Volume (cm³)</td>
<td>15, max</td>
<td>16</td>
<td>17</td>
<td>-73</td>
<td>20.5</td>
<td>-74</td>
<td>16</td>
</tr>
<tr>
<td>Moisture content (% wt)</td>
<td>10, max</td>
<td>8.47</td>
<td>8.65</td>
<td>-8</td>
<td>8</td>
<td>-33</td>
<td>8.25</td>
</tr>
</tbody>
</table>
### Table 6. Polymer used in beneficiated Andrassy and Mansuli samples

<table>
<thead>
<tr>
<th>Polymer Dispersant</th>
<th>Viscometer dial reading</th>
<th>Gel (lb/100ft²)</th>
<th>pH</th>
<th>Filtrate (ml)</th>
<th>PV (cP)</th>
<th>YP (lb/100ft²)</th>
<th>YP/PV</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>300 rpm</td>
<td>600 rpm</td>
<td>10 second</td>
<td>10 minute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SA5-1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tannatin (% wt)</td>
<td>1.00%</td>
<td>4</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2.00%</td>
<td>6</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>4.00%</td>
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<td>15</td>
<td>0</td>
<td>0.5</td>
<td>8.5</td>
<td>14.5</td>
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<tr>
<td>CMC (% wt)</td>
<td>1.00%</td>
<td>3.5</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>8.5</td>
<td>32</td>
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<tr>
<td></td>
<td>2.00%</td>
<td>7.5</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>4.00%</td>
<td>10.5</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
<td>20</td>
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<tr>
<td><strong>SA5-3</strong></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Tannatin (% wt)</td>
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<td>10</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
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<tr>
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<td>15</td>
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<td>14</td>
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<tr>
<td></td>
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<td>18</td>
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<td>0</td>
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<td>12</td>
</tr>
<tr>
<td>CMC (% wt)</td>
<td>1.00%</td>
<td>9.5</td>
<td>15</td>
<td>4</td>
<td>20</td>
<td>8.5</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>2.00%</td>
<td>16.5</td>
<td>23</td>
<td>7</td>
<td>35</td>
<td>8.5</td>
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<td></td>
<td>4.00%</td>
<td>16</td>
<td>25</td>
<td>8</td>
<td>45</td>
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<td>17</td>
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<tr>
<td><strong>SA5-4</strong></td>
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<td></td>
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<td>3</td>
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<td>14</td>
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<td>10</td>
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<td>1.00%</td>
<td>14</td>
<td>19</td>
<td>8</td>
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<td></td>
<td>4.00%</td>
<td>19</td>
<td>30</td>
<td>15</td>
<td>40</td>
<td>8.5</td>
<td>15</td>
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<tr>
<td><strong>SA5-7</strong></td>
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<td></td>
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<tr>
<td>Tannatin (% wt)</td>
<td>1.00%</td>
<td>6</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>8.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2.00%</td>
<td>10</td>
<td>15</td>
<td>2</td>
<td>12</td>
<td>8.5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>4.00%</td>
<td>7</td>
<td>13</td>
<td>2</td>
<td>9</td>
<td>8.5</td>
<td>9</td>
</tr>
<tr>
<td>CMC (% wt)</td>
<td>1.00%</td>
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local bentonite samples, especially the SA5-3 sample. Hence, it is desirable to find a solution and the possible solution is to add some polymer extender that can improve the viscosity generated. There are two types of polymer dispersants were used for this study; Tannathin (Ground Lignite) and high viscosity carboxymethyl cellulose (CMC). Tannathin is normally used as a bentonite thinner, dispersant or as a filtration loss reducer. CMC is an example of polyelectrolyte and mainly depends on the degree of polymerization. The higher the degree of polymerization, the higher the molecular weight will be, and can generate more viscosity. From Figures 2 and 3, the viscometer 600 rpm dial reading is directly proportional to the increment of the polymer dispersant concentration. The bentonite suspensions with Tannathin show higher value of the reading as compared to the one with CMC. This is generally because the Tannathin originally is the specific dispersant for bentonite and has a better association with the bentonite particles. From these samples, the order from the lower to higher value of viscometer 600 rpm dial reading is as follows: SA5-3, M4, SA5-7, SA5-1 and SA5-4. However, all treated bentonite samples still failed to meet the API specification 13A requirements with a maximum allowable polymer dispersant of 2% by weight of bentonite (Ta, Dinh Vinh et al., 1989). In order to determine the required dispersant concentration for the bentonite to achieve the specific requirement, the addition of more dispersant had been proceed to the bentonite sample that has the highest value of dial reading, SA5-4. From Figure 3, it is indicated that SA5-4 sample successfully reached the minimum requirement of viscometer 600 rpm dial reading (24 cp) that is contributed by an addition of 3% by weight of Tannathin polymer. It is because the Tannathin had successfully hydrated and uncoiled in the suspension with the bentonite particles of SA5-4 sample.

CONCLUSIONS

The bentonite can be beneficiated based on organic acid treatment by applying organic acid concentration of 7.1 kg m⁻³, pH less than 2, 80 °C temperature and 2 hours stirring time. It was found that the highest CEC is 72 meq/100 g from an original value of 27 meq/100 g. In addition, Sabah bentonite cannot meet API Spec 13A of drilling mud material. The beneficiated bentonite performance as drilling mud material can be improved by 3% wt Tannathin addition.

REFERENCES


Figure 2: Viscometer 600 rpm dial reading of beneficiated bentonite suspension with addition of Tannathin.

Figure 3: Viscometer 600 rpm dial reading of beneficiated bentonite suspension with addition of CMC.


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EFFECTS OF DROPLETS ON THE FLAME SPEED OF LAMINAR ISO-OCTANE AND AIR AEROSOLS

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ABSTRACT

It is well established that the laminar burning rate plays an important role in turbulent combustion and previous work at Leeds has shown that the laminar burning velocity of an aerosol mixture is little different from that of a gaseous mixture at similar conditions. However, it has been shown that flames within aerosol mixtures more readily become unstable than for gaseous ones and this increases the practical burning rate. Flame instabilities, characterised by wrinkling and cellular surface structure, increase the burning rate due to the associated increase in surface area. In aerosol combustion, the presence of liquid droplets has been shown to influence instabilities by causing earlier onset of cellularity than for gaseous flames. Thus an understanding of the influence of the presence of liquid droplets in laminar aerosol flames is vital before the behaviour of practical spray combustion can be fully understood. In this paper, spherically expanding flames at near atmospheric pressures are employed to quantify the differences in the burning rates in laminar gaseous and aerosol flames. Iso-octane-air aerosols are generated by expansion of the gaseous pre-mixture to produce a homogeneously distributed suspension of fuel droplets. The droplet size varies with time during expansion; hence the effect of droplet size in relation to the cellular structure of the flame is investigated by varying the ignition timing. It is shown that the burning rate of lean mixtures is independent of droplet diameter. However, at higher equivalence ratios, the burning rate becomes a strong function of droplet diameter and equivalence ratio.

Keywords: Aerosols, Homogeneous, Laminar, Droplets, Flames, Burning Rate

INTRODUCTION

Combustion of clouds of fuel droplets is a very important area in gas turbines, diesel and sparkignition engines, furnaces and hazardous environments. There is theoretical [1,2] and experimental [3,4,5] evidence to suggest that flame propagation through aerosol/vapour clouds, under certain circumstances, is higher (possibly by up to a factor of 3) than that in a fully vaporised homogeneous mixture. Even though this may be advantageous in giving more rapid burning in engines, its effects on emissions are uncertain. Thus an understanding of the influence of the presence of liquid droplets in laminar aerosol flames is vital before the behaviour of practical spray combustion can be fully understood.

This paper was presented at the 10th International Congress on Liquid Atomization and Spray Systems (ICLASS-2006) in Kyoto, Japan, 26 August – 1 September 2006
Practical combustion in engines takes place under turbulent conditions, as does most combustion in boilers, burners and in the hazards context. However, the exploration of important parameters in practical combustion systems is difficult due to the multiplicity of dependent variables. It is well established that the laminar burning rate plays an important role in turbulent combustion [6]. Yet, information on laminar burning velocity is sparse, even for gaseous mixtures at conditions pertaining to engines, which range from sub-atmospheric to high pressure and temperature. At present, such data for fuel sprays and for gas-liquid co-burning [7-10] are even more sparse than for gases. As a consequence, there is little experimental data of a fundamental nature that clearly demonstrates the similarities and differences in burning rate, either laminar or turbulent, between single and two phase combustion.

In this paper, spherically expanding flames following central ignition of globally homogeneous combustible fuel mixtures at near atmospheric pressures are employed to quantify the differences in the structure of instabilities in laminar gaseous and aerosol flames. Iso-octane-air aerosols, in the size range of up to 25 μm, are generated by expansion of the gaseous pre-mixture to produce a homogeneously distributed suspension of fuel droplets. The droplet size varies with time during expansion; hence the effect of droplet size in relation to the cellular structure and burning rate of the flame is investigated by varying the ignition timing.

It is shown that the burning rate of lean mixtures is independent of droplet diameter. However, at higher equivalence ratios, the burning rate becomes a strong function of droplet diameter as well as equivalence ratio.

**EXPERIMENTAL SETUP**

**Apparatus**

Figure 1 shows a schematic of the combustion apparatus. Full descriptions of the system and aerosol generation technique are presented in [11]. The explosion vessel, which essentially resembled a Wilson cloud chamber [12], was a cylindrical vessel of 305 mm diameter by 305 mm long. Optical access windows of 150 mm diameter were provided on both end plates for characterization of aerosol and photography of flame propagation. Four fans, driven

![Figure 1: Schematic of the combustion apparatus.](image-url)
by electric motors, adjacent to the wall of the vessel, initially mixed the reactants. Two electrical heaters were attached to the wall of the vessel to preheat the vessel and mixture to 303 K.

Aerosol Generation and Characterization

Iso-octane-air aerosol mixtures were prepared by a condensation technique [11], used elsewhere in combustion studies by [10,13,14], to generate well-defined, near mono-dispersed, droplet suspensions in-situ by controlled expansion of a gaseous fuel-air mixture from the explosion vessel into the expansion tank, which was pre-evacuated to less than 0.001 MPa. This caused a reduction in mixture pressure and temperature, which took it into the condensation regime and caused droplets to be formed.

The characteristics of the generated aerosol were calibrated by in-situ measurements of the temporal distribution of pressure, temperature, and droplet size and number, without combustion, with reference to the time from start of expansion. The droplet arithmetic mean diameter, $D_{10}$, was measured using a Phase Doppler Anemometer system. The number density of droplets, $N_D$, was estimated from laser extinction measurement method during expansion by using the Beer-Lambert Law correlation given in [15]. Because expansion took place over a period of several seconds while combustion took place over less than 100 ms, the far field values of $D_{10}$ were assumed to be constant during combustion. A detailed description of the techniques for characterization of the mixture droplets has been published elsewhere [11].

Figure 2 shows a typical variation of pressure, temperature, droplet size, and number density of droplets with time from the start of expansion for a stoichiometric iso-octane-air mixture expanded at 0.25 MPa and 303 K. The measured temporal variation of temperature, $T_m$, initially exhibited a polytropic relationship, as shown by the dashed curve in Figure 2, in which the index of isentropic expansion, $\gamma$, is 1.35 [16]. At the start of droplet nucleation, approximately one second after the start of expansion, the measured temperature departed from that of the polytropic expansion, in part due to the latent heat of condensation. This was also evident by the increase in $N_D$ and $D_{10}$. It is shown that $N_D$ is nearly constant after 1.25 seconds from the start of expansion.

Also shown in Figure 2 are the standard deviation of the droplet mean diameter, $\sigma_D$, and the ratio of $\sigma_D/D_{10}$. The low values of $\sigma_D$ indicate the near monodispersed distribution of droplet size that results in the present apparatus. This is also supported by the typical histogram in Figure 3, which shows a narrow droplet distribution at 1.5 seconds after the start of expansion.
The initially high ratio of $\sigma_D/D_{10}$ is caused by the small size of the droplets at the nucleation stage. The spatial distribution of droplet size was also monitored and was found to be reasonably uniform [11].

**Recording of Flame Images**

The droplet size varies with time during expansion; hence the effect of droplet size in relation to the cellular structure of the flame is investigated by varying the ignition timing. The aerosol mixture was ignited at the centre of the explosion vessel by an electric spark of about 500 mJ. The flame front was monitored through the vessel’s windows by schlieren movies, which were recorded using a high-speed digital camera at a rate of 1000 frames per second and with a resolution of $256 \times 256$ pixels. The flame image was processed digitally to obtain the flame radius using image processing software.

The flames speed, $S_n$, is obtained from the measured flame front radius, $r$, against time by

$$S_n = \frac{dr}{dt}$$  \hspace{1cm} (1)

The flame speed is not a unique property of a combustible mixture [17]. A more fundamental property is the laminar burning velocity, $u_l$. However, the calculation of $u_l$ requires another property known as the unstretched flame speed, $S_u$, which cannot be determined in most cases reported here due to the onset of instabilities, which occurred very early during flame development. This was especially so for the rich flames. Therefore, for comparison, flame speeds at a radius of 48 mm, $S_{n,48}$, is used [16] in the present work. This is the largest radius at which most flames could be fully observed through the windows at all equivalence ratios. (For slow burning mixtures, buoyancy effects resulted in flames drifting towards the top of the vessel and, hence, reducing the maximum radius for full flame observation).

Another method of observation, employed in the present work, was a laser sheet imaging technique, which was also used to view the droplets ahead of the flame front. This technique uses a thin sheet of laser light to produce a cross-sectional two-dimensional image of the three dimensional flame. The laser light is scattered by the suspended liquid droplets to cause illumination. The flame is identified as the frontier between the bright unburned, and the dark burned regions in the illuminated zone [18]. The laser sheet images were captured by a high-speed digital camera.

**RESULTS AND DISCUSSION**

Figure 4 shows a typical laser sheet image of an aerosol and its flame ignited at $\phi = 0.8$, $P = 0.11$ MPa, $T = 265$ K, and $D_{10} = 12$ μm. The laser sheet passed, from right to left in Figure 4, through a 25-mm lateral window in the explosion vessel. The visible section of the spherical flame expanded from left to right. The flame front and the combustion products within are identified as the large black zone in Figure 4. The white dots at the right of the flame front are the droplets in the cold reactant region.

![Figure 4: Typical laser sheet image of laminar iso-octane-air aerosol and its flame at $\phi = 0.8$, $P = 0.11$ MPa, $T = 265$ K, $D_{10} = 12$ μm.](image)

It is shown in Figure 4 that the boundary at which droplets are fully evaporated is clearly visible. The sudden disappearance of droplets gives an indication that the rate of evaporation very close to the flame front is rapid. The thickness of the evaporation zone is smaller than the image resolution; however the
corresponding flame thickness was estimated to be about 0.07 mm [16]. The image shown in Figure 4 displays a near homogeneous droplet distribution, as observed by other workers [14,19] who used the Wilson cloud chamber method [12].

The effects of the presence of droplets and of the droplet size were investigated by comparing flames of laminar gaseous with those of aerosols at similar initial conditions. Figure 5 shows the variation of flame speed with radius for gaseous and aerosol mixtures at an equivalence ratio of 1.2 at near atmospheric condition. The squares represent an aerosol at $D_{10} = 19 \mu m$, $P = 0.124 MPa$ and $T = 275 K$, while the triangles represent an aerosol at $D_{10} = 4 \mu m$, $P = 0.146 MPa$ and $T = 282 K$. The gaseous flame, ignited at $P = 0.100 MPa$ and $T = 303 K$, is represented by the circle markers. The slightly different pressure and temperature for the three flames is due to the method of thermodynamic aerosol generation. Since it is well known that an increase in temperature results in an increase in burning rate, but that the effect on pressure is less sensitive, one would expect a gaseous flame at the same temperature as the aerosol ones to have a slightly lower velocity than that shown in Figure 5. Immediately after spark ignition, all flame speeds were fairly high due to the high temperature and active radicals provided by the spark energy. At approximately 4 mm radius, speeds reached a minimum as the effects of the spark decayed while the normal flame chemistry was yet to develop. It was suggested by Bradley et al. [20] that at this stage, also known as the spark-affected period, the flames were not fully developed and therefore should not be used for the determination of burning rates.

Considering, first, the gaseous flame in Figure 5, it is shown that after the end of the spark-affected period, the flame speed developed very rapidly within the first 10 mm before attaining an approximately constant value of about 2.5 m/s at larger radii. Conversely, the two aerosol flames developed more slowly, in an increase in burning rate, but that the effect on pressure is less sensitive, one would expect a gaseous flame at the same temperature as the aerosol ones to have a slightly lower velocity than that shown in Figure 5. Immediately after spark ignition, all flame speeds were fairly high due to the high temperature and active radicals provided by the spark energy. At approximately 4 mm radius, speeds reached a minimum as the effects of the spark decayed while the normal flame chemistry was yet to develop. It was suggested by Bradley et al. [20] that at this stage, also known as the spark-affected period, the flames were not fully developed and therefore should not be used for the determination of burning rates.

![Figure 5](image_url)

**Figure 5:** Flame speeds of iso-octane-air mixtures at $\phi = 1.2$, near atmospheric conditions and at different flame radii. Inset: the corresponding schlieren images at radius of approximately 48 mm.
but attained higher, and still accelerating values at higher radii. The initially slower flame speed, and the lower minimum values are probably due to the more demanding ignition requirements of an aerosol, requiring evaporation and mixing as well as ignition, compared with the gaseous flame. The flame speed of the aerosol with the largest droplets \( D_{10} = 19 \mu m \) accelerated relatively slowly at radii above 5 mm but continued to accelerate significantly throughout the field of observation such that the flame speed surpassed that of the gaseous flame at a radius of about 25 mm. This was also the case for the aerosol with finer droplets \( D_{10} = 4 \mu m \), although the effect was not so dramatic and it was not until a radius of 50 mm that its speed surpassed that of the gaseous flame.

Also shown in Figure 5 are the corresponding schlieren images of the flames at \( r \approx 48 \text{ mm} \). These photographs show the effect of droplet diameter on the flame structure for these centrally ignited aerosol iso-octane-air mixtures. It must be noted that the small difference in pressure, \( P \), and temperature, \( T \), between the conditions in the three images has been shown, for gaseous flames, to have little effect on the flame structure [20]. Hence, it is assumed that the difference in the structure is entirely due to the effects of droplets.

The surface of the gaseous flame shown in Figure 5 is the smoothest among the three; depicting that the flame is stable, resulting in the observed near constant plot of flame speed against radius. The flame remained nearly smooth with the appearance of only a few shallow large cells throughout the whole period of observation. The long crack near the bottom surface originated by the perturbation from the spark electrodes, and such crack changed very little throughout flame propagation. The smooth profile of the flame front boundary in the gaseous flame is similar to that observed in stable aerosol flames as shown, using laser sheet imaging, in Figure 4.

Conversely, both aerosol flames shown in Figure 5 are cellular in structure, indicative of unstable flames; the greater diameter and amplitude of the flame cells being within the aerosol with the largest droplet \( D_{10} = 19 \mu m \). Hence, the comparison demonstrates that aerosol flames are more unstable than that of an equivalent gaseous flame \( D_{10} = 0 \mu m \). The level of instabilities increases as the droplet size increases and Figure 5 shows that this correlates well with the observed increase in flame propagation rate. This is a consequence of the increase in surface area caused by the cellular wrinkles.

Figure 6 shows the variation of flame speed at a radius of approximately 48 mm, labelled as \( S_{n,48} \), with equivalence ratio for gaseous and aerosol mixtures at similar initial pressures and temperatures. The thick line, which represents the gaseous results, was obtained from experiments at an initial condition of 0.100 MPa and 303 K and these were corrected as recommended by [16] to yield the reported values at 0.14 MPa and 280 K. The experimental results for the aerosol flames are represented by symbols for droplet sizes between 5 and 20 \( \mu m \) and were obtained at a narrow range of pressure and temperature as indicated on the Figure. The fine lines were obtained by correcting the experimental results to values at 0.14 MPa and 280 K and drawing a best-fit curve through them. It is clearly shown in Figure 6 that the flame speed of lean mixtures (below \( \phi = 0.9 \)) is independent of droplet diameter. However, at higher
equivalence ratios, the flame speed becomes a strong function of droplet diameter. The variation of flame speed with equivalence ratio has a similar parabolic profile for each droplet diameter. However, the peak of the curve for gaseous mixtures is at $\Theta = 1.2$, but that for aerosols increases with droplet diameter.

Although the gaseous flames presented in this work were stable, they can become unstable at larger flame radius or at other conditions such as higher initial pressure as shown, for example, in [21]. The conditions at which gaseous flames can become unstable are related to the strain rate Markstein number and the critical Peclet number [17,22]. Like gaseous flames, this relationship can hold true for aerosol flames, but the functionality is dependant on droplet diameter. Hence, Lawes et al. [23] suggested that enhanced burning rates in aerosol mixtures are due to the 'earlier' onset of such instabilities. This is confirmed by the present study since droplets appear to induce flame instabilities, manifested by wrinkling and cellular surface structures that are not present in the gaseous flames. Moreover these instabilities are a function of droplet diameter.

The mechanism of flame instabilities, which cause burning velocity enhancement, is probably related to the heat loss from the flame and local rapid expansion through droplet evaporation. However droplet evaporation can also cause high gradients in the mixture strength (variations in local equivalence ratio), which might have an effect on the flame. To overcome such doubts, the effect of the presence of a water aerosol in gaseous propane-air mixture was investigated at an equivalence ratio of 1.3. The mixture of water aerosol with propane-air was generated using the same expansion technique as for the other experiments in the present work. Clearly, the introduction of water had the opposite effect on mixture strength to the use of fuel droplets. The effect was to locally dilute the mixture rather than to enrich it.

Figure 7 shows a photograph of the resulting flame of gaseous propane-air mixed with water aerosol, at a radius of 60 mm. Prior to ignition the mixture was at $T = 265$ K and $P = 0.110$ MPa, which is close to that of the other experiments reported here. It is clearly shown in Figure 7 that there is a well-developed cellular surface structure that manifests instabilities. Conversely, a similar experiment, without water aerosol, and another containing 30 μm diameter glass beads resulted in smooth and stable flames, similar in appearance to the flame of gaseous iso-octane-air in Figure 5. Thus it is evident that the presence of droplets most probably plays an important role in the introduction of instabilities due to evaporation rather than by flame distortion by, for example, their physical presence and aerodynamic drag. In addition, it is also concluded that as the droplet size, and hence, the evaporation rate increases instabilities and higher burning rate will result.

**CONCLUSION**

The effect of droplets in the size range of up to 20 μm on the flame speed of iso-octane-air aerosols has been experimentally studied in centrally ignited spherical laminar aerosol flames in which a cloud of fuel droplets was suspended in a mixture of quiescent air and fuel vapour. These were compared with those for gaseous flames. Inspection of schlieren cine photographs revealed that aerosol flames are, in general, more
unstable than gaseous flames and become more so as the droplet size increases. The flame instabilities are manifested by a cellular surface structure, which increases the surface area of the flame front and consequently increases the flame speed.

The increased propensity to instability results in the burning rate of initially quiescent aerosol mixtures being faster than those in the gaseous phase at similar conditions. This is so, although the fundamental unstretched laminar burning velocity is probably unchanged by the presence of droplets.

The role of droplet size has been shown to result in a greater level of instabilities, hence a higher burning rate. Like gaseous flames [17,20], the onset of aerosol flame instabilities is probably defined by a critical Peclet number and is a function of the strain rate Markstein number. However, the functionality is dependant on droplet diameter.

NOMENCLATURE

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Greek symbols

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REFERENCES


Shaharin Anwar Sulaiman graduated in 1993 with a BSc in Mechanical Engineering from Iowa State University. He earned his MSc in Thermal Power and Fluids Engineering from UMIST in 2000, and PhD in Combustion from the University of Leeds in 2006. During his early years as a graduate, he worked as Mechanical and Electrical (M&E) Project Engineer in Syarikat Pembenaan Yeoh Tiong Lay (YTL) for five years. His research interests include combustion, sprays and atomization, HVAC and renewable energy. He joined Universiti Teknologi PETRONAS in 1998 as a tutor, and is a lecturer in the Mechanical Engineering program since 2000. He is also a certified Professional Engineer with the Board of Engineers, Malaysia, and a Corporate member of the Institution of Engineers Malaysia.
A NEW APPROACH OF STRUCTURAL ANALYSIS IN CONJUNCTION WITH STRUCTURAL DESIGN AND OPTIMIZATION

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ABSTRACT

Structural design, particularly during the conceptual stage, requires quite a number of analyses to obtain structural responses under various geometrical and loading configurations. During this stage, the objective is to find a robust and economical structural configuration. This paper presents object-oriented approach of structural analysis and its implementation within a finite element (FE) program. The objective is to simplify the cycle of data preparation and analysis. To attain this, “object-wrapper” is created to link “structural data” with FE program. The term “structural data” has been broadened to include data for a complete structure rather than merely data for an element of a structure. Any change in the structural element such as material, basic geometrical configuration, and loading condition is easily changed with a simple command. This paper also outlines an extension imposed to OpenFEM in such a way that a typical structure is defined by a minimum structural geometric definition. The system is developed under the Matlab environment.

Keywords: structural optimizations, structural design, structural analysis, finite element method, object oriented approach

INTRODUCTION

As has been practiced during structural conceptual design, as many problem geometries as possible are studied to obtain general information on structural responses, or to conduct proof of concept. The engineer tries to establish an optimal structural system by considering every possible configuration, for example material to be used (steel vs. concrete), structural system (flat slab vs. beam and frame system; member type (tubular vs. conventional steel section), basic geometrical dimension (height, floor to floor distance, span, column layout etc.), cost comparison, constructability and others. It is in this stage that a significant number of analyses are performed, and when finite element (FE) program is being used, data preparation becomes repetitive and cumbersome. More often the study only needs a small change in problem geometry and/or material properties from one analysis to the other.

The objective of this work is to propose a new approach that eliminates the need to restart overall problem definition during FE analysis, particularly if only a small part of data is changed during the
study. In this approach the structure is treated as a single entity where its basic geometrical dimensions, type of structural system, type of structural member, type of material, and loading configurations are viewed as attributes to the entity. It is in this respect that the structure is viewed as an object with many attributes. Changes to the structural performances can be achieved by changing those attributes. The structural performances could be evaluated based on its structural integrity, serviceability limit, cost and others. In this context the term “structural data” has been broadened to include all of the structural attributes, and also in this context that object oriented approach is appropriate to design the system.

To achieve this objective OpenFEM, an open source FE program developed by INRIA [1], is adopted as the platform for the development. The advantage of using OpenFEM is, among others, open access to its source code. An object wrapper is developed that provides interface to the original OpenFEM functions. In addition, new utilities are developed to add new program functionality, particularly methods to modify the attributes.

The paper is organized as follows. In Section II, basic commands available in original OpenFEM are discussed in detail. Proficiency in OpenFEM commands is compulsory because the methodology requires construction of a complete structural model. Works to extend the capability of original OpenFEM is given in Section III, and examples of the application are then presented in Section IV.

OPENFEM FINITE ELEMENT PROGRAM

In this section salient characteristics of OpenFEM program is discussed in detail. The objectives are two folds, the first is to give interested reader sufficient background to construct their own structural entity, and the second is to give an overview on how the OpenFEM works in relation to the proposed extension (Section III). The disposition does not intend to replace the original manual, rather, to complement the manual by directing the reader to OpenFEM commands to perform a specific task.

In general, structural analysis using FE methodology consists of the following generic phases: (i) pre processing phase (model building by discretizing problem domain into nodes and element, assigning material to each element, and assigning properties to each material), (ii) analysis phase (assembling stiffness matrix and load vector, stiffness matrix modification due to boundary condition and solving linear algebraic equation to obtain displacement), and (iii) post processing phase (calculating secondary quantities such as forces, stresses, total weight of structure, and graphical presentation of results).

Using OpenFEM is not a straight forward procedure compared to current commercial program which has an extensive interactive pre- and post-processing support. It also differs with the older program that uses batch mode with input data written in ASCII data file. OpenFEM works in a series of utility command (or function) provided for a specific task. The program work on “model” data structure (Table 1) that contains all information needed to specify the problem and “DEF” data structure that stores all the solutions. However, it is not necessary to define all of the model data structure to run the analysis. The model data structure is built with various utility commands available in OpenFEM. The procedure to run OpenFEM is similar to generic finite element procedure, with sequences of command written in Matlab [2] script m-file.

Problems are specified by their topology (nodes and element connectivity) and behavior (materials and loads). Computational aspects of the problem (static analysis, dynamic analysis etc.) are characterized by “case” to be solved. There are seven basic commands provided in OpenFEM to build a model, assemble the stiffness matrix, mass matrix and load vector and solve the algebraic equation, they are \texttt{fe\_mesh}, \texttt{fe\_util}, \texttt{fe\_load}, \texttt{fe\_case}, \texttt{fe\_c}, \texttt{fe\_mk}, \texttt{fe\_mknl} and \texttt{fe\_stress}. Each command also has “key word” to perform a more specific task. In the next discussion each step to execute FE analysis using OpenFEM will be given in detail.
Model Building

Problem Domain

The problem topology can be built either by direct geometry definition (nodal coordinate and element connectivity) or by automatic model generation. Automatic model generation, i.e. nodal and element information can be obtained by \texttt{fe\_mesh} command. Node attributes (nodal coordinate, coordinate system) are stored in model.Node structure, and element information (element type, material type, section type, and element connectivity) are stored in model.Elt structure.

Element properties are stored in model.il. Material properties are stored in model.pl, problem degree of freedom in model.DOF, and case in the agenda for execution in model.Stack. All six model structure members must be defined prior to stiffness matrix and load vector being assembled. Each member structure is created at different stage of model building and with different OpenFEM command.

Ranges of keywords are available for different purpose, for example to generate, to divide, and to rotate a particular element. Other keywords are to select a group of nodes and elements for a particular operation. At the end model.Node and model.Elt are updated.

Boundary Condition

Consideration of the boundary conditions can be performed in two methods. In the first method, removal of the unused degree of freedom (DOF) can be achieved at problem definition stage (using \texttt{fe\_c} command), and the second method, removal of DOF is performed at assembly stage (using \texttt{fe\_case} command).

In the first method, the unused DOF is identified and the active DOF is used as the model DOF, and constraint handling is performed by \texttt{fe\_c} command on the identified DOFs. The \texttt{fe\_c} different operations are controlled by various combination of input/output definition. Different combination would produce different results. Typical steps to set boundary conditions are as follows:

<table>
<thead>
<tr>
<th>Data</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>.bas</td>
<td>local coordinate system definitions</td>
</tr>
<tr>
<td>.cta</td>
<td>sensor observation matrix</td>
</tr>
<tr>
<td>.copt</td>
<td>solver options</td>
</tr>
<tr>
<td>.DOF</td>
<td>DOF definition vector for the matrices of the model. Boundary conditions can be imposed using cases.</td>
</tr>
<tr>
<td>.Elt</td>
<td>elements. This field is mandatory.</td>
</tr>
<tr>
<td>.file</td>
<td>storage file name</td>
</tr>
<tr>
<td>.il</td>
<td>element property description matrix. Can also be stored as ‘pro’ entries in the Stack.</td>
</tr>
<tr>
<td>.mind</td>
<td>element matrix indices</td>
</tr>
<tr>
<td>.Node</td>
<td>nodes. This field is mandatory</td>
</tr>
<tr>
<td>.Opt</td>
<td>options characterizing models that are to be used as super elements</td>
</tr>
<tr>
<td>.pl</td>
<td>material property description matrix. Can also be stored as ‘mat’ entries in the Stack.</td>
</tr>
<tr>
<td>.Patch</td>
<td>Patch face matrix</td>
</tr>
<tr>
<td>.Stack</td>
<td>A cell array containing optional properties further characterizing a finite element model</td>
</tr>
<tr>
<td>.Ref</td>
<td>Generic coordinate transformation specification</td>
</tr>
<tr>
<td>.tdof</td>
<td>test DOF field</td>
</tr>
<tr>
<td>.TR</td>
<td>projection matrix</td>
</tr>
</tbody>
</table>
i. select a set of nodes to be constrained (this could be achieved by a range of keyword for \textit{fe\_mesh}),

ii. for a set of nodes selected in (i), restrain the DOFs. The \textit{fe\_c} command provides method to apply restrain to the selected DOF.

Suppose that we have a set of nodes, \( A \) to be restrained, the following \textit{fe\_c} command will perform the task:

\[
adof = \text{fe\_c}(mdof, adof, 'dof', ty)
\]  

(1)

where \( mdof \) is the original DOF definition vector, \( adof \) in right hand side is a set of nodes of interest, \( dof \) is keyword saying that the operation work on DOF, \( ty \) is an option to keep \( adof \) in right hand side (\( ty=2 \)), or to delete \( adof \) in right hand side out from the original DOF definition vector (\( ty=1 \)). The \( adof \) in the left hand side is new active DOF definition vector. \( adof \) in right hand side can accept different form, i.e. \( adof \) could be either a set of nodes, \( A \), or a set of DOF associated with nodes.

In the second method, the boundary condition is considered as a \textit{case} (other case is \textit{load}) and the unused DOFs are taken into consideration when assembling the stiffness matrix. By considering boundary condition as a \textit{case} it is possible to analyze a problem with different boundary condition. Basic \textit{fe\_case} commands are as follows:

\[
\text{Case} = \text{fe\_case}(\text{Case}, 'EntryType', 'EntryName', Data)
\]  

(2.a)

There are three types of \textit{load} that can be generated: (i) \textit{PointLoad}, (ii) \textit{SurfaceLoad}, and (iii) \textit{VolumeLoad}. All of them are either generated using \textit{fe\_case} command or generated using \textit{fe\_c} command.

Building \textit{PointLoad} can be accomplished either by using Eq. (2) or Eq. (3), e.g.:

\[
\text{model}\!=\!	ext{fe\_case(model,'AddToCase1',...}
\]  

‘DofLoad’,’PointLoad’,data)  

(3)

### Case Definition

OpenFEM can be arranged to run model using several geometry and load conditions by building cases to be executed. For example, as the first case the structure is subjected to a combination of gravity and live loads, and the second case by a combination of gravity and wind loads. Instead of rebuilding the whole structure from the beginning, the execution can be performed in sequence without building from scratch. Building case \textit{Stack} is achieved through \textit{fe\_case} command.

| Table 2: Valid entry type for \textit{fe\_case} command related to boundary condition and load definition |
|-----------------|-----------------|
| **Entry Type** | **Remark** |
| DofLoad | loads define on DOF |
| DofSet | imposed displacement on DOF |
| FixDof: | eliminated DOF specify in stack data |
| FSurf | surface load defined on element face |
| FVol | volume load defined on element |
| Info | store non standard entry |
| KeepDof | eliminated DOF not specified in stack data |
| spc | multiple point constraints |
| normals | field of normal at nodes |
| rigid | linear constraints associated with rigid link |

<table>
<thead>
<tr>
<th>Table 3: Case data structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stack</strong></td>
</tr>
<tr>
<td>Case.Stack</td>
</tr>
<tr>
<td>Case.T</td>
</tr>
<tr>
<td>Case.DOF</td>
</tr>
</tbody>
</table>
**Problem Solution**

**Matrix Assembly**

The `fe_mk` and `fe_mkn` commands are used to assemble the mass and stiffness matrices, the latter being assembler for nonlinear analysis.

The linear version of the commands is

\[
\text{model} = \text{fe_mk}('\text{model}', '\text{Options}', \text{Opt}) \tag{3.a}
\]

\[
[m, k, \text{mdof}] = \text{fe_mk}(..., [0 \text{ OtherOptions}]) \tag{3.b}
\]

\[
[\text{mat}, \text{mdof}] = \text{fe_mk}(..., [\text{MatType} \text{ OtherOptions}]) \tag{3.c}
\]

Other options work for nonlinear analysis is:

\[
\text{Case} = \text{fe_mknl}('\text{init}', \text{model}) \tag{4.a}
\]

\[
\text{mat} = \text{fe_mknl}('\text{assemble}', \text{model}, \text{Case}, \text{MatType}) \tag{4.b}
\]

where: `model` is data structure describing nodes, elements, element properties, material properties, and `case` data structure (describing constraints and loads). `m` is mass matrix and `k` is stiffness matrix. `mat` is returning matrix (the type depends on `Opt(1)`), and `MatType` is parameter controlling return matrix `mat`. Various option of `MatType` and return quantity are shown in Table 4. The range of available options makes it possible to perform static analysis and eigenvalue analysis with unlimited load combinations.

**Table 4: OpenFEM options for MatType**

<table>
<thead>
<tr>
<th>MatTyp</th>
<th>Return quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>both mass and stiffness matrixes, stiffness matrix, mass matrix, viscous damping, Hysteretic damping</td>
</tr>
<tr>
<td>11</td>
<td>stiffness matrix</td>
</tr>
<tr>
<td>12</td>
<td>mass matrix</td>
</tr>
<tr>
<td>13</td>
<td>viscous damping</td>
</tr>
<tr>
<td>14</td>
<td>Hysteretic damping</td>
</tr>
</tbody>
</table>

OpenFEM can be arranged to run `model` built using several geometries and load conditions by building cases to be executed. For example, the first case could be the structure subjected to a combination of gravity and live load, and the second case could be a combination of gravity and wind load. Instead of rebuilding the whole structure from the beginning, the execution can be performed in sequence, based on information stored in `case.Stack`. Building `case.Stack` is achieved through `fe_case` command. In addition, `fe_case` command can also be used to define the boundary condition of the structure. The procedure is as follows:

i. The structure is solved for one cycle.
ii. The same structure is subjected to several load case. For this case the stiffness matrix is formed only once and the load vector is built for each load case.

**Equation Solver**

Solving the simultaneous algebraic equation is performed using standard Matlab function “\” (slash). OpenFEM provides several options for the equation solver such as Cholesky decomposition, sparse matrix solver and others. The following commands solve the final linear algebraic equations,

\[
\text{kd} = \text{ofact}(k) \tag{6.a}
\]

\[
\text{def} = \text{kd} \backslash \text{Load.def} \tag{6.b}
\]

where `kd` is factored stiffness matrix and `def` is calculated deformation vector.

**Post Processing**

Functionality for post processing is also available in OpenFEM including interactive graphical user interface (GUI) for displaying and editing the graph, `fecom` and `medit` respectively.

**Summary**

In the preceding sections salient features of OpenFEM program was discussed. Various functionalities to create data, run analysis, and process and present analysis results were also discussed. The purpose of the discussion is to identify commands available to perform structural analysis. Table 5 summarizes all OpenFEM commands to perform all the process for structural analysis. Table 5 also identifies functionality not available in OpenFEM but thought to be useful during the analysis.
Table 5: OpenFEM command for FE analysis

<table>
<thead>
<tr>
<th>Analysis Phase</th>
<th>OpenFEM Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Model building:</td>
<td></td>
</tr>
<tr>
<td>a. Element generation</td>
<td>femesh, fe_util</td>
</tr>
<tr>
<td>b. Load case generation</td>
<td>fe_case</td>
</tr>
<tr>
<td>c. Boundary condition and constraint</td>
<td>fe_case, fe_c</td>
</tr>
<tr>
<td>2. Program execution</td>
<td></td>
</tr>
<tr>
<td>a. Assembling stiffness matrix</td>
<td>fe_mk, fe_mknl</td>
</tr>
<tr>
<td>b. Assembling load vector</td>
<td>fe_load</td>
</tr>
<tr>
<td>c. Solving linear equation</td>
<td>Standard Matlab function</td>
</tr>
<tr>
<td>3. Post processing</td>
<td></td>
</tr>
<tr>
<td>a. Stress calculation</td>
<td>fe_stress</td>
</tr>
<tr>
<td>b. Weight calculation</td>
<td>n.a</td>
</tr>
<tr>
<td>c. Displacement extraction</td>
<td>n.a</td>
</tr>
<tr>
<td>d. Displacement plot</td>
<td>feplot</td>
</tr>
</tbody>
</table>

PROGRAM EXTENSION

Motivation and Approach

The objective of program extension in this work is to extend OpenFEM in the following aspects:

i. To complement existing native command in OpenFEM with new commands those are considered necessary during the conceptual design of a structure.

ii. To provide object wrapper for possible interfacing with other program. In this aspect, several scenario of application will be considered. For example, interfacing OpenFEM with optimizer tool will result in the capability of the combined tools to perform structural optimization.

iii. To establish framework to build structural library for various types of structure.

To achieve the objectives, the component of the system will be identified by first discussing the conceptual design of the system.

Conceptual Design

In practice, structural analysis is always used as parts of other process e.g. design process, optimization process and other. Figure 1 shows use case scenario of the system with two possible uses of structural analysis. The purpose of use-case diagram is to determine interaction between actors (users) and the system, to identify sub-system within the system and to determine interaction among sub-systems. For the purpose of discussion, two examples are given, the first as part of structural size optimization process and the second as part of a design process.

The main controller of the system is called “data distribution center” which is the only place where user interacts with the system. The function of the data distribution center is to accept data from and publish report to the user, and to control the overall management of system performance particularly the data transfer mechanism.

The use case diagram identifies six main sub-systems and other minor sub-systems (or sub-sub-system). The main sub-systems are data distribution center, structural analyzer, system optimizer, structural designer, data distributor, and low-fidelity model constructor. The minor sub-systems are GA optimizer and other optimizer (sub-system of system optimizer); low-fidelity and high-fidelity models (sub-system of structural analyzer). Low fidelity model has been used extensively to reduce computational cost during engineering optimization [1, 2, 3].
Data for running the analysis consists of general problem data, structural analyzer data (for low- and high-fidelity models), structural design data and optimizer data.

Building the proposed system into working software within object oriented approach has been achieved by others as reported elsewhere [6, 7, 8, 9, 10, 11]. Motivation to use object oriented system in structural engineering is mainly to be able to integrate smoothly two or more different systems developed by others to run a specific new task [12, 13, 14]. A system designed based on object approach or object oriented system, is known to be flexible for future extension, easy to be integrated with other system, and cheaper to be maintained.

Adaptation of object oriented approach for this work make it possible to treat the whole structure as an entity (or object) with several behaviors (or attributes) predefine for the object, and hence provide an efficient geometric and material change, as often encountered during structural design process and structural optimization. Methods are procedure to change the attributes of an object in object oriented terminology.

**System Component**

The overall system interactions and behaviors are shown in the form of use-case diagram, class diagram and inheritance diagram. Use-case diagram is shown in Figure 1, class diagrams are shown in Figure 2 and 3.

The system uses a combination of high-fidelity and low-fidelity model. High-fidelity model is used to construct low-fidelity model through and to update the low-fidelity model when necessary. Finite element method (OpenFEM) is used as a high-fidelity model and surrogate model (also called response surface model, RSM) is used as a low-fidelity model. Methods such as stiffness matrix assembly, material property change, solving linear equation, structure weight calculation, stress calculation and others can be encapsulated within the object.

The total system is seen as a collection of sub-systems collaborating to perform a given task. The use-case diagram in Figure 1, identifies several sub-systems and the function of each sub-system has been elaborated in previous discussion. Class is an implementation of the function of sub-system. For example, the function of system optimizer, that is to seek the optimum objective by interacting with structural analyzer subsystem and section database, is implemented in optimizer class. Class consists of data abstraction and procedural abstraction. Object is an instantaneous of class. In the next section, implementation of each sub system as class and object will be elaborated further. As class is the implementation of sub system, the term sub system and class is interchangeable.

---

**Figure 1:** Use-case diagram for the proposed system showing sub-system and interaction among sub-systems
Main Sub System

Main class diagram for the system is shown in Figure 2. Data distribution center class takes the role of a controller for program execution and flow. The sequences of task implementation are: (i) accept and distribute data for each class, (ii) construct surrogate model, (iii) create structure, and (iv) perform optimization. Interface between data distribution center with other sub systems is via interface functions such as receiveData(), constructSurrogate(), createStructure(), and processOptimization() function. Other functions for each class are private therefore they are not accessible from other class. Additional function of data distributor class is to update data for other classes through updateData() function.

Data Distributor Sub System

Figure 2 shows data distributor class as an implementation of data distributor sub system. Relationship between classes and super class is aggregation similar to “consist-of” type relationship. For example, the relationship could be read as “data consist of problem data (PROBData), surrogate model data (SURData), genetic algorithm data (GAData), structure data (STRData) and other optimization data (OTHERData)”.

Data distributor will accept data through receiveData() interface function and automatically update the data for other sub system through interface function updateData().

Structural Analyzer Sub System

Figure 3 shows implementation of the structural analyzer sub system as structural analyzer class, its inheritance and interaction with other sub systems. As mentioned before, the total system will work with both high-fidelity and low-fidelity models.
The low-fidelity model for the system is surrogate model. The low-fidelity and high-fidelity model are implemented through lowfidelity and highfidelity Class, respectively, where both are abstract classes. Characteristics of the low-fidelity model can be found in [15].

Creation of structural entity is performed by data dist center class through the interface function createStructure() which in turn interacts with highfidelity class with the same interface function during optimization process. Other functions in str_x class are private and are only accessible to the class for calculation of the objective. Table 5 list methods identified and its function.

### Implementation

The implementation of the high fidelity method in the STRUCTURAL ANALYSER Class is discussed next. The implementation and testing of low fidelity method will be reported elsewhere.

Implementation is considered for two cases. In the first case the characteristic dimensions of structure are changed to study the structural responses. The characteristic dimension which may include floor to floor distance, typical span distance or girder spacing must be easily changed during conceptual design. This is accomplished via a flexible structural creation implemented in createStructure command.

In the second case the topology, boundary conditions and loads remain unchanged and the structural dimensions are changed, as usually the case, during structural design and structural size optimization. For this case the step only includes element size change.

#### Structural Creation

Structural creation consists of three steps: (i) mesh generation, (ii) boundary condition definition, and (iii) load case definition. Structural creation is achieved by createStructure() command. The structure is built using available OpenFEM functionality discussed in Section II.

### Program Execution

Problem solution is accomplished using solveSTR() function. The solveSTR() function accepts several options such as static analysis or eigen analysis, linear or nonlinear analysis, and single load or multiple loads analysis. During static analysis only stiffness matrix is required to be computed, and in eigen analysis both the mass and stiffness matrices are required. Option for linear and nonlinear analysis prompted the use of different OpenFEM function, either fe_mk for linear or fe_mknl for nonlinear analysis. For analysis with multiple load combinations only recalculation of load vector is necessary while the stiffness matrices recalculation is not necessary.

Within the function, three processes are executed: (i) assembling the stiffness matrix, (ii) assembling the load vector, and (iii) solving the algebraic equation. The command for assembling the stiffness matrix is assmblSTR() and for load vector assembling is assmblLoad() which are both common for all types of structure.

#### Objective Evaluation

Some types of constraint evaluation are required during both structural size optimization and structural design. The constraints could be either displacement limit or stress limit or both displacement and stress limit. The command for objective evaluation is calcObj(). Several options are available such as to evaluate constraint violation in (i) displacement, (ii) stress, and (iii) both displacement and stress. Displacement evaluation is necessary to evaluate serviceability limit of the structure and stress evaluation is necessary to evaluate the integrity of the structure.

The selections of input data are (i) quantity to be evaluated (displacement, acceleration or stress), (ii) location to be evaluated (selected nodal points, global coordinate of selected nodes or selected elements), and (iii) constraint limit (upper and lower bound). The output is the state of violation to the constraints. Other functions required are chkDisp() and chkStress(), to check displacement and stress...
violations respectively. The `calcObj()` function is transparent or method to the object while `chkDisp()` and `chkStress()` functions are private functions transparent only to `calcObj()` function.

**Total Weight Calculation**

Minimum total weight is often one of the criteria targeted during structural size optimization. The total weight of the structure is obtained using the `calcWeight()` command that is transparent to the object.

**Material Section Change**

Change in material or section size is excessively used during size optimization. In the context of OpenFEM the change could be easily implemented for both material change (e.g. from steel to aluminum) and section change. The command is `changeMat()`. The option for input includes: (i) selection of material or section to be changed, (ii) section number, (iii) database of the new section, and (iv) section number in the database. The `changeMat()` function is transparent or method to the object and is served by two other private functions namely `searchMat()` and `assignMat()`, which search the section properties in the database and assign new value to the section properties, respectively.

### Summary

In this section, application and relationship of structural analysis with structural optimization and structural design has been identified. Classes and methods for each class have also been defined. The methods for STRUCTURAL ANALYSER Class includes `createStructure()`, `solveSTR()`, `calcObj()`, `calcWeight()` and `changeMat()`. The other private functions are `chkDisp()`, `chkStress()`, `searchMat()` and `assignMat()`. To add new structure type it is needed to create only the implementation of `createStructure()` function for the new type of structure and all its private functions when required.

In the next section, the implementation of the system in conjunction with OpenFEM in Matlab environment will be demonstrated.

### RESULTS AND DISCUSSIONS

Two examples are given to illustrate the idea proposed in this paper. The first example is a 120-bar dome space truss [16] and the second example is jacket structure. From nine methods identified in Table 6, only `createStructure()` function can be demonstrated with example.

Figure 4 shows basic geometrical properties of roof dome which are defined by six parameters. The structural members are grouped into three groups of elastic material. The model building for the analysis is prepared in Matlab script file using native command of OpenFEM.

### Table 6: Identified methods for Structural Analyzer

<table>
<thead>
<tr>
<th>No</th>
<th>Method</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><code>createStructure()</code></td>
<td>Create structural entity with minimal geometric parameter</td>
</tr>
<tr>
<td>2.</td>
<td><code>solveStructure()</code></td>
<td>Solve algebraic equation</td>
</tr>
<tr>
<td>3.</td>
<td><code>calcObj()</code></td>
<td>Calculate defined objective to minimize in structural optimization</td>
</tr>
<tr>
<td></td>
<td><code>changeMat()</code></td>
<td>Change material properties</td>
</tr>
<tr>
<td>4.</td>
<td><code>calcWeight()</code></td>
<td>Calculate total weight of structure</td>
</tr>
<tr>
<td>5.</td>
<td><code>assmblStr()</code></td>
<td>Assemble stiffness matrix and load vector</td>
</tr>
<tr>
<td>6.</td>
<td><code>chkDisp()</code></td>
<td>Check displacement for design compliance or constraint</td>
</tr>
<tr>
<td>7.</td>
<td><code>chkStress()</code></td>
<td>Check member stresses for design compliance or constraint</td>
</tr>
<tr>
<td>8.</td>
<td><code>searchMat()</code></td>
<td>Search section properties in a given database</td>
</tr>
<tr>
<td>9.</td>
<td><code>assignMat()</code></td>
<td>Assign values to section properties</td>
</tr>
</tbody>
</table>
Dome and jacket structure shown in Figure 5 and 6 are created with simple Matlab type statements. Examples of typical program statements are given in Table 7. The `createSTR()`, `runSTR()` and `plotResults()` functions are all the interface to STRUCTURAL ANALYSER Class.

The first line is an object constructor command for dome object. To construct the jacket structure the equivalent command is `obj=JACKET`. Since the object, either dome or jacket, is sub class of STRUCTURAL ANALYSER Class, the object has access to all of its interface functions. To create the structure, the object is passed to the `createSTR` function, along with basic dome geometry contain in parameter `domeGeom` (line 2). Running the analysis is achieved by the `runSTR()` function (line 3). Parameter required to create the jacket structure, contained in the `jackGeom` parameter, includes: (i) base dimension of the leg, top side and lay down, (ii) number of bay and bay to bay distance of horizontal stiffener, (iii) floor to floor distance of the top side, and (iv) base dimension of frame connecting the leg and top side.

It can be seen in the above process that only limited optional parameters, along with the object, are passed to the function to initiate the process. This is possible in object oriented approach since data and methods are encapsulated within the object. Processes to create the dome and jacket structure are totally different even though it is accessed using the same interface function.

Implementation of other method identified in Table 6 will be presented in the context of structural optimization and structural design in the future paper [17].

**Table 7:** Typical command lines to generate dome and jacket example

<table>
<thead>
<tr>
<th>Line</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><code>obj=DOME</code></td>
</tr>
<tr>
<td>2</td>
<td><code>obj=createSTR(obj, domeGeom)</code></td>
</tr>
<tr>
<td>3</td>
<td><code>obj=runSTR(obj, OPT)</code></td>
</tr>
<tr>
<td>4</td>
<td><code>obj=plotResults(obj, OPT)</code></td>
</tr>
</tbody>
</table>
CONCLUDING REMARKS

The paper presented a system design for an extension of OpenFEM program in structural optimization and structural design, using object oriented approach, by providing complementary command and object wrapper.

The system requirements were established through use case scenario that identified sub systems with specific tasks for each sub system. Detailed discussions of the structural analyzer sub system were also given in the context of structural optimization and structural design. Examples are given for application in the creation of roof dome and jacket structure.

ACKNOWLEDGMENT

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FLOW ANALYSIS IN SPIKED SUPersonic intAKES OF A/C (I – INVISCID)

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ABSTRACT

The intakes of supersonic aircraft are usually affected by two substantial factors, namely, the “spike” and the “angle of attack”. The aim of the present work is to analyze the flow field structure in the supersonic intakes equipped with spike. The analysis is carried out under the assumption of non-viscous, steady, two dimensional and compressible fluid flow. The external flow is analyzed analytically by using the compressible flow equations. The internal flow inside the intake is analyzed by CFD technique based on finite difference approximation. The governing equations of the internal flow in their partial differential form are solved iteratively using Newton-Raphson method. The results are obtained for Mach numbers ranging from 1.4 to 3 at different angles of attack (0 to 20). The analysis is carried out for two spike deflection angles, 6° and 12°. The results obtained are based mainly on the observation of the pressure recovery at inlet of the compressor for different spike configurations at different fly conditions.

Key words: CFD, compressible fluid flow, supersonic intakes, inviscid flow, spiked intakes.

INTRODUCTION

There are four requirements the engine inlet must meet:

a. It must match the air flow captured by the inlet to the air flow required by the engine under all conditions of operation, from subsonic to Mach 3+,
b. Since all turbojet engines require a constant volume of air, they require subsonic flow at the inlet to the compressor face, it must reduce the velocity of flow to about Mach 0.3 to 0.5 as it enters the engine; this is no small task,
c. While it is reducing the velocity of the air at the compressor, it must simultaneously retain the greatest possible air pressure in order to boost flow to the compressor,
d. It must minimize the momentary effect upon air flow from external perturbations; e.g. gusts.

To achieve the above goals, a spike is installed in the intake to provide shock series outside the intake frontal face. The modern fighters are designed with movable spikes to provide variable geometry intakes [1]. Such type of design is basically required to produce a throat area which is large enough for the establishment of supersonic flow and, which can subsequently be reduced to provide efficient wedge compression in the running conditions. The intakes are, substantially, affected by two operational factors. The first is the spike which control the geometry of the intake and secondly, the angle of attack (Incident angle) which affect the structure of the waves system that occurs in the windward side and in the lee side.
For 2-D supersonic intakes, the spikes may have one deflection feature, two deflections feature or may be designed with curvature surface.

The objective of the present paper is to compute the flow structure and analyze the effect of the angle of attack and the spike geometry on the flow at entrance to the compressor stage. The one deflection type has been selected for the present analysis. Such type is possessing one oblique shock wave (O.S.W.), one normal shock wave (N.S.W.) as shown in figure.1. The analysis involves programming of the analytical solution of the waves system outside the intake, while the flow field inside the intake is analyzed computationally by finite difference technique (FDT).

MODES OF INTAKES OPERATION

In climbing operation, the angle of attack, or so called the incidence, (α) is larger than zero and the upper deflection angle is (δ - α), while the lower deflection angle becomes (δ + α) as shown in figure 2. Thus, the shock system would be different on the upper and lower sides, and consequently, the departure from zero incident angle leads to non-symmetrical spiked system. As a result of that, the flow structure inside the diffuser will be non-symmetric as well.

During pitch up, the upper O.S.W. (i.e., in the leeside) will possess a smaller shock angle and may end inside the intake and reflected from the upper wall to the spike surface. In the lower side, i.e., wind side, the deflection of the shock wave is large and the variation of properties is larger than in the upper surface. In some situations at high pitch up, the incidence α becomes larger than the spike angle δ. This will lead to supersonic expansion and Prandtl–Mayer wave is created [2].

The possibilities of the wave formation are shown in figure 2.

MODELING AND SOLUTION TECHNIQUE

The analysis of the flow field has been subdivided into three different regions. Firstly, the flow change across the oblique shock wave is predicted by analytical simulation using the governing equations 1 to 6. [3]
\[ M_2 = \frac{[(y-1)M_2^2 \sin^2 \sigma + 2]}{2y M_1^2 \sin^2 \sigma - (y-1) \sin^2(\sigma-\delta)} \] 

\[ \frac{P_2}{P_1} = \frac{2y}{\gamma + 1} M_2^2 \sin^2 \sigma - \frac{y - 1}{\gamma + 1} \] 

\[ \rho_2 = \frac{(y + 1)M_2^2 \sin^2 \sigma}{2 + (y - 1)M_1^2 \sin^2 \sigma} \] 

\[ \frac{T_2}{T_1} = \left( \frac{2y}{\gamma + 1} M_2^2 \sin^2 \sigma - \frac{y - 1}{\gamma + 1} \right)^{\frac{1}{\gamma-1}} \] 

\[ \frac{P_{02}}{P_{01}} = \frac{P_2}{P_1} \left( 1 + \frac{y - 1}{2} M_2^2 \right)^{\frac{1}{\gamma-1}} \] 

It should be mentioned that equation 1 looks to evaluate \( \delta \), but, in fact is the spike angle and the equation is used to evaluate the shock angle \( \sigma \). Iteration technique is used to solve for \( \sigma \).

The second flow region to be predicted is across the N.S.W. Equations 7 to 11 are adapted as the governing equations. [3]

\[ M_x = \sqrt{\frac{(y-1)M_x^2 + 2}{2y M_x^2 - (y-1)}} \] 

\[ \frac{P_x}{P} = \frac{2y}{\gamma + 1} M_x^2 - \frac{y - 1}{\gamma + 1} \] 

\[ \rho_x = \frac{(y + 1)M_x^2}{2 + (y - 1)M_x^2} \] 

\[ \frac{T_x}{T} = \left( \frac{2y}{\gamma + 1} M_x^2 - \frac{y - 1}{\gamma + 1} \right) \left( \frac{2 + (y - 1)M_x^2}{(y + 1)M_x^2} \right)^{\frac{1}{\gamma-1}} \] 

\[ \frac{P_{0x}}{P_{0x}} = \frac{2y}{\gamma + 1} M_x^2 - \frac{y - 1}{\gamma + 1} \left( \frac{(y + 1)M_x^2}{2 + (y - 1)M_x^2} \right)^{\frac{1}{\gamma-1}} \] 

Where, \( p, P_0, T, M \) and \( \rho \) are pressure, stagnation pressure, temperature, Mach number and density respectively. The subscripts 1 and 2 are before and after the O.S.W. \( x \) and \( y \) are before and after the N.S.W.

The above set of equations have been programmed and solved under various operation conditions, i.e. at different Mach number, different spike angles and different incidence angle. The final results obtained after the N.S.W are representing the inlet conditions to the internal part of the intake.

The solution in the internal part of the inlet is carried out numerically under the assumptions of 2-D, compressible, non-viscous flow, [Ref.4]. Accordingly, Navier-Stokes equations which are governing the flow become:

The Continuity

\[ \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} = 0 \] 

X-Momentum

\[ \frac{\partial (\rho u^2)}{\partial x} + \frac{\partial (\rho uv)}{\partial y} = -\frac{\partial p}{\partial x} \] 

Y-Momentum

\[ \frac{\partial (\rho v^2)}{\partial x} + \frac{\partial (\rho vu)}{\partial y} = -\frac{\partial p}{\partial y} \] 

The Energy

\[ u \frac{\partial}{\partial x} \left[ C_y T + \frac{u^2 + v^2}{2} \right] + \] 

\[ v \frac{\partial}{\partial y} \left[ C_y T + \frac{u^2 + v^2}{2} \right] = 0 \] 

And, the state equation is derived with respect to \( x \) and \( y \) as:

\[ \frac{\partial p}{\partial x} = R \left[ \rho \frac{\partial T}{\partial x} + T \frac{\partial \rho}{\partial x} \right] \]
\[
\frac{\partial p}{\partial y} = R \left[ \rho \frac{\partial T}{\partial y} + T \frac{\partial \rho}{\partial y} \right]
\]  
\text{... (16b)}

Where, \( u \) and \( v \) are the velocity components in \( x \) and \( y \) directions respectively.

The set of equations 12 to 16 has been applied to a set of nodal network by subdividing the physical domain which represents the flow in the diffuser as shown in figure 4.

The application of finite difference approximation for a system of partial differential equations governing a 2-D flow in divergent grid causes high numerical instabilities and unsatisfactory results which leads to lack of convergence, [Ref.4]. These difficulties could be avoided by re-mapping of the nodal network represents the complex physical domain to a rectangular computational nodal network. The resultant grid is satisfactory for the finite difference discretization of the governing equations. The transformation scheme is shown diagrammatically in figure 4.

In the physical domain, each node in the flow field is specified by it's coordinates \( x \) and \( y \). In the computational domain, the nodal point is specified by the \( \xi \) and \( \eta \) coordinates [5]. In that sense, the transformation from the physical domain grid to the computational domain grid is carried out under:

\[
\xi = \xi(x, y) \quad \eta = \eta(x, y)
\]  
\text{... (17)}

For any property \( () \), the variation in \( x \) and \( y \) plane can be transformed to \( \xi \), \( \eta \) plane as following:

\[
\frac{\partial ()}{\partial x} = \frac{\partial ()}{\partial \xi} \xi_x + \frac{\partial ()}{\partial \eta} \eta_x
\]

\[
\frac{\partial ()}{\partial y} = \frac{\partial ()}{\partial \xi} \xi_y + \frac{\partial ()}{\partial \eta} \eta_y
\]  
\text{... (18)}

The criteria have been applied to the set of P.D.E. 12 to 18. The resultant sets of equations are re-written in finite difference form with equal discretization in \( \xi \) and \( \eta \) coordinates. The set of finite difference algebraic equations is programmed and solved iteratively using Newton-Raphson method [4].

**RESULTS AND DISCUSSION**

The results obtained from the present work covered many design and operating parameters affecting the performance of the supersonic spike. A very important parameter which alters the smooth operation of the intake is the non–zero incidence angle which is the main objective of the present work to highlight. The total pressure recovery ratio \( (p/p_{\infty}) \) is the dominated parameter for comparison at different conditions.
For confidence of understanding, figure 1 shows the various windward side, leeside, cowl lip and locations used in discussion.

The results are obtained for different operation conditions at incidence angles = 0°, 4°, 8°, 12°, 16° and 20°. Fly Mach is varied in the range of 1.4 up to 3. The entire analysis is carried out for two types of spikes. Firstly with spike deflection angle equal 6° and secondly with spike angle deflection angle equal 12°.

For the first spike configuration, the results are presented in figure 5 for the leeside and in figure 6 for the windward side. From figure 5, it could be noticed that the T.P.R. degrades by increment of the incidence due to lose in the body compression. The results in the figure indicate that when the incidence equal to the deflection, i.e., $\alpha = \delta$, the total pressure recovery reduces precipitously and the reduction phenomenon becomes steeper as the fly Mach increases higher than 2.2. This operation situation should be avoided since it produces a large difference in pressure forces compared with the windward side at the front of the compressor. This happens because the compression surface becomes straight and there is no deflection in the flow stream. The same trend has been experienced by the works of [6] and [7].

The total pressure recovery is reduces in the leeside by increasing of the free stream Mach due to the weakening of the O.S.W. and the reduction of its angle as illustrated in table 1. The O.S. would end at the internal surface of the intake and reflected to the spike and so on. The inlet in such case experience series of reflections terminated with high reduction in the T.P.R.

### Table 1: The T.P.R. in the leeside for $\delta = 6^\circ$

<table>
<thead>
<tr>
<th>$M_{\infty}$</th>
<th>$p / p_{\infty}$ $\alpha = 0$</th>
<th>$p / p_{\infty}$ $\alpha = 4$</th>
<th>$p / p_{\infty}$ $\alpha = 8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>0.76</td>
<td>0.72</td>
<td>0.676</td>
</tr>
<tr>
<td>2.6</td>
<td>0.607</td>
<td>0.5903</td>
<td>0.3802</td>
</tr>
</tbody>
</table>

In the windward side for spike angle of 6°, the results are shown in figure 6. The T.P.R increases slightly as the incidence increases because the compression surface increases and the shock becomes stronger with higher angles at the nose of the spike. The O.S.W. is followed by N.S.W. at the cowl lip. This operation situation is called “critical operation”, and, this condition is matched, because the demand airflow is exactly equal to the maximum with maximum T.P.R. and minimum drag. The T.P.R. achieved at this condition is called “critical T.P.R.”

The values shown in table 2 are demonstrating that both of the operating parameters, Mach and incidence, are contribute considerably in the T.P.R. difference. E.g. for 16° incidence and Mach 2.6, the T.P.R. is 25.3% greater in the windward side than that in the leeside. If the cruising Mach is increased to 2.6, the difference increases 58.2%.

### Table 2: Variation in T.P.R. at various cruising Mach number, ($\delta = 6^\circ$).

<table>
<thead>
<tr>
<th>$M_{\infty}$</th>
<th>$p / p_{\infty}$ $\alpha = 0$</th>
<th>$p / p_{\infty}$ $\alpha = 8$</th>
<th>$p / p_{\infty}$ $\alpha = 16$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leeside</td>
<td>0.76</td>
<td>0.676</td>
<td>0.59</td>
</tr>
<tr>
<td>windward</td>
<td>0.76</td>
<td>0.78</td>
<td>0.79</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{\infty}$</th>
<th>$p / p_{\infty}$ $\alpha = 0$</th>
<th>$p / p_{\infty}$ $\alpha = 8$</th>
<th>$p / p_{\infty}$ $\alpha = 16$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leeside</td>
<td>0.607</td>
<td>0.38</td>
<td>0.28</td>
</tr>
<tr>
<td>windward</td>
<td>0.607</td>
<td>0.638</td>
<td>0.705</td>
</tr>
</tbody>
</table>
This demonstrates the non uniform distribution of the pressure forces in front of the compressor leading to unfavorable operation conditions, as well as the importance for design consideration.

The analysis has been carried out for spike angle equal 12° under the same operation conditions applied for the 6° degree spike angle. The results are presented in figures 7 and 8.

When the spike angle increased, the results have shown higher T.P.R. under same operation conditions as presented in table 3 for example.

<table>
<thead>
<tr>
<th>$M_{\infty}$</th>
<th>$\alpha$</th>
<th>Spike angle $\delta$</th>
<th>$p / p_{\infty}$ leeside</th>
<th>$p / p_{\infty}$ windward</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>4</td>
<td>6</td>
<td>0.6</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>0.7</td>
<td>0.77</td>
</tr>
<tr>
<td>Percent of $p / p_{\infty}$ increment</td>
<td>14.5</td>
<td>11.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONCLUSION**

The flow in a 2-D single deflection spiked intake is studied to analyze the flow structure and the resulting effects at various angles of incidence. Analysis of the outer part of the flow is carried out analytically, while the interior part of the flow is carried out computationally by finite difference CFD technique. Due to informality of the physical domain, axis transformation technique from the physical to computational network is adopted. The results based on the total pressure recovery evaluation demonstrate considerable variation in the pressure forces at the compressor inlet. The spike angle contributes effectively in the flow structure and the resulting pressure recovery in front of the compressor.
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EFFECT OF INJECTION TIMING ON THE ENGINE PERFORMANCE OF CNG DIRECT INJECTION SPARK IGNITION ENGINE

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ABSTRACT

An experiment was carried out in a dedicated compressed natural gas direct injection (CNG-DI) engine with a compression ratio (CR) of 14 and a central injection system. Several injection timing parameters from early (300° BTDC) to intermediate (180° BTDC) to late injection (120° BTDC) were investigated. The 300° BTDC injection timing experiment was carried out to simulate the performance of port injection engine and the result is used as a benchmark for the engine performance. The late injection timing resulted in a 20% higher performance than the early injection timing for low engine speed up to 2750 RPM. Intermediate injection timing shows the highest performance over an extensive range of engine speed because the 180° BTDC injection timing has a similar volumetric efficiency as in late injection timing. However, the earlier injection events allowed for a better air-fuel mixing. The early injection timing gives superior performance for engine speed above 4500 RPM. This could be attributed to the fact that the penalty of the reduction in volumetric efficiency is compensated by the increase in mixing time for the air-fuel mixture.

Keywords: compressed natural gas, direct injection, injection timing

BACKGROUND

The use of natural gas in the transportation sector has been increasing over the years. This is further supported by the increasing concern on environmental problems and energy security. The development of natural gas as fuel closely followed the growth of vehicle conversion from both gasoline- and diesel-fuelled engines to the natural gas fuelled in many countries. Fueling systems are becoming the critical parts in the vehicle conversion process [1, 2]. In the spark ignition (SI) engine category, fueling systems can be classified as carburetor, single/multi port injection, and direct injection. For natural gas vehicle, the first generation fueling system is the mixer system and this has progressed to the more sophisticated single- and multi-port injection systems. Recent investigations in natural gas engine are looking at the direct injection system as a possible progression to the fourth generation fueling system for natural gas engine to increase the natural gas engines’ performance. A direct injection system is expected to increase the volumetric efficiency of the natural gas engine and is able to operate in lean conditions.

The feasibility to implement the direct injection systems in CNG engines has been investigated by a few researchers. Huang et al. [3-5] discussed the
possibility of direct injection system in CNG engine using rapid compression machine (RCM) with a 10 CR and observed that injection timing significantly affected the intensity of fuel stratification before ignition which in turn is affecting the combustion behavior of CNG-DI engine[3-5]. Hayashida et al. [6] proved that injection timing could increase the engine volumetric efficiency and brake power while the best fuel air mixing occur with the injection events around inlet valve closing (IVC).

These researches were conducted on either a rapid compression machine or a converted gasoline fuelled engine in which the compression ratio was maintained near the knock limiting value for gasoline. In order to fully utilize the capability of the CNG fuel which has a higher knock limit, the current research was conducted on a dedicated engine with a compression ratio of 14. The results of varying injection timing to the performance of the CNG-DI engine at wide-open throttle (WOT) are presented.

**METHODOLOGY**

This research is based on the experimental study conducted at the Centre for Automotives Research (CAR) in Universiti Teknologi PETRONAS (UTP). The test conducted follows the SAE standard on engine performance and emission testing.

Wide-open throttle is specified in this experiment as representatives for full load condition. The equivalence ratio was kept constant at 1.0, and the ignition timing was adjusted via the ECU to obtain the best torque reading.

The engine speed range was 2000-5000 RPM. The injection timing was varied from a very early injection timing at 300° BTDC (intake valve start to open at 372° BTDC) to late injection timing at 120° BTDC (intake valve close at 132(BTDC). In Figure 1, the early injection timing with the start of injection (SOI) at 300° BTDC is to simulate port injection fueling system. At SOI of

![Injection Duration Diagram](image_url)

**Figure 1:** Injection timing characterization
180° BTDC, a partial direct injection was achieved, while the complete DI is achieved for injection events after the IVC. It should be noted that late injection timing is limited by the ignition timing for safety reasons. Hence, in our investigation, all injection events were completed before ignition occurred. All experiments were conducted with a stable operation with a 5% COV of IMEP.

**EQUIPMENT**

The engine used in this experiment is a four-stroke spark ignition single cylinder research engine. Table 1 elaborates the specification of the experimental engine. Fuel pressure regulator was used to control the fuel rail pressure and stabilized the injector pressure. Engine control parameters such as injection timing, ignition timing and air-fuel ratio were controlled via the engine control unit (ECU).

Figure 2 shows the injector position at the centre of cylinder head relative to the spark plug position, which is slightly offset at an angle. A modified long tip spark plug was used in order to reach deeper into the combustion zone to assure combustion of the CNG fuel.

![Intake port and Exhaust port](image1)

![Injector and Spark position](image2)

**Figure 2:** Engine cylinder head section

<table>
<thead>
<tr>
<th>Table 1: Engine Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINE PROPERTIES</strong></td>
</tr>
<tr>
<td>Displacement volume</td>
</tr>
<tr>
<td>Cylinder Bore</td>
</tr>
<tr>
<td>Cylinder Stroke</td>
</tr>
<tr>
<td>Compression Ratio</td>
</tr>
<tr>
<td>Exhaust Valve open (EVO)</td>
</tr>
<tr>
<td>Exhaust Valve Closed (EVC)</td>
</tr>
<tr>
<td>Inlet Valve Open (IVO)</td>
</tr>
<tr>
<td>Inlet Valve Closed (IVC)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Fuel System Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel System Specification</strong></td>
</tr>
<tr>
<td>Rail Pressure</td>
</tr>
<tr>
<td>Injector Position</td>
</tr>
<tr>
<td>Injector Type</td>
</tr>
</tbody>
</table>

Table 2 highlights the fueling system designed for the CNG operation for a fuel rail pressure of 18 bar. The fuel rail pressure is adjustable from 8 to 20 bar, with supply from a CNG tank at 200 bar pressure.

**RESULTS AND DISCUSSIONS**

The effects of varying injection timing on CNG-DI engine are shown in Figure 3. The engine performance is presented in term of torque, power, BMEP, and BSFC to describe the engine output for various injection timing conditions.

At lower engine speed, the late injection timing resulted in a 10-20% higher torque compared to early injection timing. Maximum torque was achieved by the DI for engine speed below 2750 RPM. However, early injection timing resulted in a better torque at the engine speed above 4500 RPM.

Effect of injection timing on power is illustrated in
Figure 3(b). Late injection timings at 180° and 120° BTDC resulted in a 15% higher power compared to the early injection timing for the speed of less than 2750 RPM. As the engine speed increases to 3500 RPM, the performance of the engine with 120° BTDC injection timing drops below that of the 180° BTDC injection timing. The performance of the engine with 180° BTDC injection timing dominates until the speed of 4500 RPM where the performance drops to 5% below early injection timing (300° BTDC). At 5000 RPM engine speed, the maximum torque was achieved by early injection timing. Hence, the optimum operation for this engine is obtained by using a full DI operation for engine speed below 2750 RPM, using the partial DI injection at 180° BTDC for engine speed between 2750 and 4500 RPM and using the early injection timing (similar to a port injection operation) for engine speed above 4500 RPM.

The BMEP results in Figure 3(c) follow closely the torque curve profile. The maximum value of 1040 kPa is achieved at 3000 rpm with the 180° BTDC injection timing, and reduces to 750 kPa at 5000 rpm for injection timing of 300° BTDC. The BSFC results in Figure 3(d) represent the specific fuel consumption for this engine. The lowest BSFC was achieved by the injection timing of 120° BTDC, up to the engine speed of 3000 RPM. Beyond 3000 RPM, 180° BTDC injection timing gives the lowest BSFC value. At engine speed above 4500 RPM, the BSFC value is about 2% lower than that given by the operation at 300° BTDC injection timing.

The effect of injection timing to the engine volumetric efficiency is shown in Figure 4. Late injection timing of 120° and 180° BTDC resulted in overall higher volumetric efficiency (0.83 – 0.94) compared to early
injection timing at 300° BTDC. The performance of the engine is significantly affected by the volumetric efficiency at engine speed below 4500 RPM. Within this range of engine speed, the late and intermediate injection timing resulted in a higher power output. Between 2750 and 4500 RPM, the intermediate injection timing of 180° BTDC resulted in a combined effect of high volumetric efficiency with sufficient mixing time that resulted in a maximum engine performance. At engine speed above 4500 RPM, the penalty in the drop in volumetric efficiency with injection timing of 300° BTDC is compensated by the increase in mixing time of the air and fuel. This resulted in a highest torque and power for the engine.

Figure 5 shows the emissions of NOx and CO for the CNG-DI engine due to the effect of injection timing.

At engine speed below 3000 RPM, the operation with late injection timing of 120° BTDC resulted in highest NOx and lowest CO levels. At engine speed above 3500 RPM, CO production is almost equal for intermediate and early injection timing. However, NOx production is higher for intermediate injection timing, indicating a higher combustion temperature. The complete performance and emission data were presented in Firmanshah [7].

CONCLUSIONS

From the current experiment, some conclusions can be drawn on the effect of injection timing to the performance of the engine. These are:

1. Late injection timing (120° BTDC) increases the volumetric efficiency of the engine and gives better performance at engine speed below 2750 RPM.

2. Intermediate injection timing at 180° BTDC resulted in a good performance for engine speed between 2750-4500 RPM because of the slight difference on volumetric efficiency compared to 120° BTDC injection timing but with a more homogeneous mixture created.

3. At engine speed above 4500 RPM, early injection timing at 300° BTDC resulted in the highest engine performance due to complete mixing of the air and fuel, albeit the lower volumetric efficiency.
4. At engine speed below 3000 RPM, NO$_x$ emission increased and CO emission decreased with retarding of injection timing, indicating a higher combustion temperature and a more complete combustion. This could be attributed to a higher air volume per cycle and increased turbulence due to the DI operation.

5. At engine speed above 3500 RPM, the level of CO production is almost invariant to injection timing. However, NO$_x$ production is higher for the intermediate injection timing of 180° BTDC compared to early injection at 300° BTDC, indicating a higher combustion temperature. This could be due to the higher volumetric efficiency that resulted in more air volume per cycle and a higher effective compression ratio.

REFERENCES


DATA TRANSFORMATION SERVICES (DTS): CREATING DATA MART BY CONSOLIDATING MULTI-SOURCE ENTERPRISE OPERATIONAL DATA

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ABSTRACT

Trends in business intelligence, e-commerce and remote access make it necessary and practical to store data in different ways on multiple systems with different operating systems. As business evolves and grows, they require efficient computerized solution to perform data update and to access data from diverse enterprise business applications. The objective of this paper is to demonstrate the capability of Data Transformation Services DTS [1] as a database solution for automatic data transfer and update in solving business problem. This DTS package is developed for the sales of variety of plants and eventually expanded into commercial supply and landscaping business. The use of DTS package is to extract, transform and load data from heterogeneous database systems such as MySQL, Microsoft Access and Oracle that consolidate into a Data Mart residing in SQL Server. Hence, the data transfer from various databases is scheduled to run automatically every quarter of the year to review the efficient sales analysis. Therefore, DTS is absolutely an attractive solution for automatic data transfer and update which meeting today's business needs.

Keywords: data transformation services (DTS), object linking and embedding database (OLEDB), data mart, online analytical processing (OLAP), online transactional processing (OLTP)

INTRODUCTION

Information is priceless. However, making it useful and presentable is difficult. Many organizations currently face the challenge in trying to integrate mass amounts of data to make it accessible [2]. IT professionals face sizable challenges to support those applications as they continue to grow in both by numbers and sophistication. Typically, much of the data needed by a particular application resides in various database systems running on different platforms. Data collected are always segregated, usually according to departments, teams [3] or even geographical areas. Organizations need to migrate the data and access information from diverse enterprise business applications within specified time frames [3]. With the increase in an organization's size, comes the technology sophistication in consolidating those data. One solution is by using Data Transformation Services (DTS), which allows the integration of data, even from various database platforms.

RELATED WORK

Database is designed to help users examine available data from a variety of perspectives [4]. Data Transformation Services is a collection of utilities and objects that is capable of importing, exporting
and converting data from any Object Linking and Embedding Database (OLEDB) compliant data source to any data source, whether to/from another database system (heterogeneous) or to/from another server [5]. Information Technology professionals can write a data movement custom program each time a need arises, however, the problem with customising a program is that it is time-consuming, wastes valuable development resources and creates a large body of code. It becomes increasingly difficult to maintain over time [6] and this justifies the use of DTS in real enterprise environment as a database solution for automatic transfer and update. A key to understanding the DTS architecture is to understand the DTS Package, which is a complete, self-contained description of all task and steps for completing an import, expert and transformation process [8]. Ideally, end-users should be able to access data from the data warehouse without knowing either where data resides or from which database applications. Data mart approach is one of the data warehouse categories [10, 11] where it extracts data from a primary data warehouse for data mart applications. The extraction has a special purpose. Hence, the repository of the data warehouse contains the subject of information, which is in data mart format [12].

**METHODLOGY**

A proposed system framework has been implemented for creating data mart to consolidate multi-source enterprise operational data. However, Entity Relationship Diagram, ERD, will be used to model data structure for multi-source data and it depicts relationships among system entities. Hence, Dimensional Data Modeling will be used to present useful information in summarized form to identify the trends. Star schema is used to model the new data structure from ERD. Finally, the end-product of system prototyping is a full-featured, working model of database solution, ready for real implementation.

**SYSTEM FRAMEWORK**

Technically, Figure 1 shows that data mart resides in between of Online Transaction Processing (OLTP) and Online Analytical Processing (OLAP). OLTP systems represent the source systems for a data warehouse. They are transactional in nature and are frequently purge to improve performance. On the other hand, OLAP systems typically take snapshots of production data at regularly spaced intervals and can represent historical data for months or years used for business analytical processing.

---

**Figure 1:** System Framework for Creating Data Mart by Consolidating Multi-Source Enterprise Operational Data

**Figure 2:** ER Model
In this case, Sales data in Oracle, Customer Satisfaction in MySQL and Shipment Quality in Microsoft Access are all referred to as OLTP. In OLTP, data are structured in ER model as depicted in Figure 2. These data will be extracted and transformed into a dimensional model i.e. star schema, Figure 3, in Data Mart through staging area for quarterly sales analysis. Business analytical application which represents the OLAP is used to analyze the business by using the data taken from the Data Mart, which can be used strategically to obtain and analyze data based on their needs [9]. Data Mart is a smaller, more manageable implementation of enterprise data warehouse. When data warehouse or data mart combined with OLAP, such combination consists of one or small number of fact tables and conformed dimensions. As such, it generates a SalesDataMart by consolidating heterogeneous data sources for efficient quarterly sales analysis.

In addition, SalesDataMart DTS Package, Figure 1, has two Execute SQL Tasks running in parallel, one to insert new records and another is to modify records. Parallel tasks executions speed up the transformation process and thus improve performance of DTS package.

To illustrate the result of data transformation and update, there are a few assumptions applied. Imagine now is March 31, 2004 (end of Quarter 4). The last running date was December 31, 2003 (Quarter 3). Note that the company operates on a fiscal year as follows:

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Month</th>
<th>DTS running date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Apr – June</td>
<td>June 30</td>
</tr>
<tr>
<td>Q2</td>
<td>Jul – Sept</td>
<td>Sept 30</td>
</tr>
<tr>
<td>Q3</td>
<td>Oct – Dec</td>
<td>Dec 31</td>
</tr>
<tr>
<td>Q4</td>
<td>Jan – Mar</td>
<td>Mar 31</td>
</tr>
</tbody>
</table>

At the end of Quarter 4, records that need to be transferred and updated should be between Jan 1, 2004 until 31 March 2004 (records of Quarter 4). The following describes data transformation and update for each enterprise operational data: Customer Satisfaction, Shipment Quality and Sales.

CUSTOMER SATISFACTION

Customer Satisfaction data loading demonstrates...
data transformation between MySQL database system residing on Linux Fedora Server platform and SQL Server 2000 residing on Windows platform. This is possible through the Open Database Connectivity (ODBC). MySQL ODBC driver needs to be installed on the Linux box in order to perform the data transformation. Before the execution of SalesDataMart DTS Package, the data mart contains records only up to Quarter 3. At the end of Quarter 4, SalesDataMart DTS package will automatically transfer customer satisfaction records of Quarter 4 from data source (MySQL) into data mart (SQL Server), as illustrated in Figure 4.

During the loading process, two columns experience data transformation: Rating and CallDate. Rating value has been transformed into rating descriptor to ease sales analysis as follows:

<table>
<thead>
<tr>
<th>Rating Value</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Never do business with us again</td>
</tr>
<tr>
<td>2</td>
<td>Unsatisfied</td>
</tr>
<tr>
<td>3</td>
<td>Satisfied</td>
</tr>
<tr>
<td>4</td>
<td>Very satisfied</td>
</tr>
</tbody>
</table>

CallDate also has been transformed into PeriodID. dim_Period represents time dimension. Time dimension is important in optimizing the sales analysis by timeframe. A stored procedure called loadtblPeriod is used to populate the dim_Period accordingly. CallDate is mapped to corresponding PeriodID via DTS Lookup. DTS Lookup allows specifying a query that executes for each value from the source that needs to be looked up in a table that resides in destination. As the data is transferred, the following query is executed for each CallDate value from source:

```
SELECT PeriodID
FROM dim_Period
WHERE PeriodDay = ?
```

SHIPMENT QUALITY

Shipment Quality data loading demonstrates data transformation between Microsoft Access and SQL Server 2000. This is done through the Microsoft Jet drivers. The result is shown as follows:

Referring to Figure 5, at the end of Quarter 4, all shipment records of Quarter 4 will be automatically transferred into the data mart. Based on the figures, three columns have experienced some changes: ShipmentDate, ShipmentQuality and UnacceptableItems. ShipmentDate is transformed into PeriodID by using similar PeriodIDLookup used for Customer Satisfaction. Shipment Quality is transformed into a description-like term instead of numbers using the following ActiveX Script code:
UnacceptableItems is transformed from checked/unchecked format in Microsoft Access into Yes/No in SQL Server using ActiveX Script as follows:

```
If DTSSource("UnacceptableItems") = "False" Then
    DTSDestination("UnacceptableItems") = "No"
Else
    DTSDestination("UnacceptableItems") = "Yes"
End If
```

SALES

Sales data loading demonstrates data transformation between Oracle database system residing on Unix Server platform and SQL Server 2000 residing on Windows platform. This is possible through either Open Database Connectivity (ODBC) or Object Linking and Embedding Database (OLEDB). SQL Server box needs to be installed with Oracle client or also known as Net8 or Net9 client in order to enable the box to access remote Oracle database.

DTS package will capture this change and update the records so that the new sales entry will follow the new pricing, (see Figure 7).

Figure 7: Modified Product Record

Having all data of Customer Satisfaction, Shipment Quality and Sales being transferred automatically into SalesDataMart, Creative Plants now is able to perform efficient sales analysis.

CONCLUSION

Data Transformation Services (DTS) is definitely an attractive database solution for automating data transfer and update that suits well with the current trend of business data management. Evolution of legacy system such as mainframe systems demands a solution to integrate it with current technology and business needs. It demonstrates DTS capabilities in automating data transfer between heterogeneous databases such as Microsoft Access, MySQL on Fedora Linux Server and Oracle on Sun Unix Server.

With the advantages of cost effectiveness; excellent performance; powerful and intuitive interface of DTS Designer; wide range of connectivity; bi-directional
data transfer and extendable with advanced programming, DTS absolutely is a competitive Extract, Transform and Load (ETL) tool. Due to great success of Microsoft SQL Server 2000 Data Transformation Services (DTS), this gives more value to Database Administrators (DBAs) in performing their job with great productivity.

REFERENCES


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DESIGNING AN AUTOMATED STAFF AND ORGANIZATION PERFORMANCE APPRAISAL SYSTEM: A WEB-BASED APPROACH

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ABSTRACT

Key Performance Indicator is a method adopted by an organization to measure the performance of the organization and its staff. Automated Performance Review and Information System (A-PRAISe) is a web application which was developed using Java and JSP for the purpose of monitoring staff performance for Universiti Teknologi Petronas (UTP). The paper explains how the developer designed and implemented the application by combining the generic three-tier logical architecture with the Model-View-Controller architecture and Command Design Pattern. Then, the paper proposes two design improvements for the system and ends with the conclusion of all the works that had been done.

Keywords: model-view-controller, three-tier architecture, JSP, key performance indicator, key success indicator, MySQL

INTRODUCTION

Corporate Performance Management (CPM) is a concept adopted by organizations to measure and manage their performance which include managing the processes, methodologies, metrics and systems [1]. The main idea of CPM is to get every personnel in an organization involved in meeting organizational goals and performance. This task is achieved by sharing organizational vision and strategies among all levels of personnel so that everyone has a common understanding of what they need to achieve.

The advantage of implementing CPM can be felt by every level of personnel in an organization. Sharing of information will help all personnel in making daily decisions, while helping higher level management understand their business and helping executives set new targets, goals and long term decision [1].

CPM Software

Software that supports CPM needs to integrate and automate Scorecard, Business Intelligence, Planning and Financial Consolidation [1]. Scorecard involves activities in managing metrics to measure performance. Key Performance Indicator (KPI) or Key Success Indicator (KSI) is normally used in measuring organization performance.

Currently there is a lot of software that supports CPM. Three of them are Corporate Management Software (CMS) developed by CorVu, Enterprise Performance Optimization Suite (EPOS) by ALG Software and Cognos 8 BI. Table 1 describes the features of the softwares.
Universiti Teknologi Petronas started using KPIs in 1999. An Administrator manages all the KPIs. Each KPI is used to measure the performance of particular job position, and the person holding that position is known as the KPI Owner. The KPI Owner is the party responsible for the realization of a particular KPI, as well the updates on the progress of each KPI. Sometimes the KPI Owner delegates the task of updating the KPI achievements to a subordinate, who is then called the KPI Updater.

There are two types of evaluations for a KPI Owner: Business Plan (BP) and Score Card (SC). BP is an annual plan for each department and consists of Strategy, Initiative and KPI. Strategies are systematic action plans; initiatives are work that needs to be executed to fulfill a strategy while KPIs show what needs to be achieved.

The second evaluation is the SC. This is where the performance of a KPI Owner is quantitatively captured. The KPI is measured every time the KPI progress is updated. The achievement is determined based on the difference between the actual performance and the planned target. Every quarter, the KPIs are updated and measured by first comparing between the annual plan with the annual projection; then comparing the current quarter achievement against the achievement for the same quarter in the previous year; and lastly comparing the current achievement up to the current quarter against the annual plan.

The performance of a KPI Owner is measured in percentage and may be calculated using different formulas, which are specified by the KPI Administrator at the time the KPI is created. The performance of one KPI Owner can also be used to measure another KPI Owner’s performance. This form of relationship usually happens to subordinates who are also subjected to fulfill the KPIs of their superiors.

Prior to the development of A-PRAISe, a manual system was used but had encountered certain problems. Generally more efforts are required by the KPI Administrator to manage and distribute the KPIs. The KPIs are shared using email and every quarter all the updates will be sent back by the KPI Updater or KPI Owner through email. In order to

<table>
<thead>
<tr>
<th>Software</th>
<th>Modules</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS [2]</td>
<td>Metric Management</td>
<td>• Track KPI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lead data from other system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Email reminders when manual data entry is due</td>
</tr>
<tr>
<td></td>
<td>Objective Management</td>
<td>• Automated monitoring and management of strategic objective</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Association of performance and strategic objective</td>
</tr>
<tr>
<td></td>
<td>Initiative Management</td>
<td>• Performance monitoring of individual initiative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Use Gantt Chart to manage initiative status</td>
</tr>
<tr>
<td>EPOS [3]</td>
<td>Strategy and Performance Management</td>
<td>• Web-based application with centralized database to develop and communicate strategy and metric management</td>
</tr>
<tr>
<td>8BI [4]</td>
<td>Scorecard</td>
<td>• Browser-based, zero footprint application</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Create, manage, and present company’s critical metrics for individual employees, managers and executives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two levels of scorecard: discrete project and corporate wide strategies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Introduce corrective actions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Explanation for status of a KPI using reports, dashboard and other contents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Support Six Sigma, TQM, Activity-Based Costing, and Economic Value Added methodologies</td>
</tr>
</tbody>
</table>
update the KPI, the KPI Updater and KPI Owner have to collect the data from certain individuals. If the individual is not available, the KPI cannot be updated. Some KPI updaters or KPI Owners may end up using the wrong calculation formula based on their own understanding of the KPI, instead of adhering to the UTP standard measurement thus making the final output unreliable.

The rest of the paper is organized as follows: Section 2 describes the A-PRAISe system requirements and Section 3 discusses the design and implementation of A-PRAISe. Section 4 discusses recommendations for architecture improvements and Section 5 discusses the work done by the developer to investigate the system performance when run on different platforms. Finally, Section 6 presents the authors' conclusions on the paper.

A-PRAISE USER REQUIREMENTS

The Automated Performance Monitoring & Information System (A-PRAISe) is a staff monitoring system developed for UTP. The goals of developing the system are automating tasks in monitoring staff performance, reducing errors in measuring performance, making the staff performance information more reliable and allowing for easy distribution of information for authorized users.

A-PRAISe supports the task of managing scorecard for both discrete project level and corporate wide strategies. KPI Owners and KPI Updaters can update their respective scorecards and can provide some explanations or corrective actions for the current status of the KPI. The KPI Administrator can choose different calculation formulas for each KPI and the KPIs can be linked together to show how the status of one KPI can affect another KPI. The KPI Administrator can also set the ownership for a KPI. This will provide the data access security since only the owners (KPI Owner and KPI Updater) can update the KPI. Table 2 describes A-PRAISe functionalities in more detail.

<table>
<thead>
<tr>
<th>No.</th>
<th>Functionality</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manage scorecard</td>
<td>Administrator</td>
</tr>
<tr>
<td>2</td>
<td>Forward score card to be used for next year</td>
<td>Administrator</td>
</tr>
<tr>
<td>3</td>
<td>Manage KPI ownership</td>
<td>Administrator</td>
</tr>
<tr>
<td>4</td>
<td>Manage links between KPI</td>
<td>Administrator</td>
</tr>
<tr>
<td>5</td>
<td>Update quarterly all business plan and scorecard for all staff</td>
<td>Administrator</td>
</tr>
<tr>
<td>6</td>
<td>Update all KPI Owner and KPI Updater personal information</td>
<td>Administrator</td>
</tr>
<tr>
<td>7</td>
<td>Update quarterly specific score card and business plan</td>
<td>KPI Owner and Updater</td>
</tr>
<tr>
<td>8</td>
<td>Change personal information</td>
<td>KPI Owner and Updater</td>
</tr>
<tr>
<td>9</td>
<td>View all scorecard</td>
<td>Administrator, KPI owner and updater</td>
</tr>
</tbody>
</table>

A-PRAISE DESIGN AND IMPLEMENTATIONS

The A-PRAISe design was created based on the results of the analysis. The requirements were obtained from multiple interviews, discussions, analysis of sample data and documents, and feedbacks from the testing of application prototypes. Unified Modeling Language (UML) diagrams were used in the design phase. Since there are many diagrams in UML, the developer chose to use only the Use-Case, Sequence and Class diagram for modeling the analysis and design.

Design

During the design phase, the developer had identified a set of goals for the system design. Based on the user requirements defined in the analysis phase, the developer decided that the design should meet these conditions:

1. Each component can easily be reused,
2. Components are loosely coupled,
3. Presentation and business logic are separated,
4. Existing codes are easy to be modified, and
5. New functionalities can be added with minimum effort.

For the development of A-PRAISe, the Model-View-Controller (MVC) and the 3-tier logical architecture were adopted. From the hardware point of view, the developer used a 2-tier architecture but from the application point of view the developer used 3-tier architecture. Figure 1 and Figure 2 show the hardware and application architectures, respectively.

![Figure 1: 2-tier Hardware Architecture](image)
![Figure 2: 3-tier Application Architecture](image)

According to Burbeck [5], “[i]n MVC paradigm the user input, the modeling of the external world and the visual feedback to the user are explicitly separated and handled by three types of component each specialized for its task”. Table 3 lists the three components of MVC and their descriptions.

<table>
<thead>
<tr>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Manages the behavior and data of the business domain.</td>
</tr>
<tr>
<td>View</td>
<td>Manages the display of information</td>
</tr>
<tr>
<td>Controller</td>
<td>Interprets events from the user, informing the Model and/or the View to change</td>
</tr>
</tbody>
</table>

The MVC architecture was chosen because it helps to clearly distinguish between the visual part of the user interface and the state of the user interface [6].

The View component of MVC contains Java Server Pages (JSP) or Hypertext Markup Language (HTML) files to ease user interaction from the browser. In A-PRAISe, both the View and Controller are combined together in the same component.

The Model component can be divided into two: the Passive Model and the Active Model. The developer used Passive Models which delegate the task of notifying the View of the updated Model state to the Controller. Notifications of Model updates to the View components are done by storing Models as Hypertext Transfer Protocol (HTTP) Session objects. Using Session Objects minimizes the need to always query the database for the same data. This is especially useful for A-PRAISe since the KPI data are only updated once per quarter.

Command Design Pattern was implemented in A-PRAISe because it allows the creation of an object to represent an operation. This object has a method “execute” containing a command required to complete the operation. If the command within the “execute” method is executed without any error, the operation is considered successful. The operation status will be returned to the Controller to take an appropriate action based on the returned status.

Each Command component can be executed from multiple Views (through the Controller) or reused and combined with other components to create a new component to solve operations that are more complicated. Command Design Pattern also allows the developer to easily add new functionalities to the application by simply creating a class based on the Command Design Pattern. A View and Controller component for the user can also be created, if necessary, to send requests to the Command Design Pattern class. Database updates are addressed using Data Access component in the Data layer which will communicate with the database.
Figure 3 shows how the MVC architecture and the generic 3-tier logical architecture are combined in the A-PRAISe architecture design. Figure 4 gives an example of how the MVC architecture implementation works in A-PRAISe.

![Figure 3: A-PRAISe MVC Architecture](image)

Figure 4 illustrates several examples of the MVC implementation in A-PRAISe. It starts with a user request to forward a Scorecard. The request will be handled by the Controller in the JSP file. Based on the request, the Controller calls the Forward Scorecard Execute method to complete the Forward Scorecard operation. In order to do so, the Add Scorecard and Add Subordinate Scorecard will be reused.

Forward Scorecard, Add Scorecard and Add Subordinate Scorecard are Command Design Pattern classes that execute commands to change data in a KPI object (Model). Add Scorecard will call methods inside the Add Scorecard DB class which is a data tier component that updates records in the database. Add Subordinate Scorecard will call methods in the Add Subordinate Scorecard DB (also a data tier component) to update the database. Next, Forward Scorecard will return the operation status to the Controller and the Controller will update the HTTP Session with the updated KPI object based on the operation status and forward the HTTP Session to another JSP file which will display the latest state of the model.

**Implementation**

The requirements for the system are that it must allow multiple users concurrently, while being accessible only via the internal network. Therefore, the developer had to choose between a distributed or web application. The developer then decided on a web application based on these reasons [7]:

1. Web-based applications can be used on multiple platform and clients may run on different environments than the server.
2. Web-based applications do not need to be downloaded, installed and configured individually on each client.
3. Installation and maintenance cost is cheaper
4. Clients do not need large memory or processors to run the application as the workload is done mostly on the server.
5. Client’s environment does not contribute in selecting programming languages.

The developer developed A-PRAISe using Java programming language and JSP technology. There are a few server-side scripting languages that can be used by the developer such as ASP.net, PHP or JSP. ASP.net is ruled out because although its framework is designed to be platform-independent, its full implementation has not been tested on platforms other than Windows [8]. The developer had to decide between JSP and PHP because both support deployment on multiple platforms, which is one of the requirements for the system. However, JSP was chosen instead of PHP because the implementation is in line with the designs and methodologies used.

There are two ways of implementing JSP [9, 10]; JSP that is directly accessed from the client’s browser (Model 1) or JSP that is accessed by the client’s browser through a Servlet (Model 2). Since the A-PRAISe application has a rich client interface, the developer chose to use Model 1. Most of the presentation
components are a combination of presentation codes (HTML) and controller codes (Java). The developer also included Form Validation functions which are coded in JavaScript. This ensures that all the fields in the form are correctly filled before they are sent to the server which will significantly reduce the time and workload of the server when processing the information. Most of the HTML and JSP files are atomic, thus the interface serves a specific purpose. When viewed using IFrame, the user perspective would be that the files are combined into a single composite view.

In order to minimize the development cost, the developer decided to use an open source Database Management System (DBMS), MySQL. Besides MySQL, PostgreSQL is also another open source database. From the comparison between MySQL and PostgreSQL, both DBMSs are equal in supporting basic database operations [11, 12]. However, MySQL is known to work faster than PostgreSQL. Table 4 shows the speed comparison for three benchmarking tests done by Glowiak [11] for MySQL MyISAM, MySQL InnoDB, PostgreSQL with fsync=true and PostgreSQL with fsync=false.

Besides the transaction speed factor, MySQL is also used by other current applications in UTP. So, MySQL is preferred over PostgreSQL. Other features of MySQL that makes it a good choice include portability, speed, scalability, flexibility, ease of use, fine-grained security model, and ease of access from programming languages, as reported in [13].

<table>
<thead>
<tr>
<th>Number of data: 50000</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQL</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>insert</td>
</tr>
<tr>
<td>select</td>
</tr>
<tr>
<td>delete</td>
</tr>
</tbody>
</table>

There is room for improvements on the design architecture. As mentioned in Section 1, different KPIs may be calculated using different formulas. Currently all the different calculation formulas are programmed in each KPI and QuarterKPI class and are controlled by ‘if’ statements. It makes it complicated to calculate the KPIs and difficult to customize if A-PRAISE is going to be used by other organizations with different calculation formulas. To solve the problem, the Strategy Design Pattern can be used by creating a different class for each individual calculation formula. Figure 5 illustrates the proposed changes in more detail.

Another improvement that the developer can add is the usage of the Struts framework. Struts is an open source framework for implementing MVC in web-based applications [9]. One of the advantages of using Struts is the implementation of the Front Controller Design Pattern. The Front Controller handles user requests, and executes operations to complete user
requests by calling suitable methods and selecting Views in a single component. The advantages of using Front Controller lie in the central component which will accept requests from the View and select the next View. A centralized component will improve manageability of the application flow and the design of the View component [14].

INVESTIGATING A-PRAISE PERFORMANCE ON DIFFERENT PLATFORMS

A-PRAISe was installed on a server with Intel Pentium 866 MHz, 256 MB RAM, runs on Windows NT and Apache Tomcat 5.5 web server. After testing A-PRAISe on multiple clients with different hardware specifications on Window 2000 and Window XP, there are some problems in performance. The developer had carried out an investigation to understand the problem.

The investigation runs Login, Insert New Scorecard, Update Scorecard, Delete Scorecard, Insert New Business Plan, Update Business Plan, Delete Business Plan, Choose Staff and Logout operations to record how long the web applications take to complete each operation. Except for login and insert new business plan, other operations were completed in less than a second for all clients. Login operation needs an average of one minute to complete on clients that run on Window 2000. Insert New Business Plan have 3 subcomponents, which are Add Strategy, Add Initiative and Add KPI. Add Initiative and Add KPI completes in less than a second while Add Strategy needed around one minute to complete on some clients running on Windows 2000. Table 5 shows the results of the investigation for the Login operation which was chosen as a sample since it is used by all users.

Both Login and Add Strategy operations have one common feature which is both functionalities will create a new session. Login will create a new session for users who have successfully logged in while Add Strategy will create a new session for the new strategy object created. Only these two operations create a new session while other operations just update the session.

The real cause for the performance is still under investigation and it is hard to say whether it is because the client runs on Window 2000 or because of other factors. However, a temporary solution or workaround had been found. The user just needs to submit the page twice.

<table>
<thead>
<tr>
<th>Client Specification</th>
<th>Time taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel Pentium4, T2300; Windows XP Professional SP1, SP2; Internet Explorer 6 SP1, SP2</td>
<td>Less than 1 second</td>
</tr>
<tr>
<td>Intel Pentium4; Windows 2000 SP2, SP4; Internet Explorer 5.5 SP2, 6 SP1</td>
<td>1.00.77 minute</td>
</tr>
<tr>
<td>Intel Pentium3, Windows 2000 SP2, Internet Explorer 5.5 SP2</td>
<td>1.00.80 minute</td>
</tr>
<tr>
<td>X86 Family6 Model 7 stepping, Windows 2000 SP2, Internet Explorer 5.5 SP2</td>
<td>1.00.87 minute</td>
</tr>
</tbody>
</table>

CONCLUSION

The combination of 3-tier, MVC, Command Design and Architecture Patterns serve the purpose of creating a design that allows reusability of components, separation of business logic and presentation, and reduced effort to enhance the application requirements or functionalities. Nevertheless, some improvements can be done to make customization easier by implementing Strategy design pattern and using Struts framework to improve the implementation of MVC. Using HTTP Session is a good way to store objects (MVC Model) and allow the application to display dynamic web pages without retrieving the information from a database each time the page is loaded. The developer also discovered during the testing of the application, that clients
running on Window 2000 have some performance problem which is measured by the speed it takes to complete the Login operation.

REFERENCES


SEARCH ENGINES INTEGRATION WITH HITS REDUNDANCIES FILTERING

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ABSTRACT

Finding information in the WWW has been a normal practice for most people who need fast information. Even though there exist a number of available effective search engines in the market, users are still overwhelmed with the information provided. Mass information supplied to the users might get them exhausted as they browse through each and every one of the hits returned by the search engines. This research aims to reduce users’ dilemma on mass information supplied by providing a search engine derived from a combination of features from some popular search engines. It retrieves results from some powerful search tools and omits duplicate results by filtering the identical URLs. Users can have more hits from various search engines with one single click without any redundant hits. A comparative study was conducted between our proposed search engine and a similar established search engine. The results showed that our search engine can produce more variety of hits returned to the users.

Keywords: filtered, integrated, redundancies, search engine

INTRODUCTION

Searching information on the web can be viewed as either extremely easy or difficult. This is because the WWW is not indexed like many library catalogues or journal-article index. When searching information on the Internet, the web pages collect and index the request using a search tool from computers all over the world that contains the actual web pages. Some examples of the search tools are Yahoo! Search, Google, AltaVista and etc.

The different types of search tools have their own strengths and weaknesses. Depending on your information needs, one may work better for you than another. Search directories are hierarchical databases with references to websites. The websites that are included are hand picked by living human beings and classified according to the rules of that particular search service. Whereas, search engines use software to "crawl" the Internet in search of what you would like through the use of terms or keywords. Specialized databases are the hidden parts of the World Wide Web that are normally not found by regular search engines [1].

The work for this research project namely, Integrated Filtered Web-Search Engine (IFWSE), is to enhance the searching strategies by utilizing the existing web-search tools in the market. It is mainly on developing Meta-Search engine that has the abilities of filtering redundant returned links related to the keywords searched (called hits). The prototype search engine, IFWSE, integrates three major search engines in the...
market which are Google (as S1), Yahoo! Search (as S2) and MSN Search (as S3). These three were selected as the sources because they are the most preferable search engines in the market today [2]. It is able to return the hits from all those search engines to the integrated web search page without redundancy.

RELATED WORK

Meta-Search engines do not own a database of Web pages; they send the search terms to the databases maintained by search engine companies. “Smarter” meta-searcher technology includes clustering and linguistic analysis that attempts to show the themes within results, and some fancy textual analysis and display that can help looking deeply into a set of results. However, neither of these technologies is any better than the quality of the search engine databases they obtain results from [3].

There are some intelligent search agents in the market which act similarly as Meta-Search where it can search simultaneously several search engines at one time, for example Copernic Agents by Copernic Technologies [4] and MetaCrawler developed in The University of Washington in 1994 and later operated by InfoSpace since 2000 [5][6]. Copernic features the ability of a search wizard to search using a question or keywords, keyword highlighting in results and Web pages, a detailed search history, automatic software updating and many useful search management functions [4]. By combining robustness and scalability, its technology retrieves and indexes data wherever it is found: on corporate intranets, company servers, and public websites. It makes use of advanced language and linguistic analysis technologies, resulting in unparalleled indexing precision [4]. However, it is an agent that needs to be installed on a web browser in order to be used.

MetaCrawler works by querying a number of existing, free search engines, organizes the results into a uniform format, and displays them. A so called Fast Search method produces results the quickest. After a few seconds this search method will bring up a new page filled with links to information related to the keywords as hits. The MetaCrawler operates in two general modes: Normal Mode and Verification Mode. In Normal Mode, the MetaCrawler reports results immediately after retrieval from the remote search engines. In Verification mode the MetaCrawler loads and verifies each reference to ensure the validity of the data [3]. However, it was found that the retrieved results are usually around 100 hits.

OUR SYSTEM

The prototype system discussed in this paper, Integrated Filtered Web Search Engine (IFWSE), has a similar aim as MetaCrawler which is to a single, central interface for World Wide Web document searching. However, MetaCrawler just retrieved up to 3 top pages of the search engines whereas the prototype of IFWSE can return up to top 5 pages for the time being.

Fig. 1 illustrates the flow of the processes involved in this system. The input or queries posted by the users in IFWSE will be submitted to the external search engines. Those search engines will search the keywords submitted in the internet or web for any relevant and related topics. The accuracy of the retrieved results will depend on the external search engines effectiveness in retrieving information intelligently. That’s why it is important to choose the best search engines for the platform search engines. The results from the search engines will then be retrieved by IFWSE. However, in this prototype, only top 5 pages from each of the search engines will be retrieved. The results will then be filtered for any irrelevant and duplicate link. The last process was to rank the results according to the user preferences or according to the most relevant hits to the user’s interest. Only after the ranking process, the results will be displayed and presented to the user.

HITS REDUNDANCIES FILTERING PROCESSES

The filtering process is done after the array of the results have been populated and arranged in the form where it is easier to do filtering and sorting processes. The results from each of the search engines are being filtered step by step using one particular search
engine among the platform search engines as the base search results and compared the URLs to check any redundancy. For a start, the base search engine (S1) results will be compared with the second search engine (S2) results and comparison for S1 and the third search engine (S3) will follow afterwards. Then the remaining S2 and S3 results that have no similar URL with S1 will be compared for any redundancy.

The process will be recursive while looping till the maximum number of the total results retrieved. If the similar URL found while comparing, the loop will break and continue to the next result. One of the results that have similar URL will be deleted, for example, if the URL for S1 result and S2 result is found identical, the particular S2 result will be deleted so that later on it will not be displayed twice, else the result retrieved from S2 will be added to the S1 result list. Similar process will be carried on to S2 and S3, in which the S2 list will be remained by adding up the results from S3 which are not identical to S2. The summarized algorithm can be viewed as in Figure 2.

CATEGORIZING AND DISPLAYING RESULTS

Results from the filtering process will be the non-redundant hits. For displaying purposes the filtered hits will be populated in new array in the form that it can be categorized by the source of retrieval. Let say if the hits were retrieved from \( S_1 \cap S_2 \cap S_3 \), they will be displayed on the top list followed by the hits group retrieved from \( S_1 \cap S_2 \), \( S_1 \cap S_3 \), \( S_2 \cap S_3 \), respectively, then the remaining will be hits appeared in S1 only, S2 only and last but not least S3 only.

RESULTS AND DISCUSSIONS

TEST ON REDUNDANCY

An experiment was conducted by feeding 20 keywords and phrases to S1, S2, S3 and IFWSE respectively. The keywords were randomly picked and the same keywords were keyed in 10 times in 10 different days. This was to see the behavior of IFWSE as it retrieved the results in real time from those platform search engines.
engines. The mean hits achieved after performing a number of experiments with IFWSE to acquire the total results retrieved from each search engine are being recorded to compare with the filtered hits from IFWSE. It is shown in Table 1.

Total hits retrieved from each search engine were around 45-55 as IFWSE retrieved the hit results from first 5 pages. Compare to the total hits for all three search engines, total search hits by IFWSE is reduced by about 25%.

Let’s take the first searched keyword ‘petronas’ as an example. The total hits from three search engines were 150 but the IFWSE produced only 99 hits. In details, overlapped hits for all three search engines \((S1 \cap S2 \cap S3)\) were 17, \(S1 \cap S2\) were 10, \(S1 \cap S3\) were 6, \(S2 \cap S3\) got only one overlapped result and the rest of the results were unique and non-redundant with the each other. From the observation, results that overlapped were normally high ranked results that retrieved from 1st top and 2nd top pages. The remaining pages seldom had overlapped results.

Looking at the results retrieved in Table 1, obviously IFWSE could filter the redundant hits out of each of the search engines. This is done so that, later on each of the hits that have identical URL be displayed only once for users benefits. Based on the results, it can be said that for only top five hit pages of the search engines, 75% of the hits are unique, indirectly IFWSE helps to save about 25% of the time from reading the similar hits. Here is the evidence where search engines’ hits overlap far less than we would think. That’s the reason why users constantly have the habits of opening more than one browser for another search engines.

The objective of IFWSE included filter up hits to eliminate any redundancy as well as to give users more top ranking hits taken from many search engines. The success of the first mentioned objective is being evaluated using Precision theory where it stresses on how high the precision of the filtering process.
is whereas the success of the second mentioned objective is being evaluated by the comparison of total hits returned by IFWSE and total hits returned by an established integrated search engine, in this case MetaCrawler (Meta search engine) was selected.

PRECISION

Recall is the ratio of the number of relevant records retrieved to the total number of relevant records in the database. Basically it is used to show the percentage of desired hits and successfully retrieved. It is difficult to measure recall as WWW is such a huge warehouse and we do not know how many relevant hits in it [7][8]. Hence, Precision was used in this case for the retrieval performance measurement by looking at the redundant hits. In this project, the Precision formula is as follow:

$$\text{Precision} = \frac{(A)}{(B)} \times 100 \%$$ (1)

where

- $A = \text{total hits returned} - \text{number of redundant hits}$
- $B = \text{total hits returned}$

In this case, redundant hits mean repeated hits that IFWSE failed to filter.

Figure 3 shows the preciseness of the IFWSE’s filtering process. A number of redundant hits were obtained from a very close inspection during the experiments. The precision was calculated for each of the searched keywords. Basically IFWSE can approximately filter up the hits with an average precision rate of 97%. The redundant trends are actually those results from $S_2 \cap S_3$. It is believed that, the performance of the filtering process for the second round becomes less effective. This is due to the structure of the algorithm.

IFWSE VS METACRAWLER

MetaCrawler is a free integrated search tool which consists of Google, MSN Search, Yahoo! Search and Ask.com. The comparison of total hits based on the previous keywords retrieved by IFWSE (after omitting the duplicate hits) and MetaCrawler was conducted and is shown in Figure 4.

**Figure 3:** Precision
It is clearly shown that the numbers of hits retrieved by MetaCrawler is smaller than IFWSE although IFWSE uses only three search engines whereas MetaCrawler uses up to four search engines. The rational behind this is because there were more overlapping hits retrieved by MetaCrawler as compared to IFWSE. Why was this happened? Based on the close observation, MetaCrawler retrieved up to top 3 pages of the results in each search engine whereas IFWSE retrieved up to top 5 pages from each search engine. On top of that, most of the overlapped results were highly ranked. The lower the ranking the more unique the hits returned.

Hence, the hits retrieved from MetaCrawler were mostly the top 30 of each search engine and most of the time, these results are overlapped. On the other hand, IFWSE retrieved the top 50 hits that were able to get those less overlapped results too. Basically, IFWSE gives the advantage of variety hits returned to the users.

CONCLUSION

Search engine is one of the popular tools nowadays in information searching on the web. We have Internet Directories such as Yahoo! Directory, Search Engines that crawl the web such as Google, MSN Search, and also Meta-Search that retrieved information from other search engines simultaneously such as Meta-Crawler, Dogpile and etc.

Even though search engines are sophisticated beyond the imagination of human, still they have inconvenience with their ease in use matters. Users have the tendencies to use more than one search engine to get a better results and because they have this urge to know what actually other search engine can get that their search engines do not get.

Basically, IFWSE is to integrate the major and powerful search engines into one web-based filtered search engine for users’ convenience. It does not need to
be installed in order to be used. It will benefit users in saving their time of reading results from several opened browsers. Users can get more hits with one single search as IFWSE will simultaneously send queries to several search engines at once. Other than that, it will filter out any redundant hits and display them only once so that users do not have to read them again and again. The filtering process used is simple to be implemented, just based on identical URLs. This will give the users benefits over the unfiltered meta-search engine.

For future work, it is recommended that to add more major search engines for more useful hits. As for the filtering process, instead of only based on the identical URL, to make it more effective, results refinement method can be used such as Boolean search. Other than that, the filtering algorithm could be improved to make it more precise.

REFERENCES


S. P. Yong obtained her MIT and BIT (Hons) in Industrial Computing from Universiti Kebangsaan Malaysia. Her employment experience includes IBM Malaysia Sdn Bhd, Informatics Institute Ipoh and Universiti Teknologi PETRONAS. Her research interests are in Intelligent Systems, data and text mining.
EMPIRICAL ANALYSIS ON THE EFFECTIVENESS OF DIGITAL STORYTELLING WITH PANORAMIC IMAGES – AN ADOPTION AND CUSTOMIZATION OF DELONE AND MCLEAN’S SUCCESS FRAMEWORK

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ABSTRACT

Technology advancement has now enabled experience sharing to happen in a digital storytelling environment that is facilitated through different delivery technologies such as panoramic images and virtual reality. However, panoramic images have not been fully explored and formally studied especially to assist experience sharing in digital storytelling setting. This research aims to study the effectiveness of an interactive digital storytelling to facilitate the sharing of experience. The interactive digital storytelling artifact was developed to convey the look and feel of Universiti Teknologi PETRONAS through the panoramic images. The effectiveness of digital storytelling through panoramic images was empirically tested based on the adapted Delone and McLean IS success model. The experiment was conducted on participants who have never visited the university. Six hypotheses were derived and experiment showed that there are correlations between user satisfaction of digital storytelling with panoramic images and user’s individual impact of the application to assist experience sharing among users. Hence, this research concludes a model on the production of an effective digital storytelling with panoramic images for specific experience sharing to bloom among users.

Keyword: digital storytelling, panoramic images, experience sharing, effective system, effectiveness study, human computer interaction

INTRODUCTION

In the digital storytelling realm, many types of digital technology and media have long been the enabler for narrative entertainment to reach its audience. Traditional narrative form of storytelling is transformed into a more dynamic and powerful system of communication with sound, music, visuals, interactivity navigation and user-control mechanism [1], [2]. Digital storytelling can act as glue that holds things together when developers are about to offer users with the different kinds of information, media, types of images and ideas [3].

Indicators of effectiveness of a system or application include quality of solution and error rates. So far, there has been no reported work that states a systematic measure to study the effectiveness of digital storytelling. In this study, the quality of solution is used as a primary indicator of effectiveness to measure the outcome when users (students) interact with the digital storytelling with panoramic
images application [4]. UTP-PanoView is a system that attempts to share information about Universiti Teknologi PETRONAS using digital storytelling as the medium. It utilizes Information Technology in views of multimedia and virtual reality. An empirical study based on UTP-PanoView experiment is conducted towards producing a model for an effective digital storytelling in this study.

LITERATURE REVIEW

Panoramic (from the Greek pan means ‘all’ and horama meaning ‘see’) are orientation-independent images that contain all the information needed to look around in 360 degrees. A number of these images can be connected or stitched together to form a walkthrough sequence. These orientation-independent images allow a greater degree of freedom in interactive viewing and navigation [5]. Experience refers to the nature of events that has been undergone by someone or something [6]. Humans have countless and unique ways that consist of expressions, behaviors, language and emotions to characterize and convey their moment-to-moment experiences. Hence, experience also is as an act that produces, create, and invent knowledge for effects upon the future. Interactive image sharing application nowadays [7], [8], enable users to feel like they are sharing experiences rather than just looking at pictures or sending and receiving messages with the images. With the availability of mechanisms such as MMS, online albums and moblogs, the experience sharing aspect remains problematic than the capture aspect. More fundamentally, experience sharing is highly relationship-specific.

Several measures have been examined by different prominent literatures to define the effectiveness of Information System applications. The diversity of the various measures from the previous research and empirical study on IS effectiveness was initially a cause for concern that lead DeLone and McLean to synthesize the measures into a unified model [9], [10], [11]. The DeLone and McLean’s (henceforth “D&M”) Model of IS Success has been regarded by many authors as a major contribution [12]. Realizing the fact that this model has been a great influence and inspiration to the succeeding research [19], [20], D&M Model is adapted as our evaluation model to suit digital storytelling application in our research. The D&M model basically incorporated several of the already accepted and tested dimensions or constructs of IS Success such as System Quality, Information Quality, User Satisfaction, Use, Individual Impact and Organizational impact into a single model.

RESEARCH METHODOLOGY

RESEARCH MODEL AND HYPOTHESES

Although claims on the effectiveness of digital storytelling are often made, the current literature does not reflect work on the evaluation of the effectiveness digital storytelling [13, 18]. In addition to that, there is a lack of formal guidelines or standard model on how to produce an effective digital storytelling for the purpose of facilitating the experience sharing to bloom among users. Our work was driven by the following research questions:

- Do system quality, information quality and interactivity have any significant relationship with user satisfaction of digital storytelling with panoramic images?
- Will user satisfaction of digital storytelling with panoramic images lead to any individual impact to the user?
- Will user satisfaction and individual impact of digital storytelling with panoramic images encourage the sharing of experience to bloom in user?

The hypotheses formulated are as follows:

H1: Perceived System Quality positively relates to User Satisfaction
H2: Perceived Information Quality positively relates to User Satisfaction
H3: Interactivity positively relates to User Satisfaction
H4: User Satisfaction positively relates to Individual Impact
H5: User Satisfaction positively relates to Experience Sharing
H6: Individual Impact positively relates to Experience Sharing

To determine the effectiveness of panoramic digital storytelling for experience sharing, we adapted the well-established DeLone and McLean’s (1992) Information System Success model, as illustrated in Figure 1, which has been validated empirically in several settings. We thus produced our research model as shown in Figure 2. We eliminated existing constructs of Use as it is irrelevant to digital storytelling context in which the application is used.

Figure 1: Original Delone and McLean’s Success Model that unified multi-dimensions measure (Delone and McLean, 1992).

Figure 2: Research model for evaluating the effectiveness of digital storytelling with panoramic images to facilitate experience sharing that adopted several constructs from Delone and McLean’s Success Model.
largely voluntary rather than Use construct which outlines the mandatory usage of an information system in an organization [11]. We also removed Organizational Impact construct in the existing model due to its need of greater granularity which involves many levels of organization bureaucracy. Instead, we incorporated constructs of Interactivity together with existing constructs on Systems Quality and Information Quality. The determination of the effectiveness is made through the use of constructs of User’s Satisfaction, Individual Impact and perception of Experience Sharing. The relationship of Systems Quality, Information Quality and Interactivity towards User Satisfaction [14], [15], will be determined and the relation of User Satisfaction towards Individual impact and the perception on Experience Sharing will also be determined in this adapted model.

THE UTP-PANOVIEW DIGITAL STORYTELLING

Digital storytelling can be categorized into “event-based”, “web-based” and “place-based” [2, 3]. We created a digital storytelling artefact to foster experience sharing among users to encourage or persuade them to experience the real thing. The panoramic digital storytelling artefact, UTP-PanoView, as shown in Figure 2 is categorized as “place-based storytelling”. It was produced in QuickTime Virtual Reality (QTVR) which is able to display spherical panoramas format in cubic or cylindrical panoramas projection, in a viewer where the user can move around, zooming in and out or rotate the object using the mouse and keyboard.

UTP-PanoView is an interactive digital story that also allows varying degrees of choice and control from the user’s part. It aims to facilitate audiences in connecting to locations through self-discovery where experience is revealed in context via rich visualizations of places and buildings. The experience sharing offered by UTP-PanoView allow users to experience the same thing as in the real world such as walking, stopping, running or changing direction. In other words, it is like an online expedition that is close to real campus walking tour. The panoramic images used in the study illustrated the buildings and scenes of a local Malaysian university, Universiti Teknologi Petronas (UTP) and its surroundings. Virtual campus tour could be a useful reference in the future for architects, urban planners, and government entities. In this artefact development, elements of the experience sharing consideration is fulfilled from the paradigm of experience sharing via the Systems Quality, Information Quality and Interactivity that based on user interaction and user-control mechanism such as navigation properties.

An experiment was conducted on 128 participants consisting of students selected from a secondary school. The sampling method used is a non-probability sampling which means no random selection is used during sampling process. The samples consisted of any students who have not been to UTP before. The participants were given 20 minutes to view and interact with UTP-PanoView in the school computer laboratory. At the end of the session, 5-point Likert scale survey questions were distributed for the participants to answer.
RESULTS AND DISCUSSION

The results and discussions are organized as follows: Section 4.1 discusses the data analysis and results for Instrument Reliability, Descriptive Analysis and Normality Test while this is followed by the data analysis and results for Correlation Coefficients in Section 4.2.

DATA ANALYSIS ON INSTRUMENT RELIABILITY, DESCRIPTIVE ANALYSIS AND NORMALITY TEST

To validate the data, the Cronbach's Alpha coefficient is conducted to test the consistency for all variables involved in this study. Shapiro-Wilk test of normality is then conducted to further determine the data distribution.

With reference to Table 1, the Cronbach's Alpha values for all variables are more than 0.6. This indicates that all variables scale have high reliability and internal consistency [16]. The values for skewness/standard error for all variables are out of range, which are between -2 and +2. This indicates that the data for all variables are not normally distributed. To support this analysis, Shapiro-Wilk test has been further conducted and it is noticed that the significance values for all variables are 0.00 which is less than 0.05. This testifies that the data for all variables are not normally distributed and hence, nonparametric test has to be conducted for any hypotheses testing purpose.

DATA ANALYSIS ON CORRELATION COEFFICIENTS

Since the data for all variables are not normally distributed, nonparametric test (Bivariate Spearman

### Table 1: Reliability (Cronbach's Alpha), Descriptive and Shapiro-Wilk Statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cronbach's Alpha</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
<th>Skewness</th>
<th>Skewness/Std. Error</th>
<th>Shapiro–Wilk Test</th>
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</thead>
<tbody>
<tr>
<td>Perceived System Quality</td>
<td>0.749</td>
<td>3.965</td>
<td>0.485</td>
<td>0.214</td>
<td>-1.169</td>
<td>-5.462</td>
<td>0.911</td>
</tr>
<tr>
<td>Perceived Information Quality</td>
<td>0.642</td>
<td>4.002</td>
<td>0.620</td>
<td>0.214</td>
<td>-0.493</td>
<td>-2.304</td>
<td>0.955</td>
</tr>
<tr>
<td>Interactivity</td>
<td>0.795</td>
<td>4.109</td>
<td>0.532</td>
<td>0.214</td>
<td>-1.525</td>
<td>-7.126</td>
<td>0.873</td>
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<tr>
<td>User Satisfaction</td>
<td>0.663</td>
<td>4.159</td>
<td>0.707</td>
<td>0.214</td>
<td>-0.918</td>
<td>-4.290</td>
<td>0.910</td>
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<tr>
<td>Individual Impact</td>
<td>0.755</td>
<td>3.966</td>
<td>0.520</td>
<td>0.214</td>
<td>-0.774</td>
<td>-3.617</td>
<td>0.935</td>
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<tr>
<td>Experience Sharing</td>
<td>0.752</td>
<td>3.845</td>
<td>0.555</td>
<td>0.214</td>
<td>-0.644</td>
<td>-3.009</td>
<td>0.938</td>
</tr>
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</table>

### Table 2: Summary of Correlation based on Bivariate Spearman

<table>
<thead>
<tr>
<th>User Satisfaction</th>
<th>Correlation Coefficient</th>
<th>Perceived System Quality</th>
<th>Perceived Information Quality</th>
<th>Interactivity</th>
<th>User Satisfaction</th>
<th>Individual Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correlation Coefficient</td>
<td>0.368 (positive weak)</td>
<td>0.611 (positive moderate)</td>
<td>0.409 (positive moderate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig.</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual Impact</td>
<td>Correlation Coefficient</td>
<td></td>
<td></td>
<td>0.471 (positive moderate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig.</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience Sharing</td>
<td>Correlation Coefficient</td>
<td></td>
<td>0.287 (positive weak)</td>
<td>0.604 (positive moderate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig.</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
correlation coefficients) is conducted in this research to independently measure the linear association between two scale variables for all variables towards digital storytelling with panoramic images. The Rowntree correlation classification by Derek Rowntree [17] was adopted in this study to indicate the strength of the relationship.

With reference to Table 2 above, the significance level or p-value for all relationships is 0.000, which is less than 0.05. This indicates that all variables in this study are positively correlated to each other. Results from the Spearman test also indicate that the correlation coefficient value between Perceived System Quality and User Satisfactory is 0.368 which is considered as a weak correlation; whereas the value of correlation coefficient between Perceived Information Quality and Interactivity towards User Satisfaction is 0.611 and 0.409 respectively, which both are considered as moderate relationship. These positive relationships suggest that developers or designers of digital storytelling with panoramic images should consider and focus their efforts on maintaining the overall System Quality, Information Quality and Interactivity of digital storytelling application because there is an appreciable effect of those factors on User Satisfaction level towards the application. From a more practical viewpoint, the power of System Quality, Information Quality and Interactivity as positive factors of User Satisfaction suggests that they provide an effective diagnostic framework in which to analyze system features, which may cause user satisfaction and dissatisfaction. Among these three factors, digital storytelling developers and designers should invest more resources and put high emphasis on maintaining the quality of the information or story as the core element of digital storytelling. They must ensure that the information or story quality is suitable, accurate, understandable, and bring meaning to their target audience. This is followed by the considerable importance should be given to the interactivity element of the digital storytelling design, that emphasizes on user’s involvement into the storyline, user’s ability to control the environment as well as the user-friendliness of the application.

These two aspects of Information Quality and Interactivity should be given higher priority than the overall System Quality in order to generate high user's satisfaction towards the digital storytelling. These relationships are clearly delineated in Table 2 where Perceived Information Quality and Interactivity are of moderate correlations to User Satisfaction as compared to Perceived System Quality with weak correlation. Better still, all the relationships are with positive values showing that all the three elements are vital to support an effective digital storytelling to achieve User's Satisfaction.

The correlation coefficient value between User Satisfaction and Individual Impact is 0.471 (see Table 2) which is also positively correlated with a moderate relationship. The positive association between User Satisfaction and Individual Impact also suggests that User Satisfaction towards the digital storytelling may serve as a valid factor that encourages the overall personal impact of that application to the users for instance the ability for users to appreciate and enjoy the application. User's individual impact of digital storytelling with panoramic images is also reflected via user's memory retain of the story and user's decision making ability while the application simultaneously manage to ignite user’s deeper curiosity and inspiration towards the story.

Nevertheless, the correlation coefficient value between User Satisfaction and Experience Sharing is only 0.287 which indicates they are positively correlated but with weak relationship. The result differs with the value of correlation coefficient between Individual Impact and Experience Sharing which is 0.604 that are positively correlated with moderate correlation. As such, it can be inferred that User Satisfaction does not highly influence the sharing of experience that users obtained compared to the effect of Individual Impact. The level of overall User Satisfaction towards digital storytelling with panoramic images may be low but as long as the application has given adequate Individual Impact to the users, the Experience Sharing could still be developed in users.
CONCLUSION

This section concludes the paper by describing the specific outcomes of the study and describes their importance. This research has creatively explored and formally studied panoramic images especially to assist experience sharing in digital storytelling setting. The results of this research yields evidence that panoramic images could express the experience of a place to the user and thus, later on encourage the users to share that experience. Since the challenge with digital storytelling today is the determination on the best possible way to tell a story via the objects that the place or event happen to have, telling a story could be done by putting forward the objects such as buildings and places into a narrative or storylines. Due to its wide-view characteristic, panoramic images is a wise choice in order to weave together objects that tell stories and sharing of experience. This study postulates that digital storytelling with panoramic images is worth to be experimented in other fields and settings such as a classroom teaching aid, electronic museums and historical purposes, marketing and promotional arm in tourism setting and the list is endless.

This study is significant to the field as currently the area of digital storytelling is lacking a systematic approach to determine the effectiveness of such application. As such, a model for an effective digital storytelling is proposed as the primary contribution of the study. This model should encourage the examination of System Quality, Information Quality, Interactivity, User Satisfaction, Individual Impact and Experience Sharing factors that impact the effectiveness of a digital storytelling. Researchers, designers, developers or other interested parties of digital storytelling could then utilize this model in order to evaluate effectiveness proposed in this study as a benchmark or preliminary checklist to construct a much better and effective digital storytelling that meets the user’s need.

This study has discussed and modified DeLone and McLean’s Success Model in which it has greatly inspired and influenced the researcher to develop a preliminary model to fill the gaps in the body of knowledge of an Information System Success Model. In addition, this study also contributes indirectly as an evidence to the theory set forth [18] on the taxonomy of important elements to be considered in digital storytelling.

For future work, in order to strengthen the model produced by this research, it is valuable to examine the relationships of the constructs with larger or different sets of samples or towards a totally different population.

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TRAFFIC ANALYSIS FOR QoS PROVISIONING IN BLUETOOTH AD HOC NETWORK

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ABSTRACT

Bursty traffic with self-similar property has a direct impact on network performance. Thus, if the self-similarity can be captured at an earlier stage before submission to network, a specific mechanism could be applied at a sender node so that a more regulated traffic could be obtained. As a result, deterministic network performance could be attained, and allowing Quality of Service (QoS) guarantees be granted to users. However, this can only be effectively done with support of a source traffic analysis. The objectives of this research paper are two folds: first is to identify the reason for burstiness, and second is to determine if the self-similar property can be removed from the source traffic. By executing these two, a traffic analysis is produced. Video traces of Jurassic Park and Soccer are simulated in a Bluetooth ad hoc network environment and checked against a set of criteria for self-similarity. It was found that, in the first place, self-similar behavior is indeed associated with bursty traffic. Secondly, the number of packets produced from SAR protocol is the reason for the heavy-tailed distribution of the source traffic. Finally, the SAR protocol was found unable to eliminate the self-similar property from a bursty traffic flow.

Keywords: bursty traffic; Pareto distribution; self-similar; network performance; QoS; SAR protocol

INTRODUCTION

BLUETOOTH NETWORK AND ITS QoS REQUIREMENTS

Today’s traffic are of real-time and multimedia interactive types, generated from web browsing, conferencing, video-on-demand, on-line transactions, sensing, multiparty games, etc. For certain applications, especially in implementing ad hoc networking and in supporting last-meter connectivity, Bluetooth network may be well suited to be deployed. However, Bluetooth network is well known for its limited resources, and therefore providing QoS has become a major issue, particularly when routing of packets is involved. One of the ways that service level can be improved is to consider the characteristics of the source traffic, since it is believed that it has a direct impact on how service guarantee can be granted. That is, traffic analysis of the incoming traffic is used to provide QoS in the Bluetooth network in such a way that resources are allocated according to the characteristics of the traffic stream. One of the dominant characteristics of these traffic types is that they are bursty. In its simplest form, burst is defined as the ratio between peak bit rate and mean bit rate [1]. Burst can be detected via clustered arrival phenomena, by which packets arrivals tend to form cluster with relatively short inter-arrival times within a cluster, but separated by relatively long time intervals.
between clusters. Simply, burst can be triggered from rare events, for example, a transfer of big file size as compared to average size. Figure 1 illustrates a burst pattern from a video trace of Jurassic Park, in which frame sizes may fluctuate from very small size to an extremely large size. Plotting a graph from Soccer video trace may produce the same burst pattern. However, our definition may go beyond this first order statistics to fully understand the effect of the burst behavior on network performance.

Leland and his team have found that packet inter-arrival times in local area networks (LANs) were actually following a heavy-tailed distribution of power law [2]. Traffic from Ethernet LAN was observed from 1989 to 1992, and it was established that fractal property of a traffic stream could not be captured using a conventional traffic model. A study by [4] showed that the packets’ inter-arrival time from a LAN has deviated away from exponential distribution, such as Poisson, but following a heavy-tailed distribution. One important finding was that by aggregating the traffic flows, the flows become even burstier and not smoothing out as one expected. Consequently, this traffic property was found to have a direct impact on the design and control of a network system as discussed in [7]. On an ad hoc network type, Bluetooth implements Segmentation and Reassembly (SAR) protocol at L2CAP layer, by which message blocks received from upper layers, are segmented into smaller packets types of DMx or DHx (M – Medium, H – High, x = 1, 2, or 3 slots). Work by [10] has proven that MPEG video with variable bit rate is self-similar. Thus, it can be projected that the SAR protocol execution on MPEG video traces may produce heavy-tailed distribution with respect to some of its features. Therefore, this paper is exploring ‘the burst in the burst traffic pattern,’ which requires second order statistics to describe its characteristics.

THE MATHEMATICS OF BURST

Heavy-tailed distribution is defined as follows [3]. Let \( X \) be a random variable with cumulative distribution function (cdf) of \( F(x) = P(X \leq x) \) and complementary cumulative distribution function (ccdf) of \( F(x) = 1 - F(x) = P(X > x) \). A distribution \( F(x) \) is said to be heavy-tailed if

\[
F(x) = P(X > x) \sim cx^{-\alpha}
\]

when \( x \to \infty \) for positive value \( c \) and \( 0 < \alpha < 2 \). In other words, a distribution is heavy-tailed if the ratio \( P(X > x) / x^\alpha \) is approaching 1 when \( x \to \infty \) for \( \alpha > 0 \). The asymptotic form of the distribution is following a power law. One of the simplest heavy-tailed distribution is Pareto with probability distribution function (pdf) of \( f(x) = \frac{k}{x^k} \), where \( \alpha > 0, 0 < k \leq x \). Accordingly, the distribution is respectively having cdf of

\[
F(x) = P(X \leq x) = 1 - (k/x)^\alpha
\]

and ccdf of

\[
F(x) = P(X > x) = (k/x)^\alpha
\]

where \( \alpha \) is a shape parameter and \( k \) is a scale parameter.

The mean for Pareto distribution is \( \mu = \alpha k / (\alpha - 1) \) and the variance is \( \sigma^2 = \alpha k^2 / (\alpha - 1)^2 (\alpha - 2) \). If \( \alpha < 1 \), the distribution would have infinite mean; if \( \alpha < 2 \), the distribution would have infinite variance; if \( 1 < \alpha < 2 \), it would have finite mean and infinite variance; and if \( \alpha \geq 2 \), both mean and variance are finite. In general, if its variance is infinite, then \( X \) would associate with high variability in its distribution. With respect to this, it had been identified that burst traffic is having self-similar properties. Therefore, one important property of a heavy-tailed distribution is that it is self-similar, as have been proved by [2] and supported by [13].
Additionally, as claimed by [14], superimposition of several independent of ON/OFF heavy-tailed traffic sources is just enough to produce a self-similar traffic stream.

Self-similarity is defined as follows [12]. Let $X(t)$ be a wide-sense stationary time series with mean $\mu$, variance $\sigma^2$, and autocorrelation function $\rho(\tau)$. Let $X_m(t)$ be a newly derived time series from $X(t)$ by averaging a number of $m$ non-overlapping block sizes. Its aggregated series is

$$X_m(t) = \frac{1}{m-1}(X_{m-1} + X_{m-2} + \ldots + X_m)$$

and $\rho^m(\tau)$ is its autocorrelation function. Process $X(t)$ is said to be self-similar if

$$\rho^m(\tau) = \rho(\tau) \quad \text{for} \quad m = 1, 2, 3, \ldots$$

Specifically, if its autocorrelation function is in the form of $\rho(\tau) \rightarrow \tau^{\beta} L(\tau)$ for $\tau \rightarrow \infty$, with $L(\tau)$ decaying very slowly to infinity following a power law, then this process is said to have self-similar property with Hurst parameter $H$. $H$ is used to measure the degree of self-similarity. The relationship between $H$ and the decaying rate $\beta$ for its autocorrelation function is expressed as $H = 1 - \beta/2$.

In the literatures, the many reasons for self-similarity in the traffic streams have been identified. Among them are the inter-arrival time, file transfer sizes, burst duration, and burst size as discussed in [5], [3], and [6]. However, there are still a lot more reasons to be discovered and understood. This lacking is partly due to the uncertainty in the forms, patterns, and characteristics of the source traffic, which have been represented as a stochastic model. For example, traffic characteristics may differ between real-time and non real-time, interactive and non-interactive, synchronous and asynchronous, constant bit rate (CBR) and variable bit rate (VBR), etc. Therefore, the contribution in this paper is on finding another reason for self-similar property in a traffic stream.

The rest of the paper is organized as follows. Section II states the objectives of the paper, which are to determine the reason for burstiness and whether this burstiness can be removed. Section III discusses the methodology used to validate the self-similar property. Analysis and results are presented in Section IV, and finally the conclusion is made in Section V.

**OBJECTIVES**

The objectives of this research paper are two folds: first is to identify the reason for traffic burstiness, and second is to determine whether or not the self-similar property can be removed from the source traffic. During the execution of these two determination processes, the level of burstiness and the degree of self-similarity in the traffic stream need to be measured. This traffic analysis is crucial for making relatively efficiently and reliable routing decisions at a sender node. In other words, routing decisions (or any other control decisions) are made based on analysis of the input traffic, such as that is used by a router in an ad hoc Bluetooth network. Decision technique based on mapping of the available resources to that of the traffic analysis could then be used. With this method, the QoS provisioning in Bluetooth network would be more guaranteed. The final result may be exhibited through the optimal usage of the scarce resources of the Bluetooth network. However, the resource allocation procedure is not within the scope of this paper; it should be given to Resource Manager. Thus, this work is limited to only providing traffic analysis for the Resource Manager to use.

Work by [7] has provided evidence that self-similar traffic may have a direct impact on network performance. Also, as identified by [2], if it is known that the source traffic is bursty, two definite consequences might occur: the increase in buffer requirement and the longer delay experienced. Therefore, it is important to identify whether or not the video traces of the source traffic are bursty. By doing so, an appropriate controlling scheme could be applied to reduce, if not to eliminate, the burstiness of the traffic stream. With a more deterministic network performance, QoS can then be granted to users with a certain degree of confidence.
VALIDATION METHODOLOGY

The degree of burstiness and self-similarity can be measured using the scale parameter $\alpha$ and the Hurst parameter $H$, respectively. The relationship between them for Pareto distribution is expressed as $H = (3 - \alpha)/2$. The bursty traffic are to be generated from Jurassic Park and Soccer video traces, which can be obtained from URL http://www-tkn.ee.tu-berlin.de/researc/trace.trace.html. Each trace is represented by a set of frame numbers, and each frame has its frame size. Both traces have the same frame number of 89,998 and each frame has different byte length. Therefore, there is always a chance for the two traces to be different, particularly with respect to the number of packets they produce when the SAR segmentation scheme is applied on each of the frame.

Discussed below are validation processes for burstiness and self-similarity in a traffic stream. If the degree of self-similarity can be determined, then the traffic behavior would be more predictable and measurable. Consequently, much more accurate QoS provisioning could then be granted to the requesting applications.

HEAVY-TAILED TRAFFIC DISTRIBUTION

In order to validate a heavy-tailed traffic distribution, the following steps are to be carried out:

i. Arrange the frame numbers to a certain order according to testing requirements.

ii. Plot a graph of Quantile-Quantile plot (QQ-plot) for frame sizes.

iii. Determine that $1 \leq \alpha < 2$ is obtained. Value of $\alpha \to 1$ indicates that the traffic is too bursty.

To determine the source traffic is bursty with heavy-tailed distribution, a method called QQ-plot for measuring $\alpha$ is used. If $X_1 \geq X_2 \geq \ldots \geq X_k$ are samples from a distribution $F$ and $k$ is so large, then the distribution function of $F$ at $x = X_j$ can be estimated by $P(x < X_j) = F(X_j) = 1 - \frac{1}{k+1}$. From this, QQ-plot is defined as follows: Let $X_1 \geq X_2 \geq \ldots \geq X_k = u$ is an order of statistics for Pareto distribution. Hence, if $\left( \log X_j - \log u, -\log \left( \frac{1}{k+1} \right) \right)$ is plotted with $1 \leq j \leq k$, a straight line or asymptotic line with slope of $\alpha$ shall be created. Detailed description of the method can be found in [16].

SELF-SIMILAR TRAFFIC PROPERTY

To verify that the source traffic is associated with self-similar property, the following steps are to be carried out:

i. Arrange the frame numbers to a certain order depending on testing requirements.

ii. Plot a graph of Wavelet-Analysis for frame sizes.

iii. Determine that $0.5 \leq H < 1$ is obtained. When $H$ value moves up from 0.5 approaching 1, it indicates a high degree of self-similarity.

To determine the degree of self-similarity, Hurst parameter $H$ is to be measured using Wavelet-Analysis. This method was based on multi-resolution analysis and discrete wavelet transformation. The $H$ value can then be estimated by fitting a straight line of an energy series onto $j$ octave (that describes the scaling degree $\alpha$ in the time and frequency domain). The relationship between $H$ and $\alpha$ is expressed as $H = 0.5 \left( 1 + \frac{\alpha}{\alpha} \right)$. Detailed description of this method can be found in [8].

ANALYSIS & RESULTS

A set of simulation has been applied to measure the associativity of the source traffic to a heavy-tailed distribution and the degree of self-similarity in the traffic stream.

BURST TRAFFIC VALIDATION – USING QQ- PLOT

Graph of QQ-Plot for Jurassic Park

Using the QQ-plot method as described above, Figure 2 is obtained from Jurassic Park. It was found that the slope of the asymptotic line $\alpha = -1.0384$. The positive value of the slope indicates bursty source traffic, since it is in the interval of $1 \leq \alpha < 2$. Thus, the source traffic is said to associate with a heavy-tailed distribution with respect to its frame size. Notice that the $\alpha$ value is very close to 1, hence the traffic is assumed very bursty.
Graph of QQ-Plot for Soccer
Figure 3 is the QQ-plot for Soccer. $\alpha = -1.5625$ has been obtained. Again, the positive slope value indicates a heavy-tailed distribution for the source traffic with respect to its frame size, moving away from 1 for its $\alpha$ value, reflecting less bursty traffic stream.

Figure 3: QQ-plot for frame sizes from Soccer

From these two simulations, it could be concluded that frame size of the video trace is the reason for the heavy-tailed distribution in the source traffic. Comparing these two video traces, it shows that Jurassic Park is burstier than Soccer. Therefore, based on this initial information, one could say that QoS provisioning for Jurassic Park is much harder to attain.

SELF-SIMILAR TRAFFIC VALIDATION – USING WAVELET-ANALYSIS

Wavelet-Analysis for Jurassic Park
The Wavelet-Analysis is used to measure the $H$ parameter that indicates the degree of self-similarity in the traffic stream. Figure 4 shows a Logscale graph for Jurassic Park with $\alpha = 0.7815$ in the interval of octave $j$ of $(4, 13)$. Value of $H = 0.891$ is calculated. When the calculated $H$ value is found to be equal to 0.891, then in conclusion it indicates that the source traffic is bursty. Since this value is relatively close to 1, thus the source traffic is assumed as very bursty.

Figure 4: Logscale graph for Jurassic Park

Wavelet-Analysis for Soccer
Figure 5 shows a Logscale graph from Soccer video trace with $\alpha = 0.900$ and $H = 0.950$ in the interval of octave $j$ of $(2, 12)$. Also, since 0.950 is relatively very close to 1, this traffic is very bursty too.

Figure 5: Logscale graph for Soccer

From these two simulations, it was found that Soccer traffic stream is burstier than Jurassic Park. This comparison, however, was made on different octave interval $j$. As can be seen from Figure 4, octave interval $j$ of $(4, 13)$ was chosen for Jurassic Park, in such a way that it gives the best fitting, and was not on octave interval of $(2, 13)$. Similarly for Soccer, octave interval of $(2, 12)$ was used instead of $(2, 13)$ so that best fitting is obtained. For this reason, $H$ measurement technique for the degree of self-similarity based on Wavelet-Analysis is more accurate and reliable than the other techniques. Therefore, the claim made by [15], which stated that Wavelet-Analysis is unbiased, consistent, and efficient, is valid.
THE EFFECT OF SAR PROTOCOL ON BURSTY TRAFFIC

There exist many evidences that self-similar property in the traffic stream cannot be removed when the traffic is exposed to several controlling and multiplexing techniques. For instance, as identified by [9], the ATM (Asynchronous Transfer Mode) switches have failed to remove the self-similar property from the traffic source. Therefore, there is an opportunity to examine whether or not the SAR protocol of Bluetooth stack in L2CAP layer will produce the same on the MPEG compressed video traffic source. Consequently, the following hypothesis needs to be verified: If the input traffic is self-similar, then the output traffic from a controlling scheme is also self-similar.

The Effect of SAR on Self-Similar Traffic Stream

There is a chance to eliminate the self-similar property from a bursty traffic stream with the use of SAR protocol. If the self-similarity can be removed, or at least reduced, then QoS could be provided in a more deterministic manner, such as provisioning of appropriate buffer sizes. On the other hand, if the self-similarity cannot be removed, the cause for the inability must be explained.

The Best-Fit SAR algorithm [11] is used to segment the received L2CAP data stream to smaller baseband packets of ACL. Figure 6 illustrates the pseudo-code for Best-Fit SAR algorithm. The result of segmentation is a total number of packets produced according to packet types of DH5, DH3, DH1, DM5, DM3, or DM1. However, the protocol tends to produce DHx packet types more than DMx packet types.

Figure 7 shows the QQ-plot from Best-Fit segmentation protocol on Soccer video trace. A straight line with slope value $\alpha = -1.1138$ is produced. The positive slope value indicates that the source traffic is bursty. Again, the $H$ parameter is calculated to produce 0.9431, which reflects a high degree of self-similarity in the traffic stream. This result is quite close to $H = 0.950$ produced from Wavelet-Analysis on Soccer. In a way, it is confirmed that Soccer video trace is indeed much burstier than Jurassic Park.

The overall conclusion of result analysis is that packets produced from the SAR segmentation process are still bursty. Therefore, the SAR protocol has failed to eliminate the self-similar property that is associated with a bursty traffic stream.

The reason for this is that at different time scales, the same fractal property as in the original traffic stream is being carried out to packet level traffic. This is explained by (4) and (5). In short, at different time scales, they look similar.
CONCLUSIONS

Three conclusions could be made from this research work. First, real-time and multimedia interactive traffics are indeed associated with self-similar property. Second, the number of packets generated by the SAR protocol is the reason for the heavy-tailed distribution of the source traffic. Finally, the SAR protocol was found unable to eliminate the self-similar property from a traffic stream, and thus, the hypothesis is proved to be true.

With these traffic analysis results, the QoS provisioning for Bluetooth applications must take into account the self-similar property of the source traffic. The final result may be exhibited through the optimal usage of the network resources. This is critically needed so as to achieve relatively efficient and reliable routing decision-making at a sender node, since Bluetooth network is having only a handful of resources.

The contribution from this work is the identification of another reason for self-similar property in a traffic stream, which could be useful for traffic engineering works, not only for Bluetooth network but also for any other ad hoc networks. Future research will be on the method to control the burstiness level.

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SIMULATION AND ANALYSIS OF POWER QUALITY DISTURBANCES ON A DISTRIBUTION SYSTEM

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ABSTRACT
Voltage disturbance is the most important power quality problem faced by many industrial customers [1]. Voltage disturbances include voltage sag, swell, spikes and harmonics. Harmonics are created by ‘switching loads’ or ‘nonlinear loads’. Each time the current is switched on and off, a current pulse is created. The resulting pulsed waveform is made of a spectrum of harmonic frequencies, including 50Hz fundamental and multiples of it. Voltage sag, which is a momentary decrease in RMS voltage magnitude in the range of 0.1 to 0.9 per unit caused by system faults, lightning and starting large induction motors. Due to insufficient energy, it can interrupt or lead to malfunction of electric equipment. This work presents the voltage sag problems faced by power distribution systems in general and then concentrates on analyzing an important and specific distribution system in particular. To model the system components and simulate the voltage sags by various types of faults, PSCAD/EMTDC and PSS/ADEPT software was used and the voltage severity was studied by introducing faults on selected nodes. There are several mitigation solutions available to reduce the severity of voltage sags. To meet the demand for more efficient mitigation solution, the Dynamic Voltage Restorer (DVR) was simulated and deployed. The simulation results showed that the voltage sags are mitigated satisfactorily. The results were analyzed and compared with the relevant standards for evaluating the quality of power in the distribution system. Actual physical sag measurements were also taken at the site and compared with simulated results.

INTRODUCTION
Voltage sag is a sudden reduction in voltage magnitude between 90% and 10% with duration between 0.04 sec and one minute usually caused by a fault in the utility transmission or distribution system or within a customer facility [3]. Voltage sags and short interruptions are the most troublesome and costly type of power quality problem faced by most of the customers. Compared to interruptions, voltage sags occur much more frequently. Voltage sags and short interruptions may be caused by healthy feeder affected by the faults on adjacent feeder connected to the common bus, the isolation of faults by circuit breakers or fuses causing short interruptions, the result of the operation of fast and/or slow auto reclosers, changeover of transformers, overhead lines exposed to lightning, tree felling, starting large motors [4], etc. Common voltage disturbances are shown in Figure 1.

Figure 1: Common voltage disturbances
(a) Over voltage,  (b) Harmonics,  
(c) Unbalance, (d) Fluctuations

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POWER QUALITY INDICES

The commonly used power quality index is System Average RMS Variation Frequency Index (SARFI_x)[2]. It provides a count rate of voltage sags, swells, and/or interruptions for a system. The size of the system is scalable and is defined as a single monitoring location, a single customer service, a feeder, a substation, a group of substations, or the entire power delivery system. SARFI_x is defined as

\[ \text{SARFI}_x = \frac{\sum N_i}{N_T} \]

where \( x = \) Threshold voltage (RMS), \( N_i = \) Number of customers experiencing short-duration voltage deviations with magnitude above \( x\% \) for \( x > 100 \) or below \( x\% \) for \( x < 100 \) due to measurement of event i and \( N_T = \) Number of customer served from the section of the system to be assessed. SARFI_x gives a count or rate of voltage sags, swell and/or interruptions below a voltage threshold.

SYMMETRICAL COMPONENTS

Voltage sags caused by balanced and unbalanced fault such as Single line-to-ground fault (SLGF), Line-to-Line fault (LLF), and Double line-to-ground fault (DLGF) are analyzed by symmetrical components. The vector in the original system given in Figure 2 shows an unbalanced system, where the three phasor magnitudes are not equal \( |I_a| \neq |I_b| \neq |I_c| \) and the three phase angles are not necessarily 120 degrees apart.

![Original System](image)

**Figure 2:** Unbalanced three-phase systems

UNBALANCED FAULTS BY SEQUENCE NETWORKS

**Single Line-to-Ground Fault [SLGF]**

Let \( V_1, V_2, \) and \( V_0 \) represent positive, negative and zero-sequence voltages respectively, \( Z_{S1}, Z_{S2}, \) and \( Z_{S0} \) are the source impedances and \( Z_{f1}, Z_{f2}, \) and \( Z_{f0} \) are the feeder impedance values in the three components. The normalized sequence voltages at the PCC (Figure 5) are

\[ V_1 = \frac{Z_{S1} + Z_{S2} + Z_{f2} + Z_{f0}}{(Z_{f1} + Z_{S2} + Z_{f0}) + (Z_{S1} + Z_{S2} + Z_{S0})} \]

\[ V_2 = \frac{Z_{S2}}{(Z_{f1} + Z_{f2} + Z_{f0}) + (Z_{S1} + Z_{S2} + Z_{S0})} \]

\[ V_0 = \frac{Z_{S0}}{(Z_{f1} + Z_{f2} + Z_{f0}) + (Z_{S1} + Z_{S2} + Z_{S0})} \]

**Line-to-line Fault [LLF]**

The normalized sequence voltages are

\[ V_1 = \frac{Z_{S1}}{(Z_{S1} + Z_{S2}) + (Z_{f1} + Z_{f2})} \]

\[ V_2 = \frac{Z_{S2}}{(Z_{S1} + Z_{S2}) + (Z_{f1} + Z_{f2})} \]

\[ V_0 = 0 \]

**Double Line to-Ground Fault [DLGF]**

The normalized sequence voltages are

\[ V_1 = \frac{Z_{S1}(Z_{S0} + Z_{f0} + Z_{S2} + Z_{f2})}{D} \]

\[ V_2 = \frac{Z_{S2}(Z_{S0} + Z_{f0})}{D} \]

\[ V_0 = \frac{Z_{S0}(Z_{S2} + Z_{f2})}{D} \]

where

\[ D = (Z_{S0} + Z_{f0})(Z_{S1} + Z_{f1} + Z_{S2} + Z_{f2}) + (Z_{S1} + Z_{f1})(Z_{S2} + Z_{f2}). \]

**TYPES OF THREE-PHASE UNBALANCED SAGS**

![Types of Sags](image)

**Figure 3:** shows the phasor diagram of three different types of sags.
In Figure 3, the dashed line shows the pre-fault phase voltages while the solid line shows the phase voltages during the sag. Type A indicates the balanced vectors produced by three-phase short circuit. Type B shows two vectors drop in magnitude and change in phase angle produced by LLF or DLGF. Type C shows one vector drops in magnitude and changes in phase angle caused by SLGF.

PHASE-ANGLE SHIFT IN UNBALANCED SAGS

During a fault, the phase voltage drops in magnitude and its phase angle jumps. Referring to Figure 4, \( V \) is the sag voltage magnitude and \( \alpha \) is the phase angle jump.

![Figure 4: Three voltage vector for single-phase fault](image)

Referring to the single-phase voltage divider model in Figure 5, \( Z_S = R_S + jX_S \) and \( Z_f = R_f + jX_f \) where \( R_S \) and \( X_S \) are the source resistance and reactance and \( R_f \) and \( X_f \) are the feeder resistance and reactance respectively. The argument of \( \bar{V}_{sag} \) thus the phase-angle jump in the voltage is given by the following expression.

\[
\Delta \alpha = \arg (\bar{V}_{sag}) = \arctan \left( \frac{X_f}{R_f} \right) - \arctan \left( \frac{X_f + X_s}{R_s + R_f} \right).
\]

If \( \frac{X_s}{R_s} = \frac{X_f}{R_f} \), expression above is zero and there is no phase-angle jump.

PRACTICAL CASE STUDIES

Data collection and monitoring on voltage sags were carried at four industrial sites in Malaysia, namely; Hitachi plant and Nihoncanpack at Bemban, Filrex at Bercham and Ipoh Hospital. Power quality monitoring and measurements were done. Out of the four sites, the work was focused at the Ipoh Hospital distribution system where the patient monitoring equipment like MRI, CT SCAN and other life saving equipment are frequently affected by various kinds of power disturbances both from the system and from the local power network. The power distribution system of the hospital consists of four 11 KV substations with a maximum load level of 1.2 MW. The distribution system is supplied by the local utility through a 132/11KV main intake substation. The load at the hospital mainly includes various life saving equipment and air conditioners. The power supply to an important hospital modeled in PSS/ADEPT is shown in Figure 6. An RPM power recorder was installed to monitor and evaluate the quality of the power distribution system at the substation 1 (Sub No. 1 of Power supply system shown in Appendix B) for a period of one month and readings were taken.

SIMULATION RESULTS

The PSS/ADEPT software was used to model and simulate the sag magnitudes at various nodes under fault conditions. The results indicate the voltages at the respective buses as well as at the end-user equipments. Four types of faults were simulated namely: single line-to-ground fault, line-to-line fault, double line-to-ground fault and 3-phase-to-ground fault. The location for fault simulation is Bus JawaT2 as marked in Figure 7 (Appendix B). The simulated voltage results are shown in the Tables 1 to 4 in Appendix A. This software cannot give the wave forms under fault. A Dynamic Voltage Restorer (DVR) used for voltage sag mitigation has been modeled using PSCAD/EMTDC and connected on the 11 KV bus at JawaT2. The results are presented to assess the performance of DVR as a potential custom power solution. The control scheme and test system...
implemented in PSCAD/EMTDC to carry out the DVR simulations is shown in Figure 8 (Appendix C).

DVR SIMULATION AND RESULTS

The DVR coupling transformer is connected in series with the ac system and in delta configuration in the DVR side. The Voltage-Source Controller is a power electronic device which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In voltage sag-mitigation, it is used to temporarily replace the supply voltage or generate the part of the supply voltage which is missing. By switching the power electronic devices on or off an ac voltage is obtained. A pulse-width modulated (PWM) pattern which gives fewer harmonic is used. The capacity of the dc storage device is 5 KV. Four simulations are carried out as follows.

i) The first simulation contains no DVR and a single line-to-ground fault on phase A is applied at point A, via a fault resistance of 0.5 ohms, during the period 400 - 700 msec. The voltage sag is 20% with respect to the reference voltage.

ii) The second simulation is carried out using the same scenario as above but now with the DVR in operation. Using the same scenario as above, simulations are carried out without and with DVR for line-to-line fault, double line-to-ground fault and 3 phase-to-ground faults.

The total simulation period is 300 msec. The results for the simulations are shown in Figure 6(a) to 6(g). When the DVR is in operation the voltage sag is mitigated almost completely. The Pulse Width Modulator (PWM) control scheme controls the magnitude and the phase of the injected voltages. Some transients and harmonics are observed when the DVR comes in and out of operation however; this can be improved with better design filters, including using active power filters, which will be included in a later work.
CONCLUSION

In this paper, typical distribution system was modeled using PSS/ADEPT and PSCAD/EMTDC simulation packages. PSS/ADEPT simulation tool was able to record the steady state voltage magnitude at various nodes in the network under fault conditions. The readings were used to analyze the availability of voltage at the end-user equipment terminals. Table 1 to 4 shows the magnitude of both voltage sag and swell at 11KV BUS and 415V BUS. Table 4 shows the magnitude is zero. Sensitive equipment that do not have the ride through capability under the above condition will mal-operate. Installing the uninterruptible power supply (UPS) at the consumer end is one of the most common solutions. However, the efficiency is about 92-93% and the inverter is continuously operating. Custom power equipment, namely DVR was modeled to mitigate voltage sag and was connected at the 11KV BUS. When DVR is in operation, the voltage sag is mitigated almost completely. Transients are controlled by filter circuits and the dc source to the inverter. The simulation carried out showed that the DVR provides good voltage regulation. The capacity of power consumption and voltage regulation depends on two factors: the rating of the dc voltage to the inverter and the characteristics of the series transformer [6, 7, 8].

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi PETRONAS for all the facilities provided for this research and presentation of this paper in the International Conference ICEEI2007.

REFERENCES

APPENDIX A

Table 1: Single Phase-to-Ground Fault on Phase A at Bus JawaT2

<table>
<thead>
<tr>
<th>JawaT2</th>
<th>Node 6</th>
<th>Node 7</th>
<th>Node 8</th>
<th>Node 9</th>
<th>Node 10</th>
<th>Node 11</th>
<th>Node 12</th>
<th>Node 13</th>
<th>Node 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase A</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.09 V</td>
<td>358 V</td>
<td>358 V</td>
<td>249 V</td>
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<tr>
<td>Phase B</td>
<td>8287 V</td>
<td>1.3 pu</td>
<td>8065 V</td>
<td>1.3 pu</td>
<td>7982 V</td>
<td>7959 V</td>
<td>178 V</td>
<td>178 V</td>
<td>178 V</td>
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<tr>
<td>Phase C</td>
<td>11594 V</td>
<td>1.8 pu</td>
<td>11416 V</td>
<td>1.8 pu</td>
<td>11326 V</td>
<td>11291 V</td>
<td>241 V</td>
<td>241 V</td>
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Table 2: Line-to-line Fault on Phase AB at Bus JawaT2

<table>
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<th>JawaT2</th>
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<tr>
<td>Phase A</td>
<td>3245 V</td>
<td>0.5 pu</td>
<td>3130 V</td>
<td>0.5 pu</td>
<td>3123 V</td>
<td>3078 V</td>
<td>3060 V</td>
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<td>209 V</td>
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<tr>
<td>Phase B</td>
<td>3245 V</td>
<td>0.5 pu</td>
<td>3130 V</td>
<td>0.5 pu</td>
<td>3123 V</td>
<td>3078 V</td>
<td>3060 V</td>
<td>0 V</td>
<td>0 V</td>
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<tr>
<td>Phase C</td>
<td>6491 V</td>
<td>1.0 pu</td>
<td>6259 V</td>
<td>1.0 pu</td>
<td>6247 V</td>
<td>6157 V</td>
<td>6121 V</td>
<td>209 V</td>
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Table 3: Double Line-to-Ground Fault on Phase AB at Bus JawaT2

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<th>Node 9</th>
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<tbody>
<tr>
<td>Phase A</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>203 V</td>
<td>209 V</td>
<td>209 V</td>
<td>209 V</td>
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<tr>
<td>Phase B</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
<td>0 V</td>
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</tr>
<tr>
<td>Phase C</td>
<td>9474 V</td>
<td>1.5 pu</td>
<td>9248 V</td>
<td>1.5 pu</td>
<td>9236 V</td>
<td>9148 V</td>
<td>9113 V</td>
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Table 4: Three Phase-to-Ground Fault at Bus JawaT2

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<tbody>
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<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
</tr>
<tr>
<td>Phase B</td>
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<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
</tr>
<tr>
<td>Phase C</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
<td>0.0 V</td>
</tr>
</tbody>
</table>
Figure 7: Power Supply system at Ipoh Hospital selected for case study
Figure 8: DVR model in PSCAD
P.A. Venkatachalam received his Bachelor's Degree in Electrical and Electronics Engineering with First Class Honours. He read for his Masters in MTech (Control System Engineering) from the Indian Institute of Technology, Kharagpur and his PhD (Computer Engineering and Science Software Engineering) from the Indian Institute of Technology, Kanpur. He started his career as an Electrical Engineer (1957-61) and later, served in the Indian Government as a lecturer (1961-66) and Assistant Professor (1966-76). He held the position of Full Professor at the Asian Institute of Technology, Bangkok (2 years) and at Anna University, Madras, India (10 years) where he was also the Head of its Department of Electronics, Communication & Computer Science & Engineering. From 1988-2000, he served as Professor at Universiti Sains Malaysia (1988-2000). Currently, he is a Professor at the Electrical & Electronics Engineering Program, Universiti Teknologi PETRONAS. His areas of research are in Software Engineering, Computer Networks, Image Processing, Medical Imaging and IT.

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As a lecturer, he has taught many courses ranging from Control Systems, Data Communication Networks, Circuit Theory and even Computer programming. He is also actively involved in research activities. His current research interest range from Robotics, Hybrid Vehicle, Process Modeling, Tomography and even Multimedia Networks.
BLIND DECONVOLUTION TECHNIQUE FOR DE-NOISING OF NON-STATIONARY SEISMIC SIGNALS USING DWT

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ABSTRACT

Discrete wavelet transform is an effective tool to disintegrate the time variant seismic data in time-frequency manner. This work incorporates the wavelet transform in the blind deconvolution technique to deal with the inherent non-stationarity present in seismic data and to improve the SNR of seismic data. Time varying nature of seismic data is the result of a depth varying character of seismic source wavelet (where high frequency components of the source wavelet get absorbs due to increasing heat gradient with depth) convolved with the non Gaussian distributed earth reflectivity in presence of additive Gaussian, color Gaussian noise. Seismic signal can thus be considered as a result of multiple subsystems with different constraints based on time-frequency localization convolved with input signal. Techniques based on stationarity assumptions are not effective in modeling the time variance character of source with depth. In this work we apply the discrete wavelet transform (DWT) to decompose the seismic data into different time-frequency signals. Denoising based on soft thresholding is applied to get the shrinkage effect of wavelet coefficients. Combination of blind deconvolution technique mixed with the discrete wavelet transform gives the best result in terms of reducing the noise and improving the resolution of seismic data with time. Denoising based on soft thresholding gives optimal minimum means square value, low convolutional noise and also low maximum distortion value than hard thresholding.

INTRODUCTION

In reflection seismology, a noticeable change in the apparent frequency of reflection events is quite often observed within finite time-gates of interest. The main reason of this change in frequency is due to absorption of seismic energy in the form of heat energy [1]. High-frequency energy is attenuated at a greater rate than lower-frequency energy, resulting in a progressive lowering of apparent frequency of reflection events with increasing time. In high-resolution shallow reflection data, this nature is observed more frequently than in conventional reflection data. The reasons for this seem to be related to the rapid change of elastic parameters with depth in the near surface. Heterogeneity and anisotropy in the medium may cause the seismic data to vary over time and frequency; hence the seismic data are non-stationary in its very basic nature [2]. Time-variant deconvolution can be used to compensate for the loss of high-frequency components of reflection energy, but this process can also accentuate noise if the level of reflection energy has been attenuated below that of the noise. A number of methods such as F-k field forecasting, polynomial fitting method and vector resolution method are used for noise suppressing of low resolution seismic data [3]. Recently, wavelet transform is used in suppressing random noise of seismic data. Wavelet transform can decompose the seismic signal into several scales; the nature of

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wavelet coefficients of signal and noise are different in the amplitude character and trend in each scale. The main property of this transform is that for any selected window, the resolution capabilities remain fixed all over the time-frequency plane. Improved results could be obtained by using the wavelet transform [4]-[6].

Data gathered at acquisition stage is generally too poor in temporal resolution. Deconvolution is one of the steps in processing of seismic data to improve the temporal resolution, which compresses the source wavelet and removes the noise. This process can help resolve the thin beddings at deeper ends by improving the overall resolution of seismic signals as shown in Figure 1. Seismic data in most of the cases is a result of non-minimum phase source wavelet \( h(k) \) convolving with the non-Gaussian distributed earth reflectivity series \( d(k) \). Additive noise \( n(k) \) is also added due to different noise sources present. The convolution model in Equation (1) is shown in Figure 2.

\[
v(k) = d(k) * h(k) + n(k)
\]  

(1)

Owing to the property of higher order statistics-based blind deconvolution techniques, they not only reveal amplitude information, but also reveal phase information of a system. On the other hand a higher order cumulant does not work with the Gaussian process and is only applicable to the non-Gaussian processes. Therefore, cumulant-based signal processing methods handle Gaussian, colored Gaussian measurement noise automatically, whereas correlation-based methods are not able to distinguish between the Gaussian signal and Gaussian noise. As a result, higher order cumulant-based methods boost signal-to-noise ratio and improves the temporal resolution when signals are corrupted by Gaussian noise [7]. Blind deconvolution technique based on Eigenvector approach is used for the deconvolution purpose to compress the source wavelet and reduce the smearing effect of source wavelet and hence improves the signal to noise ratio [8].

This works combine the blind deconvolution technique discrete wavelet transform technique. Denoising based on soft thresholding instead of hard thresholding is used for effective removal of noise from signal coefficients. By using hard thresholding it is not possible to take out noise from the very spiky nature of seismic data. Soft threshold reduces the threshold coefficients to zero, in order to subtract the noise from the effective spikes as well. In order to cancel out the Gaussian/colored Gaussian noise effectively, blind deconvolution technique based on 4th order of statistics is used.
behavior at different depth level. Figure 3 shows the model earth in term sum of different sub-channels $h_m(k)$ convolved with the same input $d(k)$ and noise term $n_m(k)$ in each branch can be different based on the characteristic of sub-channels to reject or accept the certain distribution of noise Equation (2).

$$v(k) = \sum d(k) * h_m(k) + n_m(k) \quad (2)$$

Where $m = 0 \ldots M-1$

The data at the receiver is combination from all the branches of a system having different responses and can contain the different statistics of noise values shown in Figure 3. Block diagram of receiver is shown in Figure 4, which consists of blind deconvolution block in combination with discreet wavelet block. Blind deconvolution algorithm is based on [8] and it is used to improve the temporal resolution and to minimize the Gaussian noise. For the effective de-nosing and to compensate for the frequency loses at deeper end discrete wavelet transform is used in combination with soft thresholding and gain compensator. Gain compensator is based on the exponential function. This shows that frequency absorption is as a result of multiplication of exponentially decaying function (with depth) with pure frequency.

$$v(k) = \sum d(k) * h_m(k) + e_m(k) \quad (3)$$

The input data $d(k)$ are assumed to be independent and identically distributed (i.i.d.) random variables with non-Gaussian probability density function and zero mean. In this case, second- and fourth-order whiteness holds for the random process $d(k)$, which means that the second- and fourth-order cumulants is zero except $r_{dd}(0) = \sigma_d^2$ and $c_{4}^4(0,0,0) = \gamma_{4}^d$

$$c_{4}^d(\tau) = E\{d^\tau(k)d(k+\tau)\} = r_{dd}(\tau) \quad (4)$$

$$c_{4}^d(\tau_1,\tau_2,\tau_3) = E\{d^\tau(k)d(k+\tau_1)d(k+\tau_2)d(k+\tau_3)\}$$

$$-E\{d^\tau(k)d(k+\tau_1)\}E\{d^\tau(k+\tau_2)d(k+\tau_3)\}$$

$$-r_{dd}(\tau_1)r_{dd}(\tau_3-\tau_2) - r_{dd}(\tau_2)r_{dd}(\tau_3-\tau_1) \quad (5)$$

The Schwarz inequality combines both $r_{xx}(0)$ and $c_4^d(0,0,0)$. Shalvi and Weinstein [8] proved that the only possible way to obtain equality is when

$$s(k) = s(k_w)\delta (k-k_w)$$

The proposed criteria for the blind equalization is based on [8] and is given by

$$\left| c_4^d(0,0,0) \right| = \max \quad \text{provided that } r_{xx}(0) = r_{dd}(0)$$

The deconvolution criterion is, to maximize the cross-cumulant given the condition that output power is constant. The cross-cumulant and the power of the equalizer output signal can be uniquely expressed in terms of equalizer coefficient vector $'e'$:

$$c_{4}^{xy}(0,0,0) = e^* C_{4}^{xy} e \quad (6)$$

$$r_{xx}(0) = e^* R_{xx} e \quad (7)$$

Now we can write the deconvolution objective function as

Maximise $|e^* C_{4}^{xy} e|$ with respect to $e^* R_{xx} e = \sigma_d^2 \quad (8)$

This maximization problem leads to the classic generalized eigenvector problem

$$C_{4}^{xy} e = \lambda R_{xx} e \quad (9)$$

choose $|\lambda| = \max \{ |\lambda_1|, \ldots, |\lambda_q| \}$

Figure 4: Receiver Architecture

Blind deconvolution based on HOS

In seismic deconvolution, the objective is to enhance the resolution of the earth response by removing source non-ideality and removing different kind of Gaussian and color Gaussian noise effects. Seismogram $v(k)$ at the output is convolution of different source wavelets $h_m(k)$ and reflectivity series $d(k)$ in addition to noise from earth and atmosphere from outside $e_m(k)$.
In the case where input signature of seismogram are completely known there we can find the coefficients of equalizer filter by using the MSE close form solutions

\[ e = R_{vv}^{-1}r_{dh} \]  

(10)

where \( R_{vv} \) is correlation matrix of output seismogram, \( r_{dh} \) is the cross correlation between the input signal and the output seismogram.

In the case of blind deconvolution from equation (8) we can write the equalizer coefficients as

\[ e = R_{vv}^{-1}\lambda^{-1}C_4 e \]  

(11)

Where cross-correlation matrix \( r_{dh} \) of MSE algorithm is replaced with the \( \lambda^{-1}C_4 e \) i.e. the cumulant matrix and eigenvector of \( R_{vv}^{-1}C_4 \) corresponding to the maximum Eigenvalue.

\textbf{Wavelet transform and thresholding}

After deconvolving the received seismic data, it must be adjusted to the different gain parameters for different time-scale components for seismic signal. Applying short-time Fourier transform (STFT) to the input data is one of the ways to disintegrate the deconvolved seismic signal. A window function is multiplied with the signal to time limit the signal. The computation of the Fourier Transform of this signal results in STFT.

\[ STFT(\tau, f) = \int x(t)g^*(t-\tau)e^{-j2\pi ft}dt \]  

(12)

Where \( x(t) \) is seismic signal and \( g(t) \) is the window to time limit the seismic signal. Several of the windows are available to time limit the signal, like rectangular, Boxcar, Hann, Bartlett, Blackman, Kaiser and Chebwin. The STFT takes a one-dimensional signal and transforms it into a two-dimensional space of both time and frequency. One of the shortcomings of this approach is that all frequencies are treated with the same time resolution shown in Figure 5.

The resolution in both time and frequency cannot both be arbitrarily small. The lower bound is their product. Resolutions in time and frequency must obey the Heiserzberg inequality.

\[ \text{Time-Bandwidth product} = \Delta t \Delta f \geq \frac{1}{4\pi} \]  

(13)

The time-frequency map of the wavelet transform shows a lot more flexibility in the time resolution at various frequencies, as well as the frequency resolution at different time scales (Figure 7).

The property of wavelet transform is that it divides the time-frequency axis non-uniformly. For lower frequencies, the time window is larger than that of higher frequencies (shown in Figure 8).
Thresholding of seismic data

After disintegrating the seismic data into time-scale components, some sort of thresholding criteria is required to reduce the noise from effective signal. One way of cutting off the wavelet coefficient is to use the hard thresholding criteria i.e. wavelet coefficients are retained only if their absolute value is greater than or equal to a threshold value ‘\( t \)’, else it is zero.

\[
q_{j,k} = \begin{cases} 
  c_{j,k} & \text{if } |c_{j,k}| \geq t \\
  0 & \text{if } |c_{j,k}| < t
\end{cases}
\]

(14)

Where \( q_{j,k} \) are the wavelet coefficients of seismic signal for different values of \( j \) and \( k \) after thresholding. The disadvantage of using these criteria is that it is not effective to reduce the noise from the regions dominated by the signal peak values. Alternatively a soft threshold is quite similar to a hard threshold but it tends to minimise the value of wavelet transform toward zeros rather than simply retaining at the original values. Soft threshold tries to minimize the noise from the effective noisy peaks of signal. Software threshold is given by

\[
q_{j,k} = \begin{cases} 
  \text{sign}(c_{j,k}) \cdot (|c_{j,k}| - t) & \text{if } |c_{j,k}| \geq t \\
  0 & \text{if } |c_{j,k}| < t
\end{cases}
\]

(15)

where \( \text{sign}(c) \) is sign of ‘\( c \)’.

Different techniques are used to find the threshold. One which is easily implemented and effective to use for the real data is described as Universal threshold.

\[
t = \sigma \sqrt{2 \log(n)}
\]

(16)

Where \( n \) is the number of wavelet coefficients to be thresholded, \( \sigma \) is the noise standard variance, estimated by taking the median value of the wavelet coefficients at the smallest scale [9,10,11].

**Time variant spectral whitening**

Input seismogram consists of frequencies band decaying with time. Since low frequency component has lower decay rate than the moderate components. Likewise higher frequency contents have more decay rate than the moderate components. A series of gain functions \( G_1, G_2, \ldots, G_n \) can be computed to describe the decay rates of each frequency band

\[
G_i = \exp(-\alpha_i n)
\]

(17)

The inverse of each gain function \( G^{-1} \) are applied to the disintegrated components of frequencies band achieved using DWT and result is summed to achieve the final output

\[
\hat{d}(k) = \sum_i G_i^{-1} \ast q_i
\]

(18)

**RESULTS AND DISCUSSION**

Use of DWT with a blind deconvolution algorithm incorporates the sub-channel assumption about the earth system. Recovery of frequency of content of seismic data is achieved by adjusting the gain function of each frequency component. In this section we will analyze the result achieved by the
use of DWT for retrieval of high frequency contents specially for deeper wells, where amplitude of seismic data also decays. This decay results in poor SNR, and seismic events are hardly visible. For removal of noise, some sort of thresholding method can be employed. Here it is shown that for seismic applications, soft thresholding methods are preferable over hard thresholding methods. Simulated data with different noise ratio is fed into the algorithm in combination with DWT. Final results are concluded in terms of minimum mean square error, convolutional noise and maximum distortion.

Ideal data

Ideal data with non-Gaussian distribution is shown in Figure 9. This contains the 2-D representation of a surface, with spikes showing the reflectivity coefficients. These coefficients represent the interface of earth beddings with different velocity and density parameters.

\[ R.C. = \frac{\rho_2 V_2 + \rho_2 V_2}{\rho_2 V_2 - \rho_2 V_2} \]  

(19)

Goal of the proposed algorithm is to get back the reflectivity coefficients, back from the noisy time-varying seismic data.

Results using Algorithm

Simulated data is generated by using the non-gaussianly disturbed reflectivity series convolved with ricker wavelet having dominant frequency of 30 Hz
in addition to Gaussian/coloured Gaussian noise of different distributions. To simulate the frequency decaying effect for different sub-channels, exponential functions of different decay rates are multiplied with each component of frequency-time component. DWT of level 2 is applied to get 4 components for this data. Here results are only shown for when SNR is 30 dB.

Figure 10a shows the synthesized data with frequency decaying effects at the lower end of the picture marked by the red circle. It is seen that due to the absence of higher frequency convolution noise gets increased by the smearing effect of source wavelet, resulting in the merging of reflectivity coefficients to wrong values. Figure 10b shows the effect of algorithm onto the seismic data. In this case hard thresholding is applied to suppress the noise. Along with compressing the source wavelet, the algorithm is successful in retrieving the true coefficients values as shown in ideal data. Polarity reversal of reflectivity coefficients is due to use of fourth order statistics, incapable to resolve the magnitude polarity. Figure 10c represents the results by the use of the same algorithm but now with soft thresholding for denoising the seismogram. It is shown that this is more effective in suppressing the noise then the hard thresholding technique. The arrows show the effectiveness of algorithm in identifying the one-pixel-away reflectivity coefficients, missing in the synthesized data in figure 10a. The merging of reflectivity coefficients is due to the non-stationary frequency absorption effect. Circles in Figures 10b and 10c show the retrieval of correct amplitude and resolution as shown in ideal data diagram.

**Analysis of Results**

This section shows the comparison of algorithm with using DWT with hard threshold, soft threshold for de-noising and without using DWT. In Figure 11, it is shown that we can get the lowest value of minimum mean square error by use of DWT with soft threshold, which is around 0.03, while algorithm without use of DWT gives value around 0.065 and also shows divergence in character. This indicates that use of DWT with soft threshold gives best optimal value in mean square error sense.
Figure 12 shows the comparison in terms of convolution noise, which in other terms, can be called intersymbol interference. With soft thresholding the value is around 0.7, while if hard thresholding is applied, the value increases to 1.2. Applying the algorithm without use of DWT gives values around 2 at convergence point. This also shows the effectiveness of the use of DWT specially in case of using soft thresholding criteria.

Figure 13 shows the maximum distortion value of the algorithm for each algorithm. The optimal value is again for the case using soft thresholding criteria, which is 2.6, while for the case of hard thresholding it is around 3.3 and for the case without using DWT, convolution noise value is 4.1

**CONCLUSION**

This paper is more focused on dealing with non-stationary non-minimum phase, non-Gaussian seismic data deconvolution. DWT transform is used to exploit the non-stationary effect of the seismic data, i.e. poor SNR at deeper ends. Identification of close earth bedding is major problem in most of the processing algorithm. This algorithm successfully identified the narrow beds, even with one pixel difference. In the areas where SNR is low, identification of seismic events was successfully achieved. The low value of minimum mean square error, convolutional noise, and maximum distortion indicates its effectiveness for non-stationary, low SNR seismic data. This algorithm can also be applied in other areas like wireless communication, radar signal processing, medical data/image processing.

**REFERENCES**

VIRTUAL GUITAR LESSON

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ABSTRACT

The objective of this work is to provide a virtual guitar lesson for beginners. The paper describes the design and implementation of the learning theories and education approach techniques that have been adopted in the development of the virtual guitar. A simple and clear guitar lesson has been developed for beginners. It provides users with basic guitar chord sound. The system has been developed using the Dual Development methodology that consists of requirements definition and analysis, design, implementation, testing and integration and documentation using Visual Basic 6.0. The system has been tested and the results of the functional and integration testing were successful. It is hoped that the Virtual guitar lesson will help self-learning guitar enthusiasts to learn in an easier way and to contribute to virtual music tutorial.

Keywords: virtual guitar, music, dual development, online lesson, educational approach and guitar lesson.

INTRODUCTION

Nowadays, technology has an important role in education. Technology can be employed together with other educational methods to capture students’ attention. Researchers have their views in using interactive way of teaching beginners up to professionals (Davies et al., 2005).

Guitar is popular amongst musicians and music fans. Along with rapid development in technology nowadays, learning guitar can be achieved in various ways. Learning guitar can be done online and with a better approach which can suit the needs of the different levels of users. In a traditional approach, learning guitar can be done by having a helper or a tutor to teach the learner step by step. To make learning process easier and more fun, technology in music learning can be used to implement the learning session, recording, storage of music data, retrieving the data and playback.

Generally, the project on developing Virtual Guitar Lesson comes from the needs of improving facilities of free and affordable source of music tutorial. As from the research done, the beginners are referred to as guitar fans who do not have basic knowledge of guitar and professionals are a group of guitarists that already know how to pick a chord and compose simple songs. Thus, in order to satisfy both parties, interactive system with details and simple approach are needed.

Only a few virtual guitar lessons are available for beginners. Most of them require users to pay for the system. Traditionally learning guitar was done in class where the tutor would show step by step. The lesson must be done repeatedly and the fees are quite expensive. However nowadays users seem to not to have the time to go to classes. Therefore, a simple and clear guitar lesson can be developed for the beginners. It needs a system to provide users with example of basic guitar chord sound.
The development of virtual guitar lesson also includes the learning theories and education approach techniques that can be adopted in the development of the virtual guitar lesson. The study will be focusing on two different areas: the education approach techniques that involve beginners and playing guitar online and how to come up with the best technique of guiding beginners with the right guitar sound. Furthermore, the scope of the study will be narrowed down to a system that works as guitar lesson that will use to teach students at the beginner level to play guitar.

**RELATED WORK**

**Music Assists in Learning Process**

Music education consists of many areas including music history, music theory, proficiency in a musical instrument and general music skills. Music can be understood as the art of arranging and combining sounds to be produced by the human voice or instrument. Music is a subject formally offered at the college level. But, since people start realizing that music can bring a lot of benefits to students, the course is usually offered to all levels of students.

Studies by Manktelow (2006) and Schellenberg (2004) have shown that music can bring a lot of benefits to students. Students are able to learn better, focus while study and create discipline personality. It is also proven that music lessons enhance Intelligent Quality.

Based on studies by The Board of Regents, the Oklahoma University (2002), OU School of Music faculty started conducting research and developing musicianship training using digital technology since the mid 80s. From this research, technologies already play its roles in music curriculum since then. The technology used such as two 21-station computer/MIDI labs, a digital recording studio, and two fully equipped performance halls. However, the technology in music still needs to be improved and the researchers are still working together to ensure that technology can be used to simplify lessons.

**Understanding Various Learning Modalities**

**Visual Learners**

Visual learners study best when the material is in graphic. The students participate in class discussions and take detailed notes during lectures. They study alone in a quiet environment and try to transcribe material on paper. They use to play with charts or table of complex abstract ideas and work alone. Visual learners always have problems working with dialogue. They find it hard to understand dialogue even if it is pertaining to the subject matter.

Becker (1998) conducted a research to find out the benefits of visual learning. The results obtained in the experiment indicated that students who can be categorized as visual learners perceive added benefit from utilizing groupware in a group project. In the study, students who preferred visual learning style perceived that their groups made more effective use of groupware in achieving project goals. In addition, students identified as more visual learners considered the inclusion of groupware to be valuable to the group process itself. It is important to note that while the more visual learners reported greater benefit to the use of groupware than the more verbal learners, all students were able to master the required course material and complete the project successfully.

**Auditory Learners**

Auditory people work as they listen to some audio while studying. They read their notes aloud, talk and repeat the important points. Joel (2003) stated that audio conference is highly effective for organizing small-team distance learning experiences. As in this case, audio can provide immediacy, a high rate of information exchange. Despite its conveniences, the audio-only approach does have significant limitations. Audio cannot enable the synchronous sharing and manipulation of object (e.g., flowcharts, memos and web pages) that help focus the cognitive synergies of a distributed team.
**Haptic Learners**

Haptic learners are people that find sitting still difficult and they must have music or a television playing in the background and are almost constantly finding themselves distracted. Haptic learners visualize complex things from the start and they already use their imagination to finish the things. Visualization is a useful tool for Haptic people where it can help to keep a positive productive outlook on the task at hand. Therefore to make learning effective, some of the tips are: try to use color; highlight the readings, read with a filtered light, put posters and bright colors around the desk (brainupgrade.com 2007).

**Constructivism theory**

Constructivism can be defined as learners responding to their sensory experiences by building or constructing in their minds, schemas or cognitive structures which constitute the meaning and understanding of their world (Gwaltney & Herman, 1999). The approach of “learn by doing” remains the primary teaching method in Teaching Environment (TE), but the actual learning activities experienced by the students have changed to reflect the evolving curriculum (Haynie, DeLuca & Matthew 2005).

**System available on Website**

Figure 1 shows the website Guitar Tuner. It allows user to play only some notes. The notes play as the user clicks the radio button. The notes offer only E, A, D, G, D and E. It uses Java Applet to develop the product. It states that even if the image of the music box is not completely uploaded, user can still play with it and the sound will still be there. Thus, this website provides simple interface without any heavy material which slows the page uploading. It is only for a user to play with the basic sound and not suitable for learning purpose since it does not provide with any instruction and supplementary documentation.

Figure 2 shows a picture of how to pick a chord. It shows the right way to pick a guitar for each basic note. But, the instruction is too simple. There are only pictures without any sound that can help the students. The pictures are not clear. The fingers are blocking which chord to pick. Students or viewers must know how the chord sounds.
METHODOLOGY

Figure 3 shows the phases included in the Dual Development methodology. This method starts with requirements definition and analysis. This phase is divided into two sections: doing research and feedback analysis and designing phase. The phase is about finding the best requirement for the intended project. Research and feedback analysis is a continuous phase that needs to be done during the whole project development. Mostly, research is done through findings on the Internet. As an example, since the project is web based, research also covers Human Computer Interaction point of view. This to ensure it is on the right track.

Design phase involves activities such as establishing and designing system workflow, system architecture, storyboard and system database. After the designing phase, next is implementation. This is the most crucial part in the project. Implementation requires a lot of time and it needs full attention. During this phase, work will carefully be monitored to ensure the intended end-product is successfully created.

Integration and testing phase is related to the implementation phase. During this phase, the product testing is performed. If there is a problem or error detected, it will go back to the implementation phase. This is to make sure that the problem will be solved and then tested again. Since the testing runs parts by parts of the project, error can easily be detected and when testing part has successfully completed, then the part by part will be integrated into a system. For integration step, it is easier to integrate a system for the smaller part since it is already tested. Documentation is a closing phase. At this phase, all documentations related to the project are finalized and a presentation will be conducted.

Virtual guitar lesson was developed using VB 6.0. Among the tools used in the development include Apache server and MySQL 4.1.8.

SYSTEM WORKFLOW

Figure 4 shows the system workflow. Once the user enters the main page, he/she can start by choosing stage 1 for novice user. Experienced user can straight away choose Stage 3. All the information is stored in the database as well as in the web server. The music can be retrieved from the server.

RESULTS AND DISCUSSIONS

Figure 5 shows the interface of Virtual guitar lesson. Figure 5(i) shows the main page which provides user with brief explanation of the website and the lesson.
Figures 5 (ii), (iii) and (iv) consist of the detailed lessons which incorporate the learning theories and education approach techniques.

The system has been tested with 5 users. The results, as shown in Table 1, indicate that the functional and integration testing were very successful.
CONCLUSION

In general, Virtual guitar lesson can be used for self taught learner ranging from novice to advanced users. For future work, the prototype can be improved by having interactive guitar lessons and further evaluation also needed including more initial feedback from users.

REFERENCE


Table 1: Functional testing result

<table>
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<tr>
<th>Component</th>
<th>Expected Test Result</th>
<th>Actual Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord Combo Box</td>
<td>· To list down the chords already provided to the user (chord stored in database).</td>
<td>· Successfully listed down all 31 chords offered to the users.</td>
</tr>
<tr>
<td></td>
<td>· To ensure user select the right chord.</td>
<td>· Successfully permitted users to select the chord.</td>
</tr>
<tr>
<td>Chord Indicator</td>
<td>· To ensure when the chord is selected by the users, chord indicates the right chord (chord indicator at the image).</td>
<td>· Successfully indicated the right chord position when the chord was selected.</td>
</tr>
<tr>
<td></td>
<td>· To show accurate chord position or at the right fret when specific chord selected.</td>
<td>· Successfully placed at the right fret and it was shown clearly and accurately.</td>
</tr>
<tr>
<td>Play Button</td>
<td>· To play the right sound when a chord is selected.</td>
<td>· Successfully played the right sound when a chord was selected.</td>
</tr>
<tr>
<td></td>
<td>· To play with the right DO RE MI melody.</td>
<td>· Successfully placed the melody of DO RE MI.</td>
</tr>
<tr>
<td></td>
<td>· To play with the good MIDI quality.</td>
<td>· Successfully played with good MIDI quality.</td>
</tr>
<tr>
<td>Strummed Check Box</td>
<td>· To play correct sound if the users tick the check box.</td>
<td>· Successfully played strummed sound when the check box ticked</td>
</tr>
<tr>
<td></td>
<td>· To produce good quality strummed sound.</td>
<td>· Successfully played good strummed sound quality.</td>
</tr>
<tr>
<td>Quit Button</td>
<td>· To quit from the system</td>
<td>· Successfully quitted from the system.</td>
</tr>
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</table>
Wan Fatimah Wan Ahmad received her BA and MA degrees in Mathematics from California State University, Long Beach, California, USA in 1985 and 1987. She also obtained Dip.Ed. from Universiti Sains Malaysia in 1992. She completed her PhD in Information System from Universiti Kebangsaan Malaysia in 2004. She is currently a senior lecturer in the Information Technology/Information System program at UTP. She was a lecturer at Universiti Sains Malaysia, Tronoh before joining UTP. Her main interests are in the areas of mathematics education, educational technology and multimedia.

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2. The manuscript must be typed on one side of the paper, double-spaced throughout with wide margins not exceeding 3,500 words although exceptions will be made.

3. Figures and tables have to be labelled and should be included in the text. Authors are advised to refer to recent issues of the journals to obtain the format for references.

4. Footnotes should be kept to a minimum and be as brief as possible; they must be numbered consecutively.

5. Special care should be given to the preparation of the drawings for the figures and diagrams. Except for a reduction in size, they will appear in the final printing in exactly the same form as submitted by the author.

6. Reference should be indicated by the authors’ last names and year of publications.

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