ENHANCED FACIAL EXPRESSION USING OXYGENATION ABSORPTION OF FACIAL SKIN

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This thesis is dedicated to my family especially my father Prof. Dr. Hazim Ameen Alkawaz, my mother and my best friend Dr. Ahmad Hoirul Basori for their endless support and encouragement.

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ABSTRACT

Facial skin appearance is affected by physical and physiological state of the skin. The facial expression especially the skin appearances are in constant mutability and dynamically changed as human behave, talk and stress. The color of skin is considered to be one of the key indicators for these symptoms. The skin color resolution is highly determined by the scattering and absorption of light within the skin layers. The concentration of chromophores in melanin and hemoglobin oxygenation in the blood plays a pivotal role. An improvement work on prior model to create a realistic textured three-dimensional (3D) facial model for animation is proposed. This thesis considers both surface and subsurface scattering capable of simulating the interaction of light with the human skin. Furthermore, six parameters are used in this research which are the amount of oxygenation, de-oxygenation, hemoglobin, melanin, oil and blend factor for different types of melanin in the skin to generate a perfect match to specific skin types. The proposed model is associated with Blend Shape Interpolation and Facial Action Coding System to create five basic facial emotional expressions namely anger, happy, neutral, sad and fear. Meanwhile, the correlation between blood oxygenation in changing facial skin color for basic natural emotional expressions are measured using the Pulse Oximetry and 3D skin analyzer. The data from different subjects with male and female under different number of partially extreme facial expressions are fed in the model for simulation. The multi-pole method for layered materials is used to calculate the spectral diffusion profiles of two-layered skin which are further utilized to simulate the subsurface scattering of light within the skin. While the subsurface scattering is further combined with the Torrance-Sparrow Bidirectional Reflectance Distribution Function (BRDF) model to simulate the interaction of light with an oily layer at the skin surface. The result is validated by an evaluation procedure for measuring the accountability of a facial model via expressions and skin color of proposed model to the real human. The facial expressions evaluation is verified by calculating Euclidean distance between the facial markers of the real human and the avatar. The second assessment validates the skin color of facial expressions for the proposed avatar via the extraction of Histogram Color Features and Color Coherence Vector of each image with the real human and the previous work. The experimental result shows around 5.12 percent improvement compared to previous work. In achieving the realistic facial expression for virtual human based on facial skin color, texture and oxygenation of hemoglobin, the result demonstrates that the proposed model is beneficial to the development of virtual reality and game environment of computer aided graphics animation systems.

ABSTRAK

Penampakan kulit wajah dipengaruhi oleh keadaan fizikal dan fisiologi kulit. Ekspresi wajah terutamanya penampakan kulit sentiasa berubah-rubah secara dinamik apabila manusia bertindak, bercakap dan dalam ketegangan. Warna kulit merupakan salah satu petunjuk utama bagi tanda-tanda ini. Resolusi warna kulit sangat ditentukan oleh penyerakan dan penyerapan cahaya dalam lapisan kulit. Kepekatan kromofor dalam melanin dan pengoksigenan hemoglobin dalam darah memainkan peranan yang penting. Penambahbaikan terhadap model terdahulu bagi menghasilkan model wajah bertekstur tiga-dimensi (3D) yang realistik untuk animasi telah dicadangkan. Tesis ini mempertimbangkan kedua-dua penyerakan permukaan dan sub-permukaan yang merangsang interaksi cahaya dengan kulit manusia. Selain itu, enam parameter yang telah digunakan dalam kajian ini iaitu jumlah pengoksigenan, penyahoksigenan, hemoglobin, melanin, minyak dan faktor adunan pelbagai jenis melanin dalam kulit yang berupaya menghasilkan gabungan yang sepadan bagi jenis kulit tertentu. Model yang telah dicadangkan ini digabungkan dengan Interpolasi Rupa Bentuk Campuran dan Sistem Pengekodan Tindakan Wajah untuk mewujudkan lima asas emosi ekspresi wajah iaitu marah, gembira, neutral, sedih dan takut. Sementara itu, kolerasi antara pengoksigenan darah dalam mengubah warna kulit wajah dan ekspresi emosi semula jadi asas diukur dengan menggunakan Oksimetri Nadi dan penganalisis kulit 3D. Data daripada subjek yang berbeza antara lelaki dan perempuan di bawah pelbagai jumlah ekspresi wajah separa ekstrim diterapkan dalam model untuk simulasi. Kaedah pelbagai liang untuk bahan-bahan yang berlapis digunakan bagi mengira profil penyebaran spektrum dwi-lapisan kulit yang kemudiannya digunakan untuk mensimulasikan penyerakan sub-permukaan cahaya dalam kulit. Penyebaran sub-permukaan kemudiannya digabungkan dengan model Fungsi Agihan Pantulan Dwi-arah Torrance-Sparrow (BRFD) untuk mensimulasikan interaksi cahaya dengan lapisan berminyak pada permukaan kulit. Hasil kajian disahkan dengan menggunakan prosedur penilaian untuk mengukur akauntabiliti model wajah melalui ekspresi dan warna kulit daripada model yang telah dicadangkan terhadap manusia nyata. Penilaian ekspresi wajah disahkan dengan mengira jarak berdasarkan kaedah Euklidan antara penanda wajah bagi manusia nyata dan avatar. Penilaian kedua mengesahkan warna kulit ekspresi wajah untuk avatar yang telah dicadangkan melalui pengekstrakan Ciri Warna Histogram dan Vektor Kesepaduan Warna bagi setiap imej dengan manusia nyata den kajian terdahulu. Hasil kajian menunjukkan penambahbaikan sekitar 5.12 peratus berbanding kajian sebelumnya. Dalam mencapai eksperesi wajah yang realistik untuk manusia maya berdasarkan kepada warna kulit wajah, tekstur dan pengoksigenan hemoglobin, hasil kajian menunjukkan bahawa pendekatan yang dicadangkan memberi manfaat kepada pembangunan realiti maya dan persekitaran permainan bagi sistem animasi grafik berbantu komputer.

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TABLE OF ABBREVIATIONS

AUs	-	Action Units
BRDF	-	Bidirectional reflectance distribution function
EFFD	-	Extended free-form deformation
FA	-	Facial Animation
FACS	-	Facial Action Coding System
FAPs	-	Facial Animation Parameters
FDPs	-	Facial Definition Parameters
FFD	-	Free-form deformation
GPU	-	Graphics processing unit
HCI	-	Human–Computer Interaction
HMS	-	Head Motion Synthesis
KNN	-	K-Nearest Neighbor
MPEG4	-	Moving Picture Experts Group
TTS	-	Text-to-speech
VHML	-	Virtual Human Markup Language
XMT	-	Explicit Multi-Threading

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Human face as one of indicator of internal body system sensation is undoubtedly the most important art object and central aspect of phenotype that plays a meaningful role in the interaction process. The proportions and the expressions of the face are important to identify the origin, emotional tendencies, health qualities, and often fundamental to human social interaction. Many different types of particular information are visible on faces. Facial animation is the essential element for expressing human emotion and personality. Diversified applications of computer facial animation in the creation of realistic virtual humans with various facial expressions are used in entertainment and edutainment (Alotaibi, 2014; Gilbert and Forney, 2015; Hsu and Tsai, 2011; Shih *et al.*, 2011). An attractive system can improve the interaction between users and machines by using interactive talking head.

In the past, Fred Park (1972) was the first person who was concerned about facial animation and used the power of 3D computer graphics to deliver the highest level of control that drives the change of face appearance (Parke, 1972). This was very special because at that time for non-verbal communication and facial expression, the applications were mainly produced by computer generated actors, as well as from less advanced research instruments. The rapid advent of online game manufacturing and growing demand required the improvement and enhancement of quality of the graphics to achieve a significant feat in artificial intelligence. These elements enforced the game industry to be full with priceless artificial intelligence and graphics closely to real human. Initially, the games consisted of a few numbers of polygons in characters and were supported by a few active computers in that regard (Entem *et al.,* 2015; Parent, 2012).

Facial appearance is primarily guided by the physical and physiological conditions. Human skin appearances change constantly along with movement, talking, undergoing stress, or expressional change. Surprisingly, the skin color is the major indicator of these changes. Facial skin color is a parameter that measures the enhanced effects of realistic expression due to its direct correlation with internal emotions or feelings. The manifestation of skin color is due to the scattering and absorption of light that occur under skin layers. These interactions are mostly caused by the presence of two chromophores concentration called melanin and hemoglobin. It is worth noting that during the facial animation the melanin concentration and its distribution remain static within the skin. This is precisely due to fact that melanin is embedded within the keratinocyte cells of the epidermis. Furthermore, the time dependent alteration for melanin concentration is usually over an hour to weeks. In fact, the short duration is not majorly affecting the facial melanin. Consequently, the distribution of hemoglobin being the primary carrier of oxygen in the blood appears as the only potentially varying factor that effects the facial skin color (Jimenez *et al.*, 2010; Kuzmina *et al.*, 2011; Madooei *et al.*, 2012; Park *et al.,* 2002). Despite some dedicated efforts the influences of blood oxygenation of hemoglobin concentration on facial color and emotional expressions are far from being understood.

1.2 Problem Background

In the past, virtual human has been developed in various forms of computer applications (Yee *et al.*, 2007). Currently, the advancements in artificial intelligence and computer graphics enable an avatar with amazing capability to interact naturally (Lee *et al.*, 2010). One of the most important motives in the use of virtual characters in a 3D environment is to create an efficient communication to attract the user. The expressions of emotions are prerequisite in building this exciting contact between the user and virtual character. A wide variety of emotions in virtual characters can realistically be displayed either by using diverse styles of motions in the body or by different facial expressions (Chaudhry *et al.*, 2015; Gachery and Thalmann, 2001; Impett *et al.*, 2014; Monkaresi *et al.*, 2012; Tol and Egges, 2009).

Earlier, (Parke, 1972; Platt and Badler, 1981) have tremendously contributed in facial modeling and animation fields. These are achieved by the generation of artificial face models expression and quite simple because they are connected by vertical and horizontal lines. However, the cited facial animation control involves a parameterization process which is too complex to be implemented by untrained users. Since the pioneer works in this field, significant progress have been recorded by researchers in computer graphics as they have developed models that are of very high quality and able to mimic facial expression almost realistically. Despite this progress, the current existing computer synthesized human facial animation is not only very costly in terms of resources and labor requirements but the achieved outcomes are still far from being realistic. Consequently, in the present development phase the results are truly cost effective simultaneously and the facial animation is still unrealistic.

Actually, the process of generating realistic synthetic faces in three-dimensional characters and trying to make it desirable has become significant. Lately, this attracted the attention of many researchers and posed a very big challenge towards the achievement of pragmatic facial expressions. Nevertheless, the continuous developments of a variety of algorithms and techniques have imparted further impetus towards the progression of facial animation schemes. Advanced 3D scanners and photometric techniques are now capable of creating precisely detailed geometry of human faces. Due to the technological progress in the areas of human faces modeling, the researchers have become less tolerant to ignore even slight imperfections in the animations and models that have been happening in the past (Ypsilos, 2004).

Efficient production of computer facial animation with appropriate and complex expressions is still lacking. The interaction with characters is a pivotal step to create effective connection with the user. Thus, virtual characters use a variety of emotions type including facial expression or diverse body motions to establish the connection effectively. Yet, these emotions seem to be affected slightly by the interaction of the user in some games. For example, a game that uses emotion to create a conversation with computer controlled characters such as Oblivion (Popa *et al.*, 2009). This game contains four instances of emotions to represent a character. However, these features are still limited due to fixed expressions as illustrated in Figure 1.1.

Figure 1.1 Representation of the four static expressions (happy, sad, fear, anger) used in the game Oblivion (Popa, *et al.*, 2009).

The construction and animation of realistic human faces in 3D remains an intricate problem in the domain of computer graphics (Mihai Daniel *et al.*, 2011). In the area of facial animation synthesis, the existing technologies are still not able to build realistic facial expressions in an effective manner that includes the underlying emotional content (Yongmian *et al.*, 2008). Recent progress in digital technology has resulted stabilized high-speed processing of vast amount of information. Hence, applications for long-distance communication such as video conferencing and telephoning are being constantly developed. Distinct elements of advanced communication technology of these systems are manifested in the presentation and estimation of emotions using facial color as well as the expression. Specifically, if the color of the face alters the related emotional changes can be used for the fusion of the facial expression to develop the basic emotions of visual anthrop orphic agents. This may play a key role in the selection of communication between computers and humans (Yamada and Watanabe, 2004).

Simulation of communicative characters requires reasonable behavior and realistic appearance. Postures in simulation also reflect the emotional attributes. Psycho-evolutionary theory of emotions was developed by Plutchik (Plutchik and Kellerman, 1980). Later, Ekman (1984) introduced the FACS. However, most of the models are appropriate merely for muscular expressions (Ekman, 1984). The change in face color in graphics too is also a less controlled field (Kalra and Magnenat-Thalmann, 1994). Facial skin enriched with blood vessels a high level of enzyme mediated activity is often reflected as elevated metabolite commotion. Many kinds of formal subsidiary in the face do exist. Kalra and Moretti (1994) have conducted a study on skin vascular patterns in different areas of the face.

Figure 1.2 shows the variation of emotion on facial expression. The region based approach revealed that areas like the nostril and forehead possess bilateral divisions at sharply acute angles called "fronds" and parts such as cheeks and jaws form one side branching nearly at right angles termed as "candlestick" (Kalra and Magnenat-Thalmann, 1994; Moretti *et al.*, 1959). Areas between the "frond" and "candelabra" exhibited intermediate types of subsidiary. Numerous areas portray several forms in the capillary stream to the skin. Commonly, there are many regional varieties and any one region varies greatly according to the individual especially with the age component. These differentials may highlight why certain areas show more external activity than others. For example, the redness may be seen more on the cheeks, ears and forehead rather than the rest of the body (Kalra and Magnenat-Thalmann, 1994).

Figure 1.2 First three images from the left show anger, where the cheeks are blushed with the appearance of red blotches. The fourth one displays intense weeping with blushing cheeks. Last three images after positions and colors changes exhibit the occurrence of droplets, perspiration effects or nose bleeding (Jung, *et al.*, 2009).

The combination of facial expressions and emotional colors is clearly depicted in Figure 1.2. The corresponding sensation is easily perceivable and more plausible for strong emotions. The changes for skin colors can be categorized according to a parameterized emotional model. A group of test on possible skin colors changes from the physiological and psychological knowledge was carried out. The combination of droplet flow and color change are used to provide a convincing real world emotion (Jung, *et al.*, 2009). Earlier, researchers focused mainly on the geometric features of these alterations. For instance, the facial surface animation considered the skin stretching and wrinkled structures only. However, changes in the hemoglobin concentration that can cause changes in skin color were not included in the model. It may also originate from the reaction of histamine or other skin conditions (blushing and rashes). Specifically, blushing consists of a number of emotions such as joy, shame, and arousal. Regardless of its ability to convey emotion, the dynamic alterations that occur in skin pigmentation are mostly ignored in the existing skin appearance models (Ersotelos and Dong, 2008; Jimenez, *et al.*, 2010).

Certainly, human skin displays a remarkable appearance primarily due to physiological and structural alterations that occurs on the skin surface and within layers. This heterogeneity could come about naturally, such as splotches, freckles, rashes, or veins, or are artificially planted by forces which are externals. For example, application of pressure can cause the blood either to increase or decrease or introducing pigmentation to the skin such as inscribing of tattoos on skin. During the building of shading models for describing and designing skin appearance, it is necessary to consider such variations. Understanding the skin appearance is highly challenging because the skin reflection is mainly contributed to by subsurface scattering (Igarashi *et al.*, 2005). Additionally, the spectral reflectance of the skin is complicated due to its numerous chemical constituents and variations of structure (Donner *et al.*, 2008; Kanzawa *et al.*, 2011).

As discussed before, simulating the human skin appearance is a complicated task due to the underlying structural complexity. Furthermore, even a little variation in the skin color and shade remarkably affect the perception of skin, as they carry information about an individual's health, ethnicity, and physiological situation. A shading model is essential for accurately describing the physical features. Complete spectral interactions between light and tissue is essential for realistic renderings of human skin (Donner and Jensen, 2006). Human skin coloration depends absolutely on the concentration and spatial distribution of the skin chromophores namely the melanin and hemoglobin (Anderson, 1981). Earlier findings revealed that the facial melanin concentration and distribution do not change with time (Park, *et al.*, 2002). In fact, hemoglobin is the only varying factor that affects the skin color (Mahmud, 2012).

Body or ornament color is a reflection of some underlying physiology in many species. Moreover, these color clues are apparent by conspecifics and utilized as social and sexual signs. Red coloration, which achieved its color based on hemoglobin, is attributed to providing signs of physiological state in birds. Blood perfusion results in red coloration in the mouth of canary nestlings. The gap increases in redness as the food deprivation level rises. Nestlings with brighter red mouths are provided with more food by the parents with an indication that the red coloration is acting as a sign between offspring and parents (Kilner, 1997). It has been observed that 29 bird genera present with this red, hemoglobin based skin flushing is a sign of health, hormonal or social condition (Negro *et al.*, 2006). Several non-human primates' species exhibit skin reddening indicating their physiological health, hormonal and reproductive state. Male rhesus macaques have redness on their face during the mating season, as a response to increase testosterone secretion (Rhodes *et al.*, 1997). Similarly, in some macaque species, the anogenital skin color of the female species turns red due to increased secretion of ovarian estrogen. This sexual skin coloration becomes deeper in redness in per ovulatory period (Waitt *et al.*, 2006).

Interestingly, increased skin redness of male faces and female anogenital regions of macaques is an attraction to the opposite sex. This suggests that redness is a signal of reproductive status and condition (Rhodes, *et al.*, 1997; Waitt *et al.*, 2003). In male mandrills, increased testosterone secretion is associated with increased social dominance rank which brings about enhanced facial redness (Joanna M. Setchell and Dixson, 2001). Other males do not get into violent conflicts with individuals having brighter and redder faces than them, which is an indication that the increased redness is a social status marker associated with dominant and subordinate males (Joanna M. Setchell and Jean Wickings, 2005). Female facial redness in mandrills mainly points in the direction of fertility across the estrus cycle and reproductive quality (Joanna M Setchell *et al.*, 2006).

Besides, in humans the skin redness resulting from skin vasodilation and vascularization is connected to physiological status that includes the health of individuals. In addition, the state of the oxygen in the blood is highly correlated to health status and this affects the skin coloration. In women, an increase in sex hormone secretion is often linked with increased skin vascularization (Thornton, 2002) and vasodilator response (Charkoudian *et al.*, 1999). This manifestation arterializes the blood that is observed in the skin (Liu *et al.*, 1992). The cutaneous vasodilator system responds more to physical training (Johnson, 1998). However, this is impaired by type 2 diabetes mellitus (Charkoudian, 2003) and hypertension (Panza *et al.*, 1990).

Oxygen level in the blood can be improved by increased aerobic exercise (Armstrong and Welsman, 2001). Whereas, the increased blood de-oxygenation may linked to hypoxia causing cyanosis (blue tinted skin), which is a pointer to lack of coronary and respiratory fitness (Ponsonby *et al.*, 1997). Furthermore, in humans there is evidence that skin coloration is often interpreted by observers as a sign to underlying physiological health status. The distribution of skin pigmentation (blood and melanin) can have an adverse effect on the health, age and attractiveness of the human face (Fink *et al.*, 2006; Matts *et al.*, 2007). The bright features and the facial skin have a role to play in the attractiveness and apparent femininity/masculinity of faces (Russell, 2003). Participants appearing in red are apparently more likely to win in most sporting contests (Barton and Hill, 2005; Greenlees *et al.*, 2008). This is possibly because redness may be viewed as dominance (Little and Hill, 2007) or anger in humans (Drummond and Quah, 2001). Women who appear in red are seen as being more attractive than their colleagues by men (Elliot and Niesta, 2008).

Stephen, Coetzee, et al. (2009) showed that color can be associated with skin blood perfusion and blood oxygen has great influences on the human health appearances of individuals face. Attractiveness is thought as signal to the underlying health state (Rhodesô *et al.*, 2007; Thornhill and Gangestad, 1993). This is strongly related to perceived state of health (Rhodesô*, et al.*, 2007) and a major factor in human mate choice, particularly by men (Buss, 1989). Therefore, an improved health appearance is most like associated with increased skin blood and blood oxygenation, which is responsible for attractiveness and choice of mate. Blood change perfusion are usually more difficult to detect in ethnic groups with dark skinned (Leary *et al.*, 1992). Darkness of the skin has been proven as a factor that affects both social perceptions (Maddox and Gray, 2002) and attractiveness ratings of faces. It is expected that reddening of the face is viewed differently for various ethnicity by light and dark skinned observers (Giard and Guitton, 2010; Ramirez*, et al.*, 2014; Stephen, Coetzee*, et al.*, 2009; Stephen, Law Smith*, et al.*, 2009).

The animated facial models are not only less expensive as compared to human performers but also more elastic, where it offers customization in style and appearance. These advantages can provide users with alternatives to substitute computer-generated models with human actors. Several ways are used to achieve 3D or 2D models in animation. A software modeling tool can be used to generate the animation manually. This is performed by capturing a 3D clay model with a digitized pen attached to a mechanical arm, which calculates the location of the tip of the pen. Besides, it can be taken from an actual human by cameras or other scanning technology. The obtained 3D data is further parameterized into a mathematical representation as in splines, implicit surfaces or polygonal models, and then manipulated using the computer (Cerekovic *et al.*, 2007; Cosi *et al.*, 2005).

1.3 Research Motivation

Animating realistic 3D facial expression is a long-standing quest within the computer graphics research community. The demand is not only for numerous applications but also for the inherent problems in creating surface deformations to express certain facial behaviors. Researchers on facial simulations have greatly created an improvement with continuing advances in computing power, display technology, graphics, image capture and interfacing tools. A realistic approximation of a 3D human face is essential for successful presentation of pragmatic facial skin color and expressions (Basori and Qasim, 2014; Choi *et al.*, 2015; Shu *et al.*, 2013; Stepanova and Strube, 2012; Suja *et al.*, 2014). The current facial expression on virtual human in terms of providing realistic expression through their facial skin changes are far from satisfactory (Elliot and Niesta, 2008; Krishnaswamy and Baranoski, 2004). This fact encouraged this research to perform better classification (basis color) for facial skin color changes of the avatar. All the previous works for color generation was limited by the real skin color changes and did not correlate blood oxygenation and de-oxygenation and the effects of hemoglobin concentration responsible for facial color alterations from one expression to another (Jimenez, *et al.*, 2010; Stephen, Coetzee, *et al.*, 2009; Stephen, Law Smith, *et al.*, 2009). For example, the high level of oxygen in the hemoglobin seems to manifest the angry face rather than the sad face.

The studies in (Donner and Jensen, 2006; Donner, *et al.*, 2008; Jimenez, *et al.*, 2010; Ramirez, *et al.*, 2014) pointed out that facial skin color rendering is not associated with the current emotional condition of the human. A novel physical method for rendering color changes in skin has been created. This allowed a successful representation of emotions and hemoglobin fluctuations on the facial skin of virtual characters. Previous works focused only on the subsurface scattering to producing wrinkle, and skin texture but not physiological condition of the human. The main drawback is that the skin surface is not linked with the avatar's facial expression and the emotion.

This study attempts to answer the question of how the concentration of the oxygen (oxygenation) under facial skin affect the skin color of human which is transferable to the avatar to produce a realistic emotional expression. Based upon the problem background presented previously, the problem statement for this study is;

Physiological involvement including oxygenation of blood under skin that occurs during the certain emotional states is lacking in the existing avatar. The facial expression of avatar that is capable to representing the current emotional state by distributing the light scattering towards face area is not widely investigated in the past. There is a need to examine the influence of subsurface scattering that focus on lighting effect in the direction of skin color without considering directly the emotional states of human. It is important to calculate the blood oxygenation underneath skin to produce realistic emotional expression that synchronizes skin color and facial expression.

The following are the research questions to be explored in order to answer the above problem statement:

(i) How to generate realistic facial skin colors and emotional expression by considering blood oxygenation together with hemoglobin concentration?

(ii) How to apply the change of skin color for each expression to the avatar?

(iii) Which parameters must be adjusted to create realistic facial skin colors and emotional expressions?

(iv) How to develop a comprehensive model that successfully reproduces the actual skin changes for each facial expression?

1.4 Research Aim

The aim of this research is to improve the Light Scattering Rendering based on Oxygenation Absorption of Facial Skin to produce Realistic Facial Expression.

1.5 Research Objectives

Based on the research questions the following objectives are underlined:

(i) To improve the realistic facial skin color technique by incorporating the blood oxygenation and de-oxygenation process in addition to hemoglobin concentration that corresponds to light scattering.

(ii) To enhance the algorithm for generating facial expression model of 3D avatar based on the combination of Facial Action Coding System and Blend Shape Interpolation.

(iii) To propose a new technique that create realistic avatar using facial skin color and expression.

1.6 Research scope

Based on the proposed objectives the scopes of this research are as follows:

(i) The main aim is to generate the realistic facial color and emotional expressions related to the facial skin appearances changes including blushing, anger or even sadness. The Microsoft Visual C# language and Unity 3D Game Engine are used as programming tools.

(ii) Six parameters are used in this research which are the amount of oxygenation, de-oxygenation, hemoglobin, melanin, oil and blend factor for different types of melanin in the skin to generate a perfect match to specific skin types.

(iii) Pulse Oximetry and 3D skin analyzer are used to record the blood oxygenation levels responsible for changing facial skin color related to basic natural emotional expressions.

(iv) Four facial emotional expressions namely angry, happy, sad and fear based on (Popa *et al.*, 2009) in addition to the neutral facial expression are used to simulate realistic skin color.

1.7 Significance of the Study

The research on facial animation exponentially grows and appears to be more realistic in term of 3D facial data. Advanced laser scan and 3D tools has imparted further impetus to the production of complex facial model. However, techniques on the creation of facial expression based on emotion condition may provide more useful information in the development of computer aided animation systems. Facial skin color is one the most important parameters that contributes in augmenting the realism of facial expression. Furthermore, it is closely related to the emotions and inner feelings of human such as anger, sadness or even blushing. As mentioned above, the color of facial skin is a key indicator of expressions that is determined by scattering and absorption of light within the skin layers. The concentrations of two chromophores hemoglobin (Oxygenation and De-oxygenation) and melanin are responsible for color transformation associated in mimicking realism of avatar in virtual environment and serious game.

1.8 Thesis Outline

Chapter 2 discusses the fundamental theories, models, and methods related to previous works. Human Skin Coloring, Facial Color Appearance, Facial Animation Techniques, Critical Analysis on Facial Skin Color and Expression on the Facial Animation Model are emphasized in this chapter. Chapter 3 describes the adopted research design and methodology to fulfill the proposed objectives. This chapter also provides the various limitations of the earlier methods and how they can be overcome. Systematic approaches towards the problem solving on the cited topic are illustrated. Chapter 4 being the core of the thesis deals with the implementation details of the proposed method and the acquired results. The creation of realistic facial skin color and expression models, the combination of them to produce the realistic facial animation of virtual human are presented. The three objectives of the thesis are achieved here. Chapter 5 is all about the evaluation of the proposed model. This chapter builds an essence regarding the attractiveness of the proposed framework and its superior performance compare to the previous approach. Chapter 6 concludes the thesis and further outlooks originated from the present studies. This chapter clearly displays the achievement of the proposed objectives, main contributions, and the associated limitations.

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