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AN INTEGRATION FRAMEWORK FOR HAPTIC FEEDBACK TO IMPROVE FACIAL EXPRESSION ON VIRTUAL HUMAN

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Abstract. *Most of the latest 3D humanoid models that are currently available can produce emotions only through facial expressions, gestures and voice. Only a few humanoid models are capable of manipulating haptic tactile emotions through vibrations. This study proposes a system, in which haptic feedback is integrated based on visual, acoustic, and haptic cues. This integrated framework is based on two major techniques: emotionvibration mapping and facial expression synthesis. In emotionvibration mapping, mapping is carried out by first scaling the joystick wavelength to the visible light spectrum. Then, a linear equation describing the magnitude force is created by using joystick wavelength and magnitude force data. Finally, the wavelength of visible light spectrum is used as parameter to compute the joystick wavelength by using a linear interpolation method, and then, emotions are generated and a complete classification table is stored for each emotion value. In facial expression synthesis, a combination of Action Units (AUs) is used to generate certain emotion expressions in the 3D humanoid model face based on Facial Action Coding System (FACS). Each action unit is characterized by its specific face region, and each face region has a special lighting colour to differentiate its appearance. The colour of light is obtained from the emotion classification table generated in the emotionvibration mapping process. Furthermore, the integration proceeds with rendering the facial expression, generating an acoustic effect from an emotional sound, and adjusting the loudness level according to the emotion value. Finally, the magnitude force of the haptic device, which is simultaneously adjusted after the synchronization of visual and acoustic cues, is integrated. In this study, a mind controller and a glove are used to capture user emotions in real time. The mind controller determines the type of emotion according to the brain activity of the user, whereas the glove controls the intensity of an emotion. The results from experiment show that 67% of the participants gave strongly positive responses to the system. In addition, 15 of 21 (71%) participants agreed with the classification of the magnitude force into the emotion representation. Most of the users remarked that a high magnitude force created a sensation similar to anger, whereas a low magnitude force created a more relaxing sensation.*
Keywords: 3D humanoid models, Facial expression, Action units, Magnitude force

1. **Introduction.** A virtual human has become a popular representation in virtual environment just as a humanoid robot in the real world. The purpose of virtual human representation is to help and guide users to control, manipulate and interact with virtual objects in synthetic world. To achieve that goal, researchers in computer graphics world mark their study to explore artificial psychology in the sense of creating interface and medium that can provide and facilitate users with attractive interaction. Human representations such as virtual assistants or virtual humans in virtual environment are considered as an interface that can create harmonious relationships between human and computer [1]. Nowadays, there are a lot of existing applications and games such as Second Life or the SIMS that manipulate avatars in their systems. Based on the research observation, previous studies are lacking the presence of virtual humans. This was caused by several factors such as the complexity of virtual human model, i.e., emotional expression [1], or incoherent animation reaction [2]. Usually, emotion is expressed by using facial expressions, voice intonations or even hand gestures. However, the latest research conducted by T. Dzmitry, has started to use haptic as an additional feature to be combined with facial expressions and acoustic effects on 3D humanoid model [3]. This work was actually initialized by J. Teh and A. D. Cheok in 2006 who proposed a hugging system for expressing feelings from a mother to her children through haptic pajama over Internet [4].

Motivation. Creating realistic avatar that can really imitate real human is very difficult, especially on expressing the emotion to the virtual human. Latest 3D humanoid model acts like human and their mimic expression is closely similar to human in real world. They are also able to change the walking style, voice intonation and even make interaction with real users. Though it has realistic visual appearance and sound, it still has weakness in terms of presence feeling. Recently, the effort to establish this feeling presence has been well researched by several researchers like the iFeelIM by Dzmitry. Dzmitry creates a haptic device that can increase the emotion sensation of avatar interaction which is applied on Second Life system. However, all these previous researchers are still not deeply focused on how to create emotion presence of virtual human model during the interaction with user. The literature review on avatar has given inspiration to this study to come up with a new idea on augmenting the realism of avatar. The idea of integration has been proposed by several researchers. Nevertheless, they come with different approaches and applications. This study improves the realism of virtual human model by integrating visual and haptic deeply to increase the presence feeling and appearance of virtual human. The other think that what we have contributed is natural interaction that acquired from brain activity of the real user while Dzmitry works is using stimulation from emotional words from their chat system.

2. **Related Works and Problem Statement.** Research on virtual reality and games still needs a lot of improvement especially on how to immerse and provide users with attractive interactions. The interactivity and immersiveness are considered as the main goals that need to be achieved in virtual reality game (VRG), particularly for educational purposes, virtual training, virtual institution, etc. [5-7]. Why do virtual reality games still need improvements? The reason is that virtual reality application is still not natural, unlike real world. Acosta (2001) mentioned that realistic virtual reality application should behave as *"look real, act real, sound real and feel real"*. In that sense, synthetic world which is called *world look real* must consist of complex visualization and animation (complex model, navigation, users interface, etc.). The word *act real* means every living object especially virtual human can behave like human being, while *sound real* can be interpreted as a sound effects like voice from the real world. Last but not least, *feel real* refers to

the presence of object in virtual environment. If these requirements can be fulfilled, the virtual reality game will cause full mental immersion where users cannot differentiate between the virtual world and the real world [8].

Wang et al. (2005) also mentioned that there are two main problems in creating a virtual human. First, construction of emotion and second generation of affection model which is purposely created to improve their presentation. The 3D humanoid model does not only represent human in terms of physical representation, it also needs some believability context. The other weakness of 3D humanoid models that need to be improved is their lack of believability [9]. Therefore, Rojas et al. (2006) proposed individualization method by putting personality, emotion and gender into the 3D humanoid model. Afterwards, Melo and Paiva (2007) made some innovations in expressing the emotion of virtual characters by putting aside body parts. They used elements like shadow, light, composition and filter as tools for conveying the characters emotion [10]. The other improvement is proposed by Zagalo and Torres (2008), they made a character that is able to express their emotions by involving the act of touching among two characters. Even though the referred touching happens in virtual environment, it has shown that touching can be used to strengthen the emotional expression. Additionally, other researcher also worked on creating a 2D interface to better control of facial expression and produce very realistic facial expression based on facial characteristic points [11].

The creativity on making 3D humanoid model become realistic is started using facial animation by F. I. Parke (1971). The avatar has changed rapidly since Wang et al. (2005) proposed an avatar that can act according to the emotion. This work has been enhanced further by other researchers by putting together facial expression, speech synthesis, body touch and lighting effect to the avatar [10,12-14]. However, the realism of avatar is still not enough because it is still stuck on visual appearance and speech without considering sense of touch (haptic). From the previous works, it is clearly mentioned that there are rooms to improve 3D humanoid model through integration of haptic elements with facial expression.

Considering this point of view, this study focuses on haptic topic to improve human emotion for virtual human (3D humanoid model). Why haptic and human emotion? As discussed previously, several researchers have built virtual human (3D humanoid model) that is able to show emotions that are approximately similar to real human by using facial expressions, lighting colour effect and sound effects. Even though the facial expressions and acoustic effects look vividly real, they are still not capable of affecting users as if they were in the real world. Why? This is due to that approaches setback of sense of touch element which is believed and considered to give more sensation of presence in virtual environment. A magnitude vibration range from haptic device (joystick) is suggested as a unique reference when users want to utilize haptic tactile in order to strengthen the 3D humanoid model.

3. **Critical Review on Colour as Emotion Representation and Facial Expression Technique.** Emotion has been divided based on colours variation since long time ago. According to Nijdam (2006), human emotion can be divided into areas of colours (see Figure 1).

Nijdam (2006) uses a circle that represents emotion classifications into colours. The outer circle gives positive impressions, the inner circle represents six basic emotions and the centre of circle reassembles all negative impressions (see Figure 2).

The colour of emotion has become a great fundamental theory on representing emotion. There are several works that concern on colour as emotion representation. N. Kaya and H. H. Epps (2005) have used subjective approach by measuring the response of college

FIGURE 1. Emotion-color classification [15]

FIGURE 2. Shirley Willett-colour mapping [15]

students to the Munsell colour system with five principles colour: red, yellow, green, blue and purple, then it also uses five intermediate hues: yellow-red, green-yellow, blue-green, purple-blue and red-purple [16]. This work has produced a good result on emotion classification based on colour properties. However, this work is a little bit hard to be implemented in computer science fields because its too subjective because the experiment is more focus on user behaviour statistic. Therefore, Nijdam work has appeared to interpret the colour of emotion into mathematical concept and 3D representation. Nijdam has come with a scientific approach by calculating the change of colour compared with emotion colour. By using this method Nijdam has demonstrate the simulation of emotion expression through colour change in 2D planar.

This research uses blend shape interpolation of facial region to perform emotional facial expression. The process of interpolation is started from neutral expression named as base, then the base will start to change into desired pose based on interpolation value. N. Bee, B. Falk and E. Andr (2009) have come up with emotional facial expression control through Xbox joystick. User will be able to create particular facial expression by pressing specific button of joystick. Their method will help user to interact with avatar facial expression. The approach has inspired this research to come up with another control of facial expression using brain activity and hand tracking. The approach is to enhance the natural interaction between avatar and users that become great elements to integrated framework.

4. **Emotion-Vibration Mapping Technique.** According to Hashimoto and Kajimoto (2008), the vibration range recognized by human is between 1 Hz and 1 KHz. They also describe that vibration below frequency of 300 is considered as a smooth object or joy feeling. High vibration in a long duration usually will cause people uncomfortable feeling,

anger, frustration and other negative feelings, while low vibration can cause relaxation, joy and even enthusiasm emotion [17,18]. Based on the previous works, the mapping from emotion into magnitude vibration is still not completed; other researcher like Nijdam (2006) has focused on mapping colour into emotion but how to represent emotion in magnitude force of haptic? It is still less explored. Nijdam (2006) has produced mathematical concept to calculate colour properties from non-direct emotional states.

Definition 4.1. *If E is defined as finite set of emotional states, $E = \{e, e', \ldots, e^n\}$, then e is value of emotion, $e = (coordinate, radius)$. On the other hand, $coordinate = (x, y)$ represents position on 2D flat surface. Radius represents the affected area using linear interpolation. Let p become the coordinate of colour that needs to be checked. R^e is the subset of R that has emotion with coordinate p within radius of emotion effect. In order to check whether p is inside emotional-state radius or not, Equations (1) and (2) calculate the difference and distance of $coordinate_e$ and $coordinate_p$.*

$$difference = coordinate_e - coordinate_p \tag{1}$$

$$distance = \sqrt{(x_e - x_p)^2 + (y_e - y_p)^2} \tag{2}$$

e will be included in R^e if $distance < radius_e$, and further let color (R, G, B) represent colour and $cfinal$ is the desired colour. In order to calculate the emotion inside R^e, Nijdam (2006) has proposed three main stages:

- First, calculating the difference between the current colour with emotion colour, e.g., if colour of emotion is $(130, 250, 140)$, current colour is $(110, 110, 110)$.
  $cdif = (130, 250, 140) - (110, 110, 110)$
  $cdif = (20, 140, 30)$
- Second, calculating the intensity of colour to see how similar the current colour with emotion colour.

$$intensity = 1 - \frac{distance}{radius} \tag{3}$$

- The last step is renewing the colour based on Equations (4)-(6).

$$cfinalR = cfinal(R) + difference(R) * intensity \tag{4}$$
$$cfinalG = cfinal(G) + difference(G) * intensity \tag{5}$$
$$cfinalB = cfinal(B) + difference(B) * intensity \tag{6}$$

The work of Nijdam has provided the fundamental of mapping from emotion into colour. These findings have motivated this research to create an innovative mapping from emotion into magnitude force through colour characteristics using formula as shown in Equation (7) that still not explored by previous researcher.

$$M = 9958 \cdot \frac{\left(530 + \frac{170R}{255} - \frac{60B}{255} - \frac{120RG}{255^2} - \frac{170RB}{255^2} + \frac{120RGB}{255^3}\right)}{230 \cdot 10^{-9}} \cdot 0.75 + 1596.5 \tag{7}$$

The process of mapping from emotion into magnitude force of vibration is conducted through four main phases. The initial phase is started by creating scaling value between wavelength of joystick and colour light spectrum. This scaling value is very important and it will be used in the further step. The scaling process happens because colour light spectrum uses nano metre unit while joysticks unit is in metre. By comparing the longest wavelength between both of them, the equation of scaling is acquired. The next step is creating the linear equation of magnitude force using joystick data and magnitude force value. Further, the wavelength of colour light spectrum will be used as parameter

Algorithm 1 Mapping Process

Input RGB colour, R Value, G value and B value

1: Compare and make scaling between wavelength of joystick and wavelength of colour light spectrum

$$\lambda_{Joystick} = \frac{\lambda_{Colour} - 470 \bullet 10^{-9}}{230 \bullet 10^{-9}} 0.75$$

2: Calculating the relationship between magnitude force and joystick wavelength
M = 9958 $\lambda_{Joystick}$ + 1596.5

3: Establishing the linear equation of joystick based on magnitude force and joystick wavelength

$$M = 9958 \quad \frac{(\ )\bullet 10^{-9} - 470 \bullet 10^{-9}}{230 \bullet 10^{-9}} 0.75 + 1596.5$$

4: Find the wavelength of joystick using linear interpolation between colour light spectrum

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{120RG}{255^2} - \frac{B}{255}(530 + \frac{170R}{255} - \frac{120RG}{255^2} - 470)$$

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{120RG}{255^2} - \frac{530B}{255} - \frac{170RB}{255^2} + \frac{120RGB}{255^3} + \frac{470B}{255}$$

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{60B}{255} - \frac{120RG}{255^2} - \frac{170RB}{255^2} + \frac{120RGB}{255^3}$$

5: Substituting the wavelength (λ_3) into the previous linear equation to calculate Magnitude force

$$M = 9958 \times \frac{\left(530 + \frac{170R}{255} - \frac{60B}{255} - \frac{120RG}{255^2} - \frac{170RB}{255^2} + \frac{120RGB}{255^3}\right)\bullet 10^{-9} - 470 \bullet 10^{-9}}{230 \bullet 10^{-9}} \times 0,75 + 1596.5$$

Output M (Magnitude Force)

FIGURE 3. Algorithm 1 – emotion vibration mapping

to compute joystick wavelength by using linear interpolation method. After that, it is continued with substituting the wavelength which is acquired from linear interpolation method into linear equation of magnitude force. The last part is emotion generation and saving complete classification table for each emotion value. This table will become a reference for future steps that include integration process with facial expression and acoustic effect. The complete pre-processing step is described in flowchart diagram in Figure 3.

The details of each step on mapping process are described in the following explanation. From joystick measurement with period of time in one second, it has been obtained that $\lambda_{\text{joystick}}$ can be classified as Table 1. This wavelength is chosen from big motor rumble result since it has the longest radius compared with small motor rumble.

According to Bohren, Red has the longest wavelength ($\lambda_{\text{red}} = 700$nm) and the shortest wavelength belongs to blue ($\lambda_{\text{blue}} = 400$nm) [19]. From the joystick physical measurement, the result shows that joystick wavelength ranges start from zero until 0.75m (0-0.75m), refer to Table 1. With all previous facts, the relationship between $\lambda_{\text{joystick}}$ and λ_{colour} can be computed through a linear interpolation method.

$$\lambda_{\text{joystick}} = \left(\frac{\lambda_{\text{colour}} - 470 \cdot 10^{-9}}{230 \cdot 10^{-9}}\right) \cdot 0.75 \tag{8}$$

There are several steps which are needed to accomplish mathematic derivation formula for acquiring magnitude force through colour properties.

1. The relationship between magnitude force and $\lambda_{\text{joystick}}$ can be made using Table 1. and excel software, the relationship between them can be modelled into a graph and

Table 1. Wavelength of joystick with period of time one second (1 second)

Magnitude Force	λ (m)
10000	0.75
9000	0.71
8000	0.67
7000	0.61
6000	0.47
5000	0.39
4000	0.27
3000	0.05
2000	0.00
1000	0.00

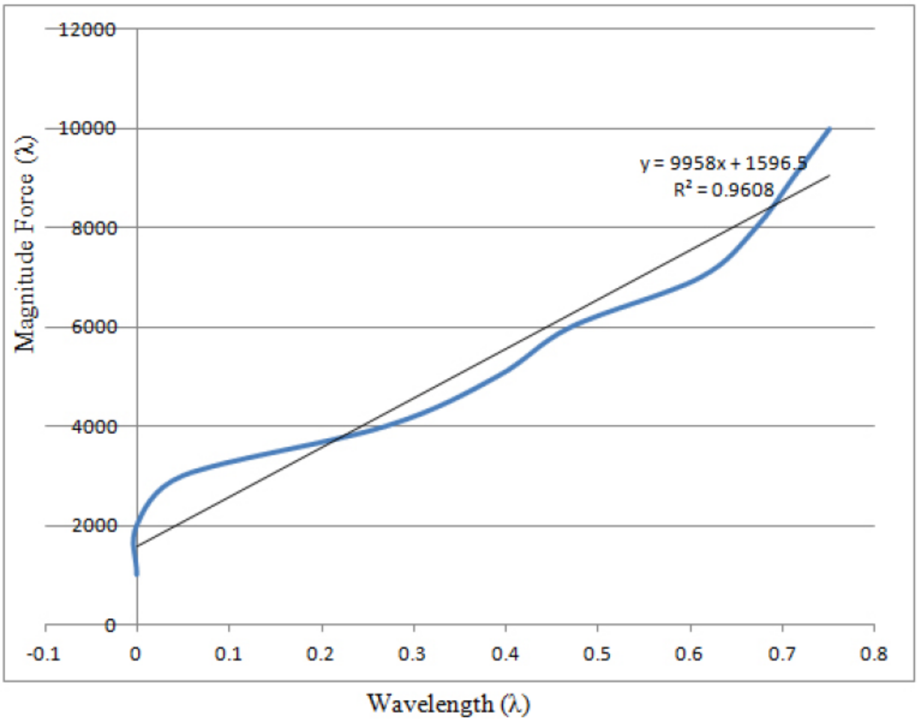

Figure 4. Graph for relationship between magnitude force and $\lambda_{\text{joystick}}$

linear equation as shown in Figure 4.

$$M = 9958\lambda_{\text{joystick}} + 1596.5 \tag{9}$$

2. How to calculate λ_{colour} Bohren (2006) measures the unit of λ_{colour} in nanometre (nm)

$$\lambda_{\text{colour}} = ()10^{-9}m \tag{10}$$

3. Converting λ_{colour} into $\lambda_{\text{joystick}}$. From Equations (9) and (10) it can be converted into

$$\lambda_{\text{joystick}} = \left(\frac{()\cdot\lambda_{\text{colour}} - 470\cdot 10^{-9}}{230\cdot 10^{-9}}\right)\cdot 0.75 \tag{11}$$

4. Establishing relationship between magnitude force and colour by substituting (9) into (11), it will obtain $M = 9958\lambda_{\text{joystick}} + 1596.5$

$$M = 9958\left(\frac{()\cdot 10^{-9} - 470\cdot 10^{-9}}{230\cdot 10^{-9}}\right)\cdot 0.75 + 1596.5 \tag{12}$$

The next step is calculating the joystick wavelength based on colour light spectrum properties using linear interpolation. The wavelength of colour light spectrum can be seen in Table 2.

There are three main steps necessary on deriving formula to find magnitude force value based on colour spectrum value. By using Linear Interpolation it can obtain wavelength of the joystick based on the colour light spectrum wavelength.

1. Find the wavelength of λ_1 by using linear interpolation (see Figure 5). In this first step, red colour used as reference, therefore, the wavelength of red colour is subtracted in the equation for calculating λ_1.

$$\lambda_1 = 700 - \left(\frac{G-0}{255-0}\right)(700-580) \tag{13}$$

$$\lambda_1 = 700 - \left(\frac{G-0}{255-0}\right)\cdot 120 \tag{14}$$

$$\lambda_1 = 700 - \left(\frac{120G-0}{255-0}\right) \tag{15}$$

2. Find the wavelength of λ_2 by using linear interpolation (refer to Figure 6).

TABLE 2. Wavelength of colour light spectrum [18]

Colour	R	G	B	Wavelength of colour of Light Spectrum (λ_{light} in nm)
Red	255	0	0	700
Orange	255	165	0	620
Yellow	255	0	0	580
Green	0	0	0	530
Blue	0	0	255	470

R = Red value (0-255);
G = Green Value (0-255);
B = Blue value (0-255)

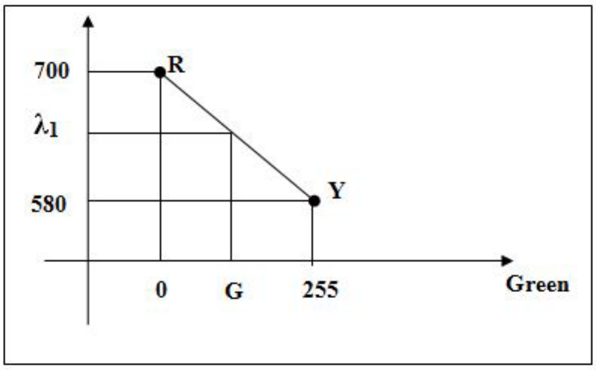

FIGURE 5. Linear interpolation between red and yellow

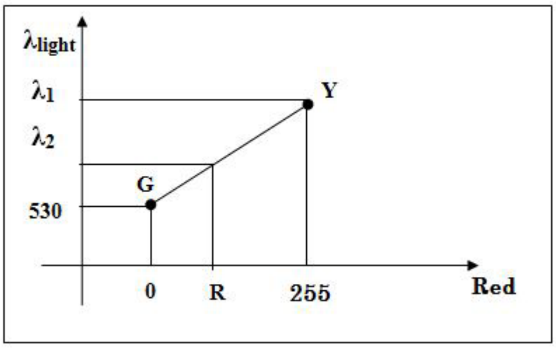

FIGURE 6. Linear interpolation between yellow and green

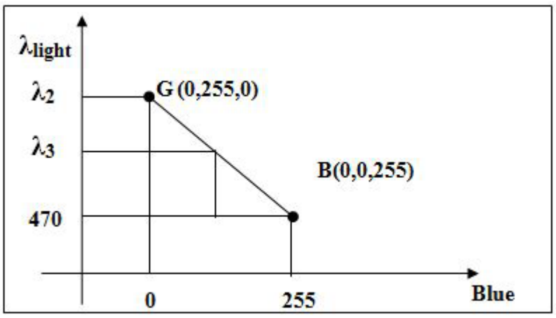

FIGURE 7. Linear interpolation between green and blue

In Step 2, the wavelength of green is used as reference to calculate linear interpolation.

$$\lambda_2 = 530 + \left(\frac{R-0}{255-0}\right)(\lambda_1 - 530) \tag{16}$$

By substituting λ_1 from value in Step 1, the λ_2 value will be changed into

$$\lambda_2 = 530 + \left(\frac{R-0}{255-0}\right)\left(\left(700 - \left(\frac{120G-0}{255-0}\right)\right) - 530\right) \tag{17}$$

$$\lambda_2 = 530 + \frac{700R}{255} - \frac{120RG}{255^2} - \frac{530R}{255} \tag{18}$$

$$\lambda_2 = 530 + \frac{170R}{255} - \frac{120RG}{255^2} \tag{19}$$

3. Find the wavelength of λ_3 by using linear interpolation, with the assumption of $\lambda_{(0,255,255)} = \lambda_{(0,x,255)} = \lambda_{(0,0,255)}$, due to a small gap between the wavelength of green and blue (refer to Figure 7).

$$\lambda_3 = \lambda_2 - \frac{B}{255}(\lambda_2 - 470) \tag{20}$$

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{120RG}{255^2} - \frac{B}{255}\left(530 + \frac{170R}{255} - \frac{120RG}{255^2} - 470\right) \tag{21}$$

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{120RG}{255^2} - \frac{530B}{255} - \frac{170RB}{255^2} + \frac{120RGB}{255^3} + \frac{470B}{255} \tag{22}$$

$$\lambda_3 = 530 + \frac{170R}{255} - \frac{60B}{255} - \frac{120RG}{255^2} - \frac{170RB}{255^2} + \frac{120RGB}{255^3} \tag{23}$$

Table 3. Conversion result for anger – red colour

No	R	G	B	H	S	V	M	Intensity	Hex Colour	Emotion	Colour
1	255	0	0	0	100	98	8935	0.970941	fa0000	Anger10	
2	252	0	0	0	100	99	9000	0.980627	fc0000	Anger10	
3	253	0	0	0	100	99	9000	0.990314	fd0000	Anger10	
4	255	0	0	0	100	100	9000	1	ff0000	Anger10	
5	255	101	101	0	60	100	5201	0.438189	ff6565	Anger4	
6	255	103	103	0	60	100	5136	0.428503	ff6767	Anger4	
7	169	69	55	7	68	66	5461	0.342323	a94537	Anger3	
8	197	100	87	7	56	77	4941	0.302512	c56457	Anger3	
9	180	84	84	0	53	71	4974	0.220682	b45454	Anger2	
10	239	156	144	7	40	94	3772	0.143151	ef9c90	Anger1	

Based on Linear Equation in (12), we can calculate the magnitude force (M) of joystick by substituting λ_3 into Equation (12).

$$M = 9958\left(\frac{\left(530+\frac{170R}{255}-\frac{60B}{255}-\frac{120RG}{255^2}-\frac{170RB}{255^2}+\frac{120RGB}{255^3}\right)\cdot 10^{-9}-470\cdot 10^{-9}}{230\cdot 10^{-9}}\right)\cdot 0.75+1596.5 \quad (24)$$

In Table 3, the conversion process for red has been successfully generated using Equation (24). The maximum value of magnitude force on red is 9065 while the lowest is around 3772. The hue = 7 is chosen because the colour is still recognised as red in the eyes perception. The other hue of red variants is also possible to demonstrate the emotion and the magnitude force relationship, however in this research the data will be carefully selected and only 10 samples of data are taken to demonstrate Equation (24) performance.

Table 4 is a conversion table for happy emotion. This table illustrates several green colour variation based on the intensity and hue mode. The maximum value of magnitude force in happy colour is 3902 while the lowest level reaches 2570.

Happy has a medium/low excitation and high pleased feeling in circumplex model, this behaviour is also similar with emotion generation result where happy is able to produce magnitude force from 2570 until 3902. These findings show that the emotion mapping process succeeds in making the relationship between colour and magnitude force. The result also match with result from Hashimoto and Kajimoto (2008) that declared high vibration carried anger while low vibration tends to make people relax and joy. The finding is very useful as a foundation of synchronizing vibration tactile with facial expression and acoustic. In the next sub section, these finding values will be examined and justified empirically based on physical characteristic of joystick as a haptic devices. Before the

Table 4. Conversion result for happy – green colour

No	R	G	B	H	S	V	M	Intensity	Hex Colour	Emotion	Colour
1	3	253	4	120	99	99	3577	0.9783411	03fd04	Happy10	
2	5	253	5	120	98	99	3545	0.969369	05fd05	Happy10	
3	3	213	3	120	99	84	3577	0.766721	03d503	Happy8	
4	3	211	3	120	99	83	3577	0.757066	03d303	Happy8	
5	0	255	0	120	100	100	3545	1	00ff00	Happy10	
6	118	253	118	120	53	99	3058	0.341254	76fd76	Happy3	
7	121	253	121	120	52	99	3025	0.321883	79fd79	Happy3	
8	32	183	3	110	99	72	3902	0.602386	20b703	Happy6	
9	107	241	81	110	66	95	3480	0.519082	6bf151	Happy5	
10	178	255	178	120	30	100	2570	0.011987	b2ffb2	Happy1	

explanation is continued with motor rumble evaluation, the previous implementation and proposed mapping will be compared with method from previous researcher like shown in Table 5, in order to show contribution of this paper.

We have described in Table 5 that our proposed approaches are also able to generate conversion-result for other emotions such as sadness, disgust or even fear. However, in this research we will take more focus on anger and happiness due to these emotions are well researched and concerned by previous researcher [13,19-21]. The subsection will prove empirically the effect of magnitude vibration power of joystick to human as well as to prove the relation between magnitude force and human emotion. Joystick as mentioned before has a magnitude force, i.e., the force that is able to produce certain rotational speed or velocity (V) and acceleration (A). Figure 8 is an illustration of Acceleration behaviour of both motor rumbles of joystick, the total of Mean A and total r.m.s A and standard deviation between both of them. The graph of total Mean A is different from the others as it rises rapidly since the starting point because the total Mean A is the sum of Mean A big motor and small motor. The other graph that is closely similar is the total r.m.s A with Mean A where r.m.s A reaches a peak with 1.28 ms^{-2}r.m.s and it decreases until zero.

The result in Figure 8 is acquired from the research experiment by measuring the physical characteristic of joystick. In order to prove the finding on emotion-vibration mapping and joystick physical measurement in previous section, it needs benchmarking parameters from previous researchers. Referring to Griffin (1990), there are numerous previous researchers who have described the implication of vibration to human. One of them has classified the vibration based on mean magnitude and semantic scales [22]:

- Mean magnitude (ms^{-2}r.m.s): $> 2.3 \rightarrow$ very uncomfortable
- Mean magnitude (ms^{-2}r.m.s): 1.2-2.3 $\rightarrow$ Uncomfortable
- Mean magnitude (ms^{-2}r.m.s): 0.5-1.2 $\rightarrow$ Fairly Uncomfortable
  Mean magnitude (ms^{-2}r.m.s): 0.5-1.2 $\rightarrow$ Comfortable

TABLE 5. Comparison of proposed method with previous method

Technique Features	Nijdam (2006)	N. Kaya (2005)	Proposed emotion-Vibration mapping
Emotion recognition through colour	√	√	√
Colour Mapping process	√	√	√
Approach model	Objective approach by using mathematical model to calculate emotion colour	Statistical approach based on user respond to particular colour	Objective approach through linear interpolation between colour light spectrum and joystick wavelength.
Other Features	–	–	This method has capability to map the colour emotion into magnitude force that not covered by previous researcher. In addition, our approach has been successfully integrated to the virtual human and it can improve the realism of their appearance.

- Mean magnitude (ms^{-2}r.m.s): 0.23-0.5 → Comfortable
- Mean magnitude (ms^{-2}r.m.s): < 0.23 → Very Comfortable

According to the result in Figure 8, it has been described that the total r.m.s A is able to reach the peak until 1.28 ms^{-2}r.m.s. When it is compared with the semantic result from Oborne and Clarke (1974), the result shows a strong relationship with emotion classification with the magnitude force above 4000 is potential to carry fairly uncomfortable and uncomfortable feeling to human. This uncomfortable feeling is similar with anger emotion behaviour which makes human feel unpleasant, i.e., annoying to them. While the Magnitude Force of 4000 and below are prospective to illustrate the behaviour of happiness emotion which causes very comfortable or pleasant feeling to human. This result is also supported by Bailenson et al. (2007) that anger has more speed, i.e., faster than happiness.

First Contribution. In this section, we have demonstrated our first contribution in term of associating emotion, colour and magnitude force of haptic. This emotion-vibration mapping has become a new method that enhances the previous mapping technique (Nijdam works) and provides the conversion table that can be used by other researcher in future works. The other researcher can use the generated magnitude force in Tables 3 and 4 or they also can apply the colour classification to their work.

5. **Facial Expression Synthesis.** This section discusses how to build facial expression to comply the second technique that has been produced in this research. Facial expression synthesis is started by creating the model and splitting up into several regions according

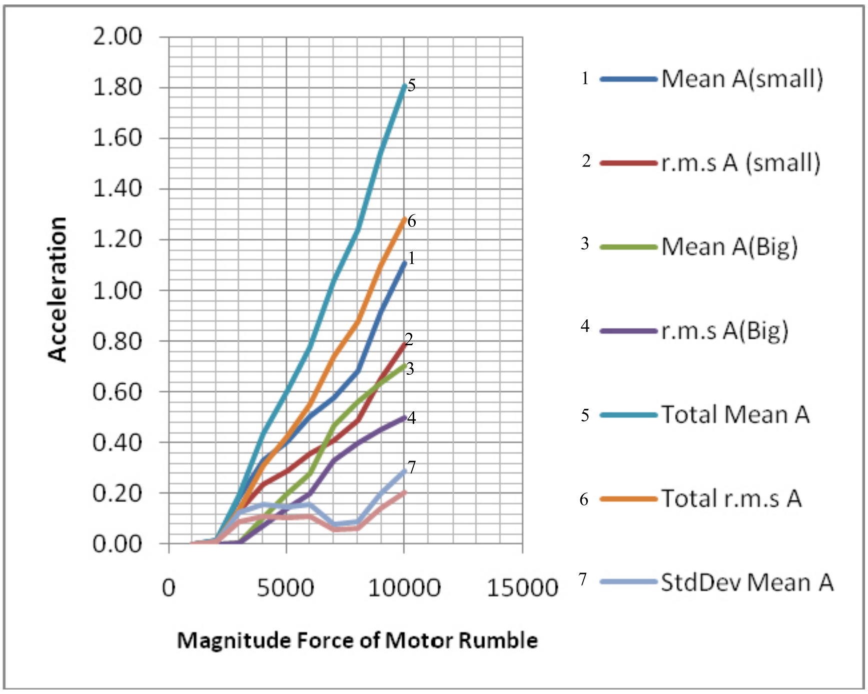

FIGURE 8. Acceleration of small motor rumble and big motor rumble from physical measurement experiment on the research

to Facial Action Coding System (FACS). The modelling procedure uses vertex animation morphing, morph animation and pose animation in order to change the facial expressions by emotion parameters. The splitting process creates a small element which is called Action Units. This Action Units (AUs) determines what kind of facial expression to appear during the rendering process. The combination of AUs will perform specific emotional facial expressions. For example, AUs1 and AUs2 will be responsible for changing eyebrow expression, e.g., for anger expression, eyebrows will be pulled up to the upper facial region or pulled down together. After that lighting effect is attached to increase the emotional expression. All emotion is triggered by stimulus signal comes from mind controller and hand glove, however this stimulation process using mind controller and glove will be discussed on other work paper. In this paper, we only assume that stimulation has been done by mind controller and glove.

In order to create full expression, pose animation uses a set of reference pose that is previously defined in mesh then stated as an offset to the original vertex data. When the blending process happens, the defined pose can be referred anytime during animation play. Every pose animation path refers to a single set of geometry on sub-mesh. The weighting of pose influences the entire animation. The process of interpolation as mentioned before is started from neutral expression called base. A number of individual targets for specific expression are generated by transferring vertices from the base model. This method requires similarity of structure between target and base (equal number of vertices and triangle and also similar connectivity). The target is also controlled by Degree of Freedom (DOF)ϕ_i that has value between 0 and 1. This DOF controls how the interpolation is made. Blended vertex position is a position calculated from base position and each target position that have DOF greater than 0 (DOF = 0 equivalent to OFF or No EFFECT). The mathematic equation to compute blended vertex position and weighted blending is

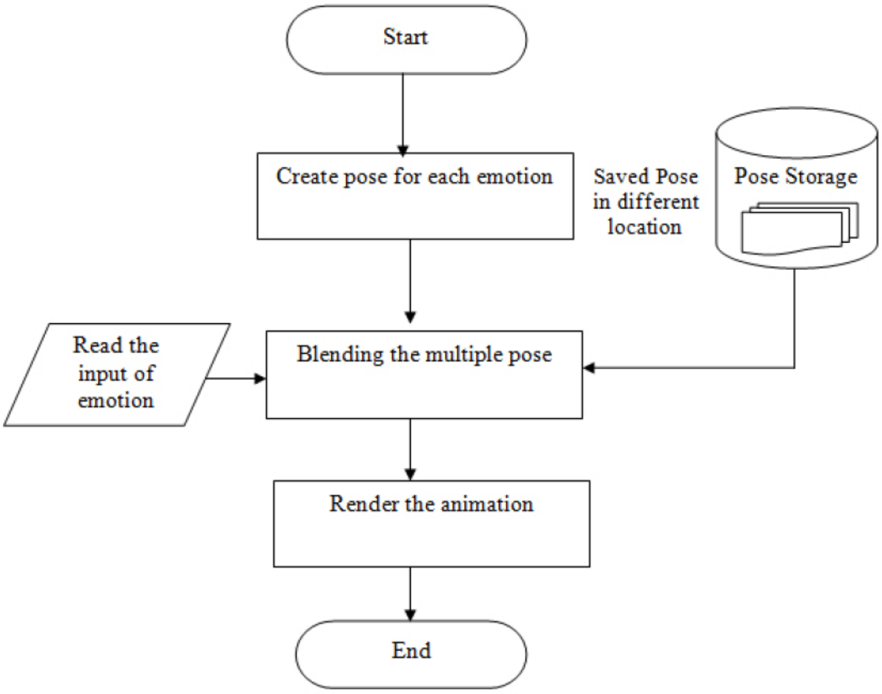

FIGURE 9. Flowchart pose animation

Algorithm loading 3D model

Input *facial.mesh*
1: Create animation for '*manual* mode
2: Set Vertex animation track
3: Generate Keyframe using vertex track
Output Loaded 3D facial object

FIGURE 10. Fragment code for loading the 3D model

shown in Equations (25) and (26).

$$v' = v_{base} + \Sigma\phi_i \cdot (\Delta v_i) \tag{25}$$

$$x' = \sum_{i=0} w_i x_i \tag{26}$$

The blended position is acquired from the base position plus target position that has DOF > 0. The whole process of this pose animation is illustrated as a flowchart as shown in Figure 9. The input of emotion determines the blending pose process and poses selection from pose storage. The file .mesh is the extension for 3D face model storage that is used by system for reference. Pre-reloading is required to combine facial mesh, manual animation and automatic animation into on animation file. $facial.mesh$ and $facial.mesh.xml$ are 2 files contributing in this system. An animation contains several key frames predefined in $facial.mesh.xml$. The process of loading the facial mesh is shown in C-Sharp code fragment in Figure 10.

The original FACS is developed in real human face by dividing human face into particular regions. Each region contributes to producing particular expression; refer to Figure 11. Figure 11(a) describes the position of Action Units (AUs) in facial area; the detailed meaning of each Action units is described by Ekman et al. (2002): AU1-"Inner Brow Raise",

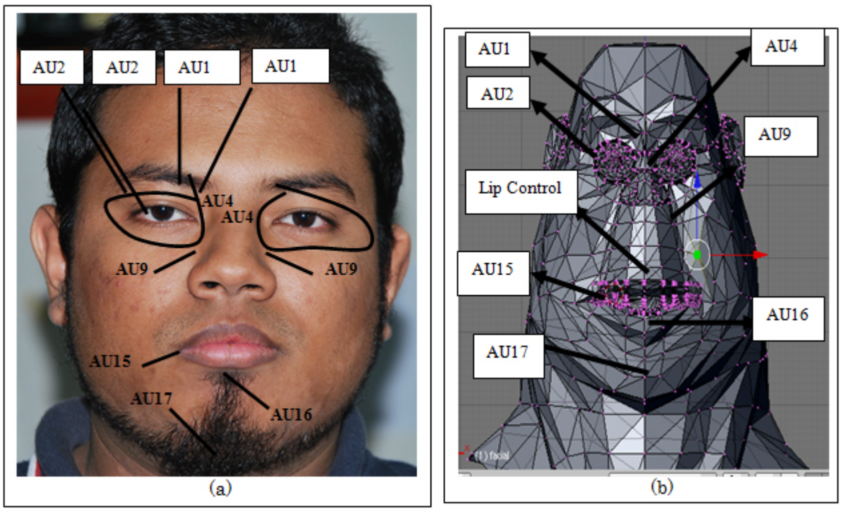

FIGURE 11. (a) Re-illustration action units (AUs) in facial action coding systems (FACS), (b) avatar model on blender tools

AU2-"Outer Brow Raise", AU4-"Brow Lower", AU9-"Nose Wrinkler", AU15-"Lip Corner Depressor", AU17-"Chin Raiser".

The mentioned Action Units in Figure 11(a) is a part of Action Units associated with facial muscle and will be used as a reference in the emotion expressions because the mentioned action units is simple but quite powerful to express to emotional expression on the face. The face offset of 3D face is created in x, y, z vertex in 3D virtual environment. This pose offset is implanted to FACS elements in 3D face model to create a particular expression of emotion. The detail illustration of FACS in our system can be described in details in Figure 11(b). AU1 and AU2 are responsible for managing the eyebrow area and generating wrinkle on the forehead in order to show particular emotions. The lighting effect is a combination of elements that contribute to augment the realism of facial expression which becomes the second contribution of this paper. In this study, the lighting is implanted into facial expression of 3D humanoid model by calculating lighting colour. The colour of lighting is calculated based on RGB elements obtained from conversion result from Tables 3 and 4. The suitable light type is diffuse component since it has a capability to add lighting colour into avatar face. Light (L) has three properties of colour L(R, G, B) which ranges between 0 and 1. Zero means no light colour while one (1.0) changes the light colour to the brightest white. Since RGB value of colour ranges from between 0 and 255, the use of lighting colour needs some scaling process as shown in Equations (27) and (28).

$$\frac{C_{RGB}}{L_{RGB}} = \frac{255}{1} \tag{27}$$

$$L_{RGB} = \frac{C_{RGB}}{255} \tag{28}$$

where C_{RGB} is the colour properties ranging from 0 to 255 and L_{RGB} is the light colour property ranging from 0 to 1. As mentioned before, the colour of light is read from conversion table, e.g., if emotion of avatar is anger, the colour is red with $C_{RGB}(255, 101, 101)$ with the intensity of 0.4 (refer to Table 3, No.5), then $L_{RGB}(1, 0.4, 0.4)$. This colour effect to the avatar can be seen in Figure 12. Figure 13 shows that 3D humanoid model is smiling and AU concentration is focusing on lip control while AU15 is focusing on stretching the lips.

Figure 12. Lighting colour effect to avatar (anger mode)

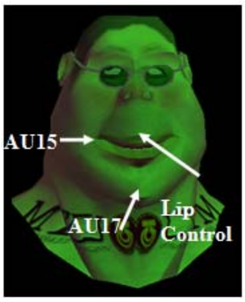

Figure 13. Expression of happy with green lighting effect

6. **Integration and Discussion.** This chapter explains the integration of facial expression, and haptic to produce a complete integrated framework. Emotion-vibration mapping will act as haptic device stimulator to create haptic sensation, while facial expression synthesis concerns on producing emotional facial expression with combination of Action Units (AUs). The magnitude force of vibration and facial expression is linked by emotion values that occur during the interaction, e.g., when anger emotion appears, facial expression will change into anger and haptic vibration will produce rough vibration according to the anger level. After that, it is followed by the evaluation on this study to test whether the proposed framework is attractive and better than previous approach. The main result of this research is achieved through several important parts like emotion-vibration mapping, facial expression synthesis, and external controller device. Each of these elements needs to work together nicely:

- Input: Input is main stimulator for this system. It is read the data from mind and hand of human in real time and used the data to control the facial expression and haptic power.
- Haptic and facial expression synchronization: The synchronization process is occurred because of data is obtained in real time and continuously read. This is mean current facial expression and haptic sensation is based on the latest data which is obtained from the input.
- External device synchronization: The external devices are referring to haptic device and sound hardware that will be controlled according to the output.
- Output: The output is the generated 3D avatar that can show facial expression, acoustic intonation and haptic sensation.
- Evaluation: Evaluation is compulsory to assure the result is on the right track.

The system is run on Pentium 4 Core 2 Duo 2GHZ with RAM 2 GB and VGA card ATI RADEON 256 MB with Windows XP as the operating system. Two haptic devices commonly used by people such as XBOX windows controller and common joystick are able to be connected to PC. If haptic device is hold by hand, it needs to be held like the sample from Griffin (1990) to obtain the optimum functionality of the haptic device. Figure 14

FIGURE 14. Grip handling based on Joystick

(a) (b)

FIGURE 15. User interaction with avatar through joystick and 5DT data Glove-1

FIGURE 16. User interactions with NIA mind controller

illustrates users interaction with avatar using XBOX controller. Avatar model used in this research is a modified model of dr.headBunsen from OgreGameEngine [23]. Other than connected with XBOX controller, the system has two external input devices, i.e., 5DT Glove and Nia Mind controller. Figures 15(a) and 15(b) show the interaction between user and avatar through haptic glove to control the facial expressions and XBOX joystick to feel the touch sensation. 5DT sends the position of finger simultaneously and continuously to the system, and it reads and sends it to change the 3D humanoid model mimic. In Figure 16, user tries to control the facial expressions of avatar through mind controller through headband around their forehead. NIA mind controller has several sensors attached to the users head that is able to record brain activities during the interaction. User can change 3D humanoid model face directly through their mind by putting their feeling into NIA mind controller. There are three inputs recognizable in this system: mind controller, glove, keyboard and mouse. The mind controller recognizes and analyses the brain activities signal and continued with classifying signal based on emotion condition.

Furthermore, the glove signal is read and interpreted according to the hand gesture shape. In this system, glove only acts as intensity controller of emotional expression, e.g., if user emotion is recognized as anger, the intensity or how strong the anger it is decided through the gesture shape. Based on previous work, the study also adapt the gesture posture such as rounded fist gesture like fist or punch to represent anger [24]. The details of how the process of emotion recognition and how the intensity of emotion is controlled will be explained further in the next section. Ekman and C. Hager (1983) have proposed FACS that combines several Action Units (AUs) to recognize and produce emotion from facial expression. The FACS in Figure 11 has revealed that muscle tension is in high correlation with emotion condition. Therefore, the created system is choosing muscle and one of alpha sensors as stimulation input. Alpha and Beta sensor show the similar measurement method on measuring the brain activities that is why Alpha1 is selected to represent brain activities signal. Mean value between muscle and Alpha sensor will be used as final input for stimulation, while other signal is kept for future research. The emotion recognition depends on average signal intensity of Muscle, and Alpha sensors (refer to Equation (29)).

$$E_s = \frac{M_s + \alpha_1}{2} \tag{29}$$

Note: E_s: Emotion Signal; M_s: Muscle Signal; α_1: Brain Activity Signal.

The tension level of Muscle and Alpha signal can be divided into four main zones as shown in Figure 18, e.g., Z1, Z2, Z3 and Z4. Nia is only capable of dividing the signal into four zones or fewer. Z1-Z4 is intensity zone of each signal that classifies the excitation level to different zone as shown in Figure 17. These four zones can be assumed as low, medium lower, medium higher and high. Low and medium lower are associated with Z1 and Z2 with intention to capture relaxed feeling which is suitable for happiness. Nevertheless, Z3 and Z4 is medium higher and high zone associated with high level of tension. This high level of tension makes muscle stressed like when anger emotion occurs, that is why Z3 and Z4 is used to stimulate anger emotion expression. Emotion signal determines what kind of emotion expression that will be performed by facial expression, haptic vibration and acoustic effect. The tension level of Muscle and Alpha signal can be divided into four main zones as shown in Figure 17, e.g., Z1, Z2, Z3 and Z4. Nia is only capable of dividing the signal into four zones or fewer. Z1-Z4 is intensity zone of each signal that classifies the excitation level to different zone as shown in Figure 17. These four zones can be assumed as low, medium lower, medium higher and high. Low and medium lower are associated with Z1 and Z2 with intention to capture relaxed feeling which is suitable for happiness. Nevertheless, Z3 and Z4 is medium higher and high zone associated with

Figure 17. Zones level of Nia sensor

high level of tension. This high level of tension makes muscle stressed like when anger emotion occurs, that is why Z3 and Z4 is used to stimulate anger emotion expression. The 3D humanoid model is stimulated and affected by these zones signal classification. For example, if the signal reaches Z3 or Z4, 3D humanoid is in anger mode and it changes the 3D humanoid faces into anger state and also stimulates the vibration into anger magnitude force. Otherwise, if it decreases until Z2 and Z3, stimulation is changed into happiness that changes 3D humanoid emotion state into happiness mode with happy facial expression. The magnitude force and acoustic effect will be adjusted as well according to the emotion state. In evaluation part, the conducted task in two ways, first, users interact with our system and, secondly, users interact with Alfred and Xface [12,13] systems as our benchmarking system. Alfred was initiated by Nikolaus [13] from The University of Augsburg, while Xface was initiated by Balci from The University of Trento [12]. All participants are trained to interact with this study's application and Alfred for a certain period of time. During the interaction, users activities and expressions through the figure are gathered. Participants need to conduct interaction with this study's system, Alfred and XFace system for a certain period of time. The interactions with Alfred system and Xface system are conducted to investigate whether users are satisfied with current emotion expression (facial expression) or not (See Figure 18(a) and Figure 18(b) for the task completion). The task of interaction with these avatar systems can be described as below:

- Interaction with our system User changes the facial expression using scroll bar and feels the emotion expression through visual, haptic and acoustic.
  User wears glove and mind controller then user tries to express their emotion naturally. After that they receive the feedback of the avatar by facial expression, acoustic and haptic effect. At the end of this interaction user needs to memorize all feeling on previous interaction, because it is used as a parameter for the next comparison with other XFace and Alfred.
- Interaction with XFace Since XFace is equipped with speech synthesis program, users interact with XFace by changing their emotional expression through the available emotion menu. Users interact with XFace during particular time and they memorize the emotion expression sensation of XFace.
- Interaction with Alfred Alfred only provides menu for changing the facial expression on their avatar through XBOX joystick. Therefore, users are encouraged to make interaction by changing the facial expression freely. This means facial expression is

(a) (b)

FIGURE 18. Task completion by interacting with Alfred systems (a) and Xface (b) [12,13]

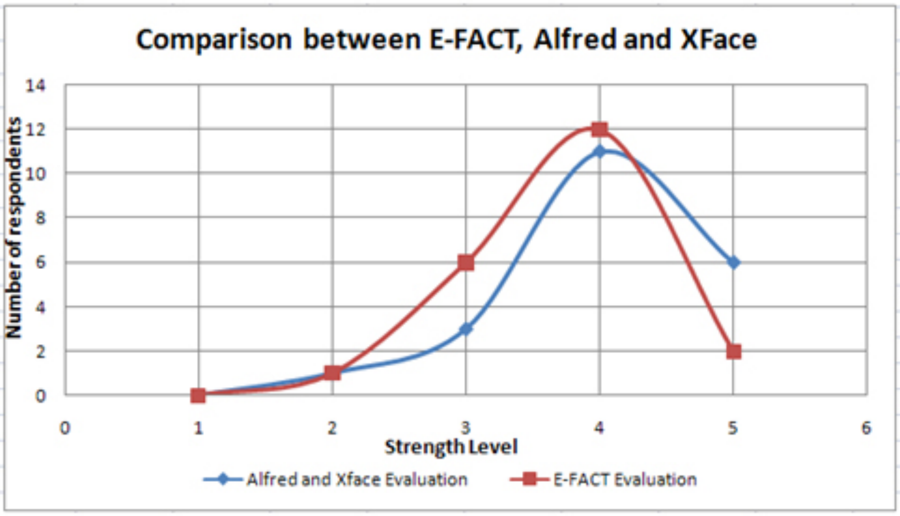

FIGURE 19. Graph comparisons of proposed framework, Alfred and XFace

not only limited into emotion expression but also into the facial expression without emotion value.

This comparison has a goal to measure how realistic is the created avatar expression compared with Alfred and Xface system. In this section, statistic analysis is computed to compare whether Alfred and XFace systems or the system with haptic integration framework is more exciting for users.

The proposed framework has obtained a significant result when users seem to have an excitement to the haptic sensation. This result is very interesting, i.e., users get more excited when they are stimulated by combination of facial expression, voice intonation and magnitude force vibration. Most users feel something different when they are triggered by numerous vibration frequencies. Some participants feel relax in particular low vibrations and feel inconvenient when shocked by high vibration. Figure 19 shows the users evaluation on benchmarking process.

From the graph shown in Figure 19, it is portrayed that the experiment gives a significant positive result which is able to drive avatar to give more realistic expressions. All users have strong confidence rate on differentiating and recognizing emotion of human. From the user testing, we obtained 67% users give strong and very strong impression that our system gives stronger emotional expression than Alfred and Xface systems. Twenty nine percent users give medium values to our system compared to Alfred and Xface systems. Finally, only around five percent users say that our system provides a little impression than Alfred and Xface systems. Furthermore, we have found an interesting finding that all users agree that high vibration of joystick is equivalent to anger emotion. Figure 19 has shown the strength of our proposed method in front of users acceptability. We also want to highlight more about effectiveness the proposed method compare to other researchers. The summarization of features it described is shown in Table 6.

As mentioned in Table 6, the proposed approaches have portrayed more effectiveness compared to the previous works. It covers two expression channels: visual and haptic that can overcome the lacking of presence of virtual human. The natural interaction also provided to make user easy to interact rather than standard interaction using keyboard and mouse. Reproducing issues for our case is very high compared to others due to the material easy to be acquired and the experiment also can be conducted by others by considering our methodology in Section 4. In term of contribution, we have contributed

Table 6. The effectiveness of our proposed method

Features	**Our System**	T. Dzmitry et al. (2010)	J. Teh and A. D. Cheok 2006	C. Melo and A. Paiva 2007	C. M. D. Melo and Gratch
Emotion Expression Channel	-Facial expression -Magnitude force of haptic -Colour	-Facial expression -Haptic Kinesthetic	-Haptic Kinesthetic (Hug)	-Facial Expression -Colour	-Facial Expression -Colour
Interaction	Natural Interaction using mind controller and glove	Using chat to stimulate the emotion	Using medium-physical interaction like human hugging a doll	Instruction using keyboard or mouse	Instruction using keyboard or mouse
Reproducing issues	Easy to reproduce using cheap and common haptic device, e.g., joystick	Need specific expert and tolls to develop	Need specific expert and tolls to develop	Only need software because did not involve any particular devices	Only need software because did not involve any particular devices
Contribution Coverages	The generated colour and magnitude force classification has wider range than previous works and it can be utilized easily by adopting the magnitude force and colour value	Specific only for their haptic device	Specific only for their haptic device	Only focus on visual appearance of avatar	Only focus on visual appearance of avatar

on classifying the colour and magnitude force, then crating facial expression synthesis and finally providing user with natural interaction. Of course, instead of the strength of our proposed method we still have weakness compared to others work in term of beauty appearance of the virtual human. Because some of previous researcher are using laser scanning system in order to produce realistic structure of virtual human face.

7. **Conclusions.** The proposed integration framework focuses on strengthening the realism of 3D humanoid model through the emotional expressions with an integration of facial expression, acoustic (loudness level) and haptic vibration. This integration has been proven empirically to give better performance and enhance the realism of 3D humanoid model. The process of integration and evaluation is explained in details in Section 6. On the other hand, Emotion-Vibration Mapping technique is the first contribution in this paper that has been explained well in Section 4. The technique describes the process of mapping emotion to vibration through linear interpolation between wavelength of colour light spectrum and joystick wavelength. The result of mapping process has proven that

the mapping technique is able to determine and justify the highest magnitude force from two motor rumbles that produce 1.28 ms^{-2}r.m.s which cause uncomfortable feeling to human. These magnitudes force power slowly decrease along with the adjustment of vibration power. This result has been supported by a subjective evaluation which shows that 71% respondents strongly agree with this finding. Facial expression synthesis has become the second contribution that obtained in this study that is well explained in Section 5. The modelling procedure uses vertex animation morphing, morph animation and pose animation in order to change the facial expression by emotion parameters. Each Action Units covers specific area on human faces, for example AU1 is holding inner eyebrow and AU2 is holding outer inner eyebrow. The facial expression is built based on FACS by integrating several Action Units and creating intensity level of each emotion. This emotion expression and intensity level will also affect the lighting colour of facial region as well. This colour comes from the emotion-vibration mapping result. The intensity level of emotion is linked with glove and it will be controlled using fist gesture. It is also stimulating haptic to generate appropriate magnitude force and loudness level of sound effect at the same time. The user study shows that, the feedback from user is very exciting with 67% of the users give strong and positive response to the system. In addition, 15 users from 21 participants (71%) agree with the classification of magnitude force into emotion representation, they say high magnitude force creates a similar sensation as when they feel anger, while low magnitude force is more relaxing to them. This integration between facial expression, acoustic and magnitude force is believed to bring strong impression and believability to user in real world and even strengthen the interactivity and immersiveness of virtual reality or serious game itself. All previous rationalization has clearly explained the contribution of this research and the positive response to the proposed framework from users during testing session. The outcome of research can be improved further to augment avatar emotion expression. Furthermore, the magnitude force classification in Section 4 is also possible to be used in other field like medical due to its capability of giving people are relaxing or tension sensation. The other usability of the research outcome comes from the utilization of brain computer interface like mind controller. It can be studied further to investigate the psychological and mental state of people by using particular methods.

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