Modelling Human Faces with Non-Contact Three-Dimensional Digitizer - Preliminary Results

Z. Majid, H. Setan, and A. Chong

Medical Imaging Research Group
Faculty of Geoinformation Science &Engineering
Universiti Teknologi Malaysia, 81310, UTM Skudai,
Johor, Malaysia
mirg@fksg.utm.my

Abstract

Currently, there are several methods that can be used for modeling and measuring of human face such as digital stereo photogrammetry, phase measuring profilometry and others. These methods were employed in medical applications for the modeling of human face soft tissue and measurement of anthropometric landmarks. Both data are required for the development of a craniofacial database in craniofacial reconstructive surgery. In this paper two laser scanners (i.e. three dimensional non-contact digitizers) were used to produce a three-dimensional model of human faces and measure anthropometric landmarks. The process comprises of four steps: scanning of human face, three-dimensional image registration, three-dimensional modeling of human face and measurement of anthropometric landmarks. The obtained anthropometric landmarks measurement then compared with the conventional measurement method using calipers. This study shows that the used of laser scanning system in modeling human face was found to be excellent and efficient

1. Introduction

The Human face is part of the human body that can be considered as a complex surface which includes different depth and texture. Several researches on the human face have been done world wide for medical applications. In medical application, facial reconstruction of craniofacial disorder (abnormal faces caused by born defect, accidents, etc) is one of the on-going research topics that required a modern and advanced technology for the three dimensional modeling of soft tissue and measurement of anthropometric landmarks. Several techniques such as digital stereo photogrammetry and coded light range digitizer have been developed to capture soft tissue data of the human faces.

D'Apuzzo N (2002) has developed an automated procedure to measure a human faces soft tissue by using a multi-image photogrammetric technique. The system which is consists of five charge couple device (CCD) cameras was setup in convergent mode was arranged in front of the subject. The projector was used to project a random pattern. This random pattern was used to facilitate the establishment of corresponding points. The frame grabber was used to digitize the data automatically and stored in the computer. From the study, the achieved accuracy of the 3D points is about 0.2mm in the sagittal direction and about 0.1mm in the lateral direction. According to the writer, the main advantages of the system are its flexibility, the reduced cost of the hardware and the possibility to perform surface measurement of dynamic events.

According to Hajeer (2002), many three-dimensional (3D) techniques have been utilized to register and analyze the human face in three dimensions, but each system has its own merits and disadvantages. From all the techniques, stereo photogrammetry have been selected as technique that provide more accurate evaluation of the human face and may adopt one or more stereo-pairs views to increase the number of 3D measurements that can be obtained to compute a 3D facial surface model. To avoid the errors that caused by the movement, the cameras that photographs from each side of the face are operated simultaneously or in other word, the cameras are synchronized. In this research, the writer proposed and designed a new 3D imaging system called a 3D non-contact vision-based imaging system. The designed of the system is based on stereo-photogrammetric concepts. This system is based on the use of stereo-pairs of digital cameras and special textured illumination which captured the facial features within 30 milliseconds and makes the system appropriate for imaging children and infants as well as adults. The accuracy of the system was evaluate by a comparison study of 3D coordinates (x,y,z) of specific landmarks digitized from on-screen 3D models for 21 plaster casts of cleft models with the 3D coordinates that derived directly from these model using a previously validated 3D contact ultrasonic measuring system. The average errors reported as below than 0.6 mm and will be an acceptable value for the study of facial soft tissue changes.

Siebert and Urquhart (1994) have reported on the development of a C3D System as known as a computer-based product for constructing 3D surface models of real world 3D object especially for human faces, from stereo image pairs. This system is based on photogrammetric concepts that applied Direct Linear Transformation (DLT) algorithm, so the user can configure the system to control the geometry of the cameras, i.e., vergence angle, baseline separation, relative orientation (RO), camera focal length and etc.

Mowforth et al (1995) described about the 3D imaging system that was setup for clinical application. For many clinical applications such as reconstructive surgery, orthodontic and maxillofacial surgery, burn area assessment as well as modeling for prosthetics and dental support, there is a requirement to capture an accurate record of both the outer 3D shape as well as the visual appearance. This research is based on photogrammetric technique where two cameras were used to capture stereo pair of images.

Siebert and Marshall (2000) described about the C3D technology that based on the speckle texture projection photogrammetry. C3D has been applied for the capturing all-round 3D models of the human body with high dimensional accuracy and photorealistic appearance. The chosen of the stereo photogrammetric technology as a base for the development of C3D system is because it is faster and consequently more suitable data capture method. Other advantages is easy to calibrate, give high measurement accuracy better that ±0.5mm RMSE on the face using TV resolution cameras, inexpensive hardware, inherently reliable with no moving parts and got a software principle component. Because the C3D system is a faster system on the data collection task, it is suitable for photographing babies and infants since they cannot remain perfectly still for more that a few second. The caused of the movement will effect the accuracy of the facial imaging (3D model development) and measurement of the anthropometric landmarks.

Hammond et al (2001) described a three-dimensional (3D) model of human faces for the delineation and visualization of congenital abnormality study. In this study, 62 children, whom 22 have a noonan syndrome, was scanned using a photogrammetric scanner TCTi DSP 400 to capture 3D facial shape and appearance and give the analysis data of those samples. The instantaneous of photographic scan is essential when capturing images of young children who do not remain sufficiently still for alternative laser-based capture. The surface geometry, typically involving between 4000 to 9000 vertices, and appearance can be view separately or in combination. In general, the DSP400 scanner can produces very good images.

Knyaz (2003) described about the used of close-range photogrammetric technique for an accurate photorealistic texture mapping for generating of metric 3D models including human faces and skull. Photogrammetric systems are usually include a set of cameras and structured light projector, which generates a special light pattern on the measured object. Structured light is used for automated correspondence problem solution. According to the writer, in order to get accurate 3D model of the object, the photogrammetric system should be calibrated. So far, the most adequate data for generating accurate textured 3D models is provided by calibrated photogrammetric systems using the same images for generating 3D model as well as textured mapping. This are the main advantages of the photogrammetric systems. The problem with others imaging system such as laser scanners is the lack of accurate textured mapping. Most of the research combined laser with photogrammetry for better data quality and accuracy.

Douglas et al (2002) reported on the use of the stereo photogrammetric tool and image processing algorithm to obtain and to extract eye features from digital photographs of 6-7 year old children for Fetal Alcohol Syndrome (FAS) screening. The camera used is Sony DKC-FP3 digital still camera mounted 104cm from the object. The camera are triggered simultaneously by remote control.

According to Kolar and Salter (1997), the laser scanning technology offers a fast, non- invasive way to collect a permanent database of three-dimensional surface contours of the face and head which can be saved for future study. The system used a light scan instead of radiation that has been used in conventional X-Ray system. For the development of the craniofacial databases, the used of laser scanning system is a better way of data collection since the databases involved with a big number of data.

Wilson et al(1997), have investigate the used of laser scanning techniques for quantifying changes in facial soft-tissue volume. From the study, three potential sources of error were identified: the registration algorithm, the inherent accuracy of the scanner and the natural minute-to-minute variability of the human faces. This three source of error is the most important factors that effect the accuracy of the measurement using a laser scanning system. The writer had conclude that the laser scanning system is a simple, non- invasive, accurate and reproducible of assessing changes in facial volume.

Cha et al (2003) investigated the possibility of clinically applying the laser scanning system for facial morphology analysis. The analysis involved with the 3D reverse engineering technology for the advance 3D analysis of orthodontic models. In this project, the scanning process was performed using the vivid 700 Minolta laser scanner with 400 x 400 pixels. These 3D laser scanners operating on a laser-light stripe triangulation range finder principle. The patient was instructed to sit still in a chair with facial muscles relaxed and eyes and lips lightly closed for 0.6 second during the scanning. The distance between laser scanner and the object (object distance) is 1.0 meter. The RapidForm software which was worked under professional reverse engineering concepts was than used to process the scan data in order to develop a 3D model of the patient's face. The face was scanned part-by-part and the initial and global registration method was used to superimpose the data to built-up the 3D model. In order to verify the applicability of the 3D method, diverse analysis was performed including volumetric and surface measurements.

According to Hasegawa et al (1999), one problem in face sensing is a measurement time. Obtaining a range image takes time compared to an intensity image. A patient must remain stationary during the measurement. This place a burden on the subject, but less attention has been paid. Even the measurement time is let say ten second, the patient unconsciously moves slightly and there will be an errors on the measurement results. To overcome the problem, this research proposed a new imaging system based on space encoding method with laser scanningtechnology.. Through this technology, the data of the human faces is collected in one second. The other advantages of the proposed system are obtaining both 3D shape and color texture of the face, occlusion-less measurement and provide high-speed measurement. The system consists of two laser scanners, one color CCD camera and a light source that setup in one platform. The output of the system is a solid 3D *model of human face with real texture with 512* x 242 pixels in resolution.

Evison (1999) described about facial reconstruction using a computer system. In this project, the laser scanning system is used to capture a 3D color digital image of the skull. The aim of the project is to develop a computer system which is accurate, rapid, repeatable, accessible and flexible. This project is done also in order to overcome the inaccurate of plastic surgery using the conventional method.

In this paper, we report on the use of three dimensional non-contact digitizer namely Minolta VIVID 910 laser scanning system series to acquire a complete and fast three dimensional human face model. The process comprises of four steps: scanning of human faces, three dimensional image registration, three-dimensional modeling of human face and measurement of anthropometric landmarks. The anthropometric measurement results obtained from this method were than compared with the conventional measurement method using calipers.

2. Minolta VIVID 910 Laser Scanner

Minolta VIVID 910 is the latest model of Minolta's VIVID family of 3D laser scanners. This laser scanning system was found ideal for various applications such as the quality control inspection of production parts, industrial design, rapid prototyping input, CAD reverse engineering, 3D shape capture of computer aided engineering analysis, machine vision, archiving, computer graphics and medical application such as surgical planning system in maxillofacial, dental and orthopedic, plastic surgery and measurement of anthropometric landmarks (www.minolta.com, 2004). Figure 1 shows the VIVID 910 3D laser scanner.

Figure 1 : Two units of Minolta VIVID 910 3D laser scanner

The Minolta VIVID 910 laser scanner operates using laser triangulation liht block method where the measured object is accurately scanned by a plane of laser light coming from the laser's source aperture. The basic and important component of this laser scanner is the light itself and the CCD camera. When the scanning process is started, the plane of light is swept across the field of view by a mirror and the laser light will be reflected from the surface of the scanned object. Then each scan line is observed by a single frame and will be captured by the CCD camera. All the related processes are running very fast where the entire area is captured in 2.5 second (fine mode) or 0.3 second (fast mode) depending on the user requirement and the number of the scanned data needed for the modeling of an object. If the complete modeling is required for an object, the rotating table will be used to make a scan at 60, 120, 180, 240, 300 and 360 degrees. This process will increase the time for the scanning. Capturing of one scan does not depend on the complexity of the scanned object.

The Minolta VIVID 910 laser scanner will provides point cloud data with over 300,000 connected points for fine mode scan and 78,000 points for fast mode scan. The scan data which consists of the point cloud and the color RGB texture information (provided by RGB filter) of the scanned object are captured with the same CCD camera in order to prevents having parallax error in the scanned data. The precision in depth measurement (Z) is recorded as ± 0.008mm in fine mode scan at the scanning accuracy in X, Y and Z is ±0.22mm, ±0.16mm and ±0.10mm respectively. The distance range between the scanner and the object is from 0.6 meter to 2.5 meter with scanning field of view between 111mm to 1196 mm in X direction and 83mm to 897 mm in Y direction. The origin (X0, Y0, Z0) of the scanning process is the scanner itself. Figure 2 shows the orientation of the axes relative to the scanner.

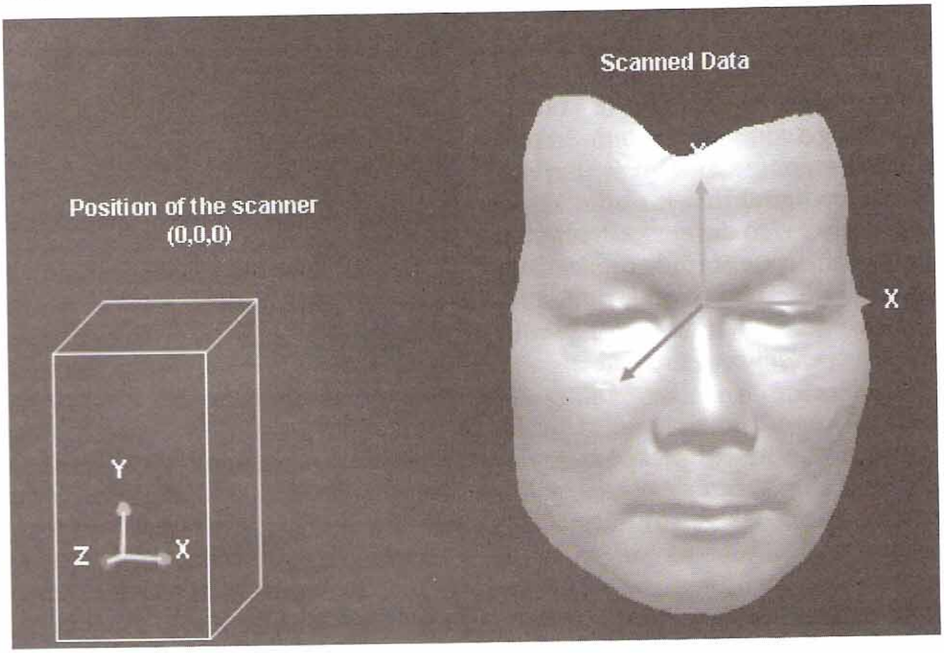


Figure 2 : The orientation of the axis relative to the VIVID 910 laser scanner

3. Methodology and Results
System Setup

In this research, two Minolta VIVID 910 laser scanners were setup 0.7 meter from the human face and setup at an angle of 90 degree (see Figure 3). Both scanners were controlled using a Polygon Editing Tools software and both images are shown side-by-side on the monitor. The scanning process was performed one after another. The first scanner was setup to be in disable mode while the other scanner was setup in enable mode. This process was needed to prevent having scanning errors.

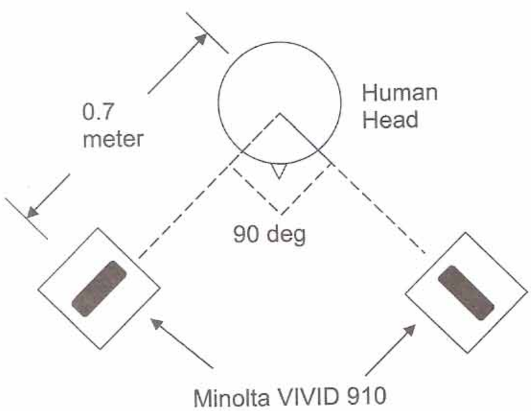


Figure 2 : The Setup of the Laser Scanning System.

Scanning of human face

The Minolta VIVID 910 laser scanner can be used to scan human faces using two methods namely the fine mode and the fast mode with three types of exchangeable lenses (i.e. tele, middle and wide). In this research the wide lens was used because the scanning distance is less than 1.0 meter. The fine mode scan could produce 3D data of 307,000 pixels while for the fast mode method it could be produce to 76,800 pixels with 640 x 480 x 24 bits color depth. Both scanning methods records RGB color texture information of the scanned object and for precise anthropometric landmark measurement, the fine mode scan is suggested. The scanning process can be done either in on-line or in off-line mode. In on-line mode, both scanners are controlled by a computer while in off-line mode, the scanning process was done using the capture button on the scanner itself. The scanned data are stored in the compact flash memory card. The card is than read using any card reader to transfer the 3D scanned data into the computer for the modeling process. Figure 3 shows the scanning process using Minolta VIVID 910 laser scanner and Figure 4 shows the scanning output from the two synchronized laser scanners.

Figure 3 : The Scanning Process

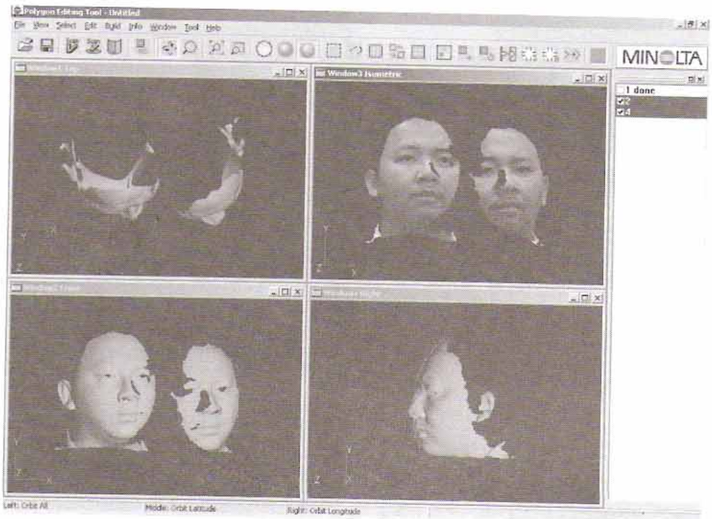
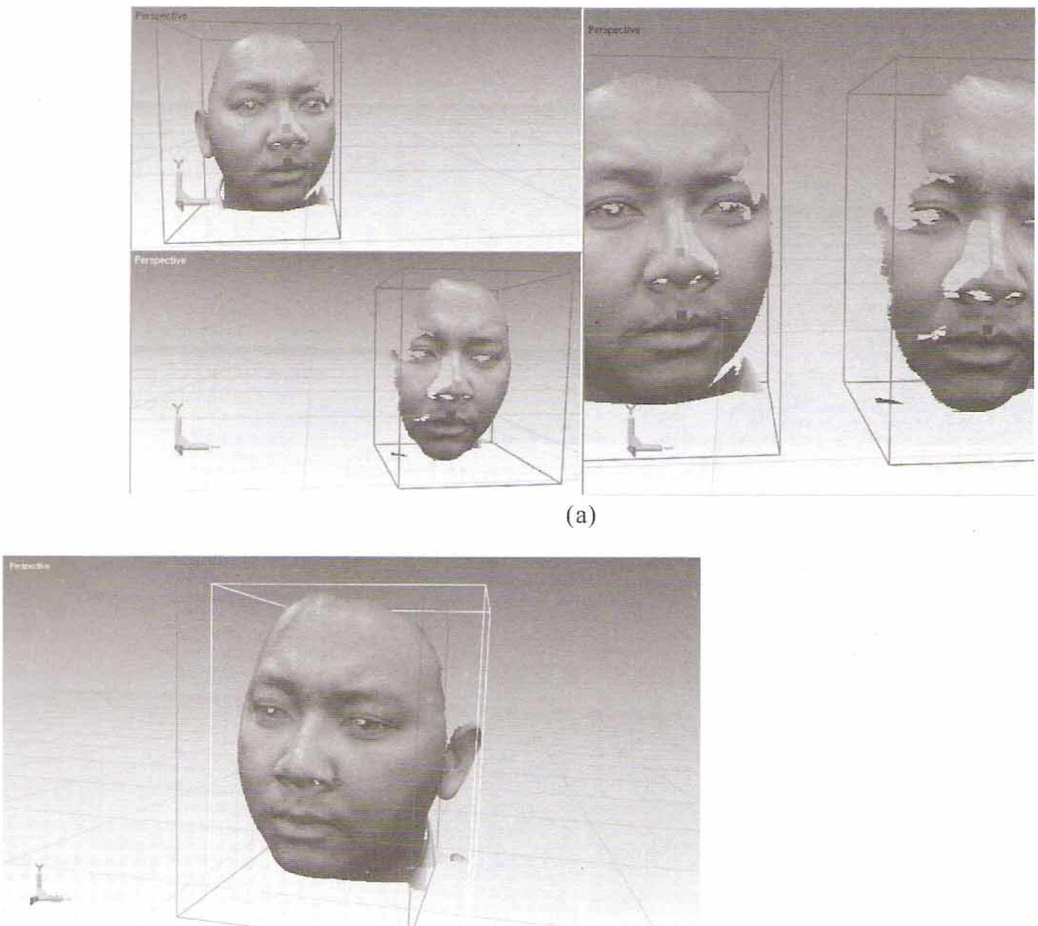


Figure 4 : The Scanning Output

In on-line mode, the scanning process can either be controlled using Polygon Editing Tool software (i.e. a software package that come along with VIVID scanner) or by using RapidForm 2004 software which is a third party software. In this research, the on-line scanning process was done using Polygon Editing Tool software, while modeling was completely done using RapidForm 2004 software. The results shown in Figure 4 we scanned using Polygon Editing Tool software.

Three-dimensional Image Registration and Merging Process

In order to obtain a preliminary three-dimensional model of the scanned face, both left and right scanned data were registered using RapidForm 2004 software. This software offers an initial image registration which based on three corresponding points that can be selected manually on the scanned images. After selecting three corresponding points, the registration process runs automatically. The merging process involves the merging of 3D scanned data and the face textures. Figure 5 shows the image registration process using RapidForm 2004 software and the merging output.



(a)

(b)

Figure 5 : Three-dimensional Image Registration Using RapidForm 2004 Software : (a)selection of three corresponding points, (b) the registration result

Three-dimensional editing and modeling

The Minolta VIVID 910 laser scanner is sensitive to black features and generates error (noise) in the three diensional model. The error caused by the dark areas shows as hole in the polygon mesh (see Figure 7). The Polygon Editing Tool software is capable of findings holes and eliminates them by adding new points and polygons, so that the local curvature of the mesh along the voundary of the hole is preserved. For human face, the error could come form the hair, eye brows, eye balls, beard and mustache. Figure 6 shows the error of the scanned data.

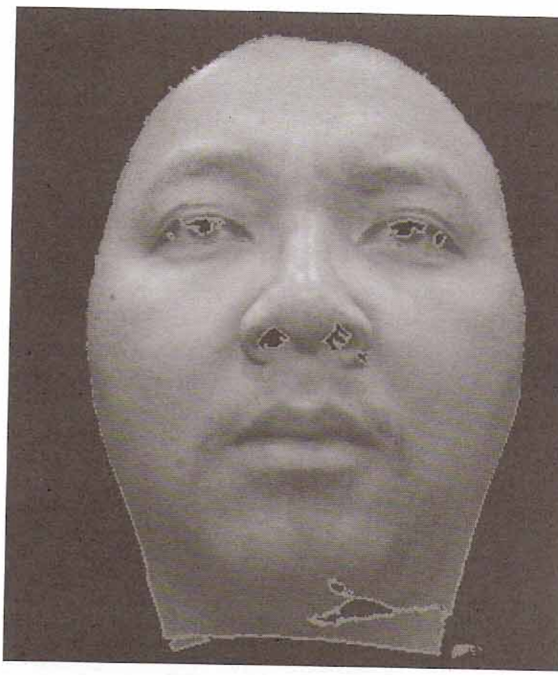


Figure 6 : Scanning Error On Human Face

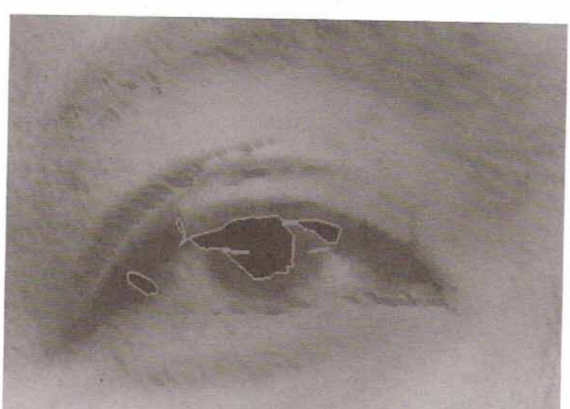


Figure 7 : Detection of scanned errors caused by unregistered areas

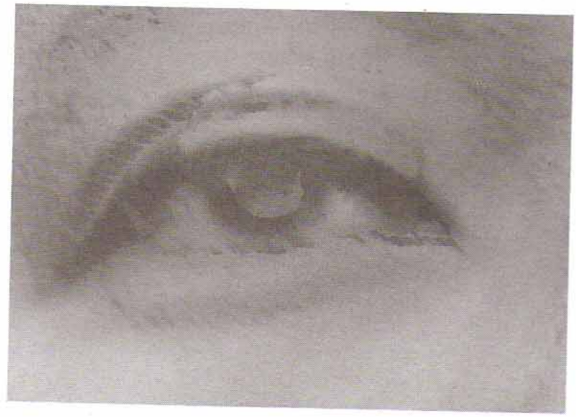


Figure 8 : Correcting of scanned errors

Measurement on 3D model

In craniofacial surgical planning, the measurement of soft tissue data (anthropometric measurement) is required. The human face soft tissue consists of 46 anthropometric landmark points where each point is located on different part of the face. Figure 9 shows some of the anthropometric landmarks that are generally used in surgical planning process.

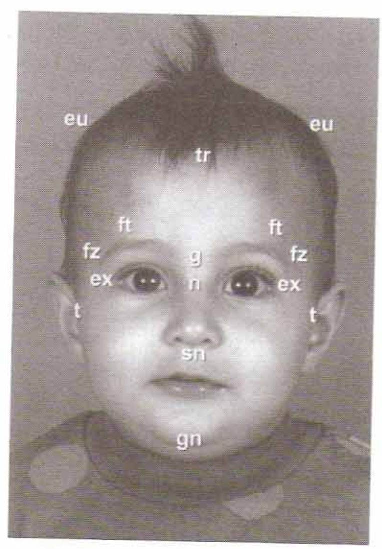
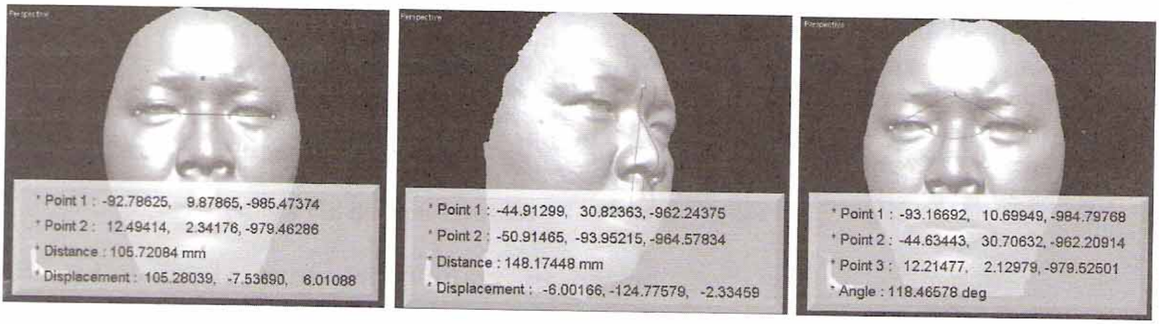


Figure 9 : Some of the Craniofacial Anthropometric Landmarks

In normal practice, a surgeon will use conventional method such as tape, spreading caliper, sliding caliper, level and angle finder to measure straight and curve distances.

The disadvantage of this method is that it uses contact measurement where the surgeon need to touch the patient's face in order to obtain a measurement. In term of measurement, the RapidForm 2004 software offers an intelligent facilities where the user can measure distance (directly or along the surface measurement), radius and angle on the three dimensional model in automatic mode. The measurement can be done from point to point mode (single measurement) or by registering the ID of the points using Automatic Measure function (see below). Figure 10 shows the single measurement facilities in RapidForm 2004 software.



(a) (b) (c)

Figure 10 : Measurement using RapidForm 2004 software : (a) straight line (direct) measurement, (b) measurement along the surface and (c) measurement at an angle

The Automatic Measure function in the RapidForm 2004 software allowed the user to set a database for measurement of anthropometric landmarks. With this function, the user has to identify the landmark on the 3D model and supply its reference ID (see Figure 11). Figure 12 shows the results of measuring using automatic mode. The results than can be saved in the database.

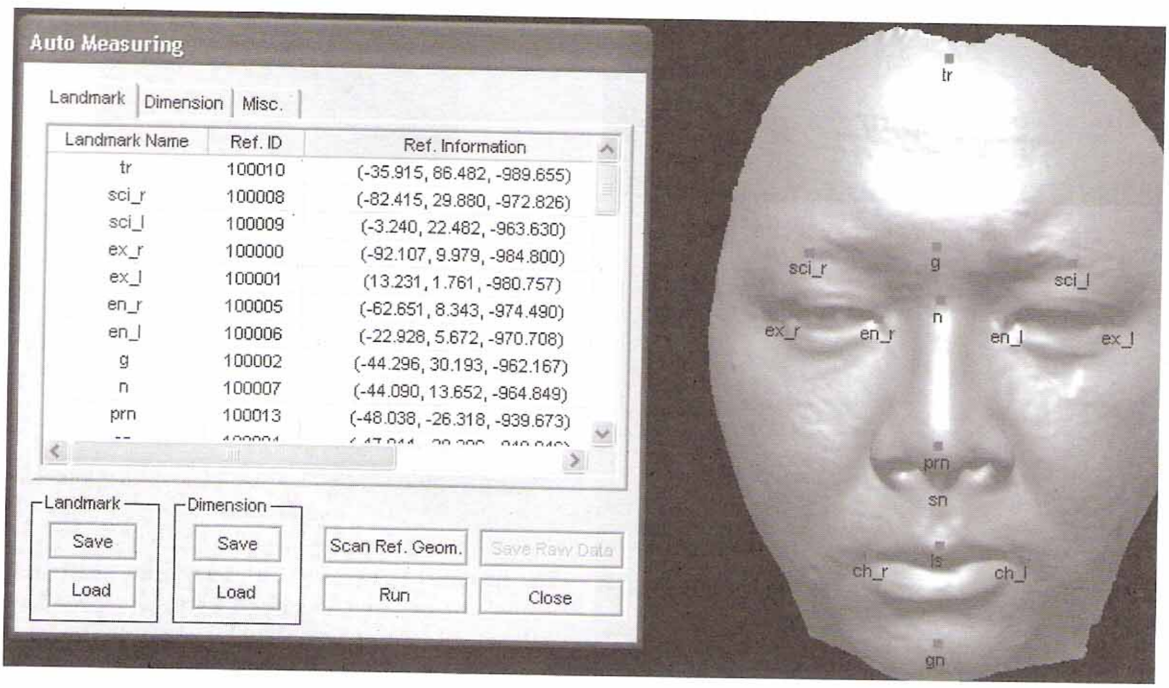


Figure 11 : Identified landmarks and reference ID's

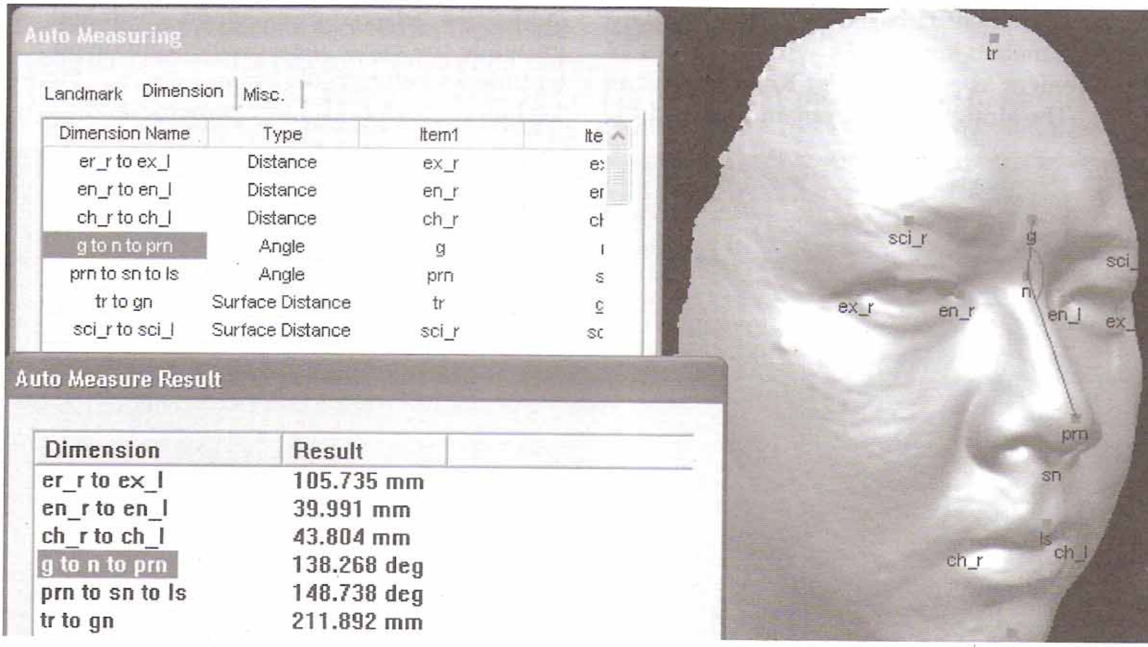
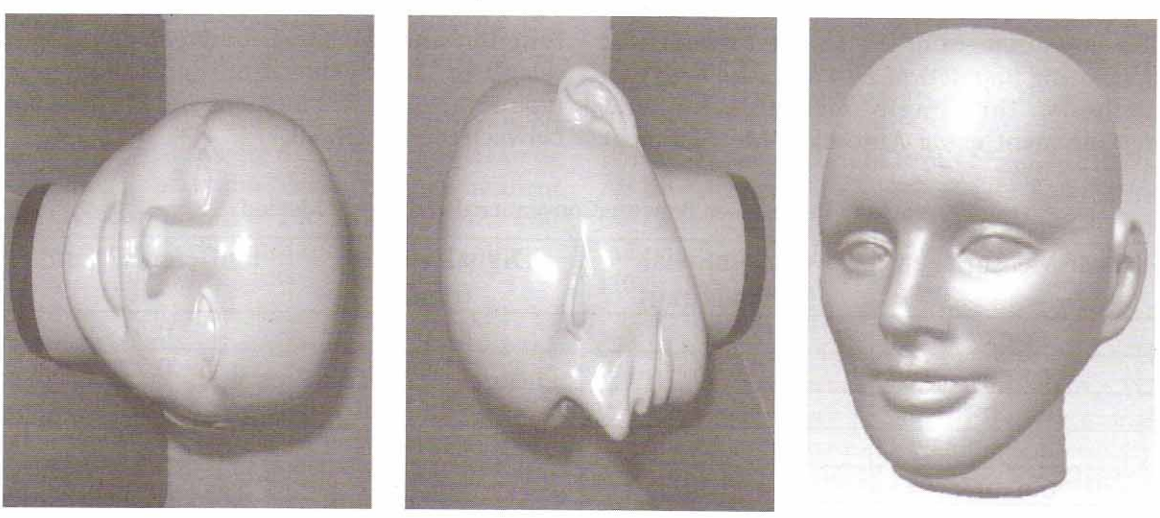


Figure 12 : The Automatic Measurement Results

Validation study between conventional and digital method

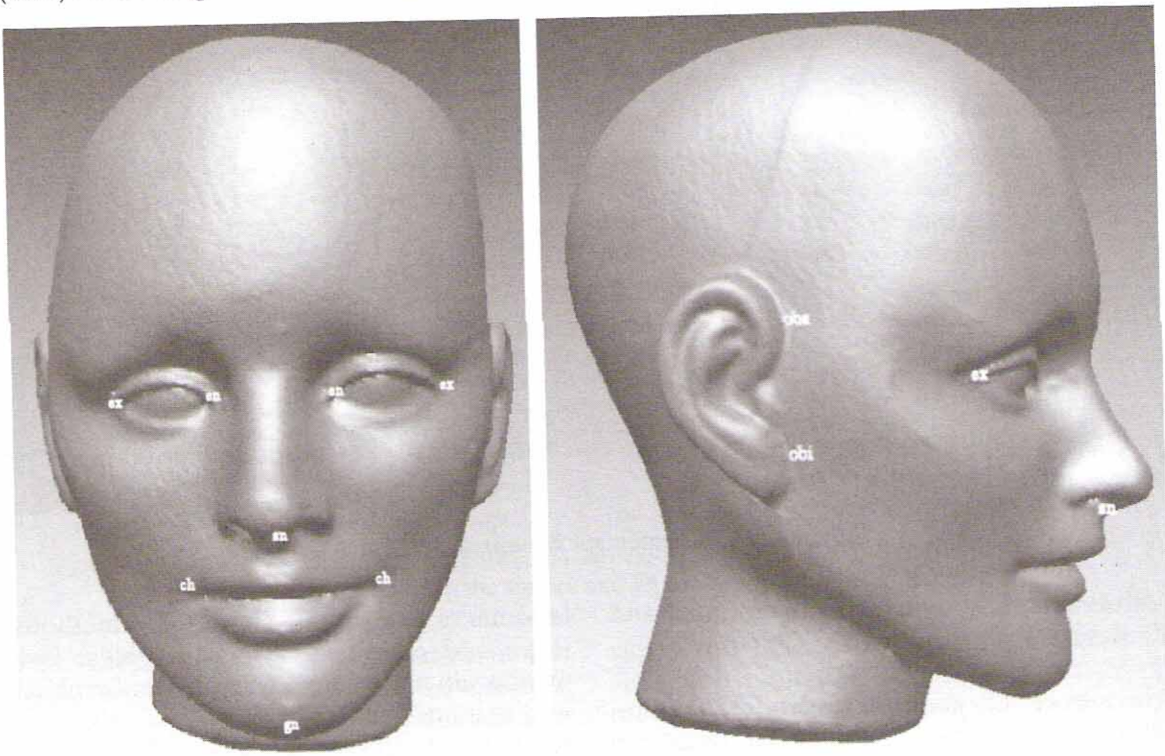
The aim of this study is to validate the non contact measurement method (i.e. using the laser scanner) using the straight and curve distances between anthropometric landmarks. The results obtained from this study were than compared with the results of the same object and landmarks using the conventional methods (tape and calipers). The test object is a mannequin of the human head. The test object was scanned using Minolta VIVID 910 laser scanner at six different angles in order to obtain a complete three dimensional model. Figure 13 shows the mannequin and the complete three-dimensional scanned model.



(a) (b) (c)

Figure 13 : Test Object : (a) and (b) Physical Model of a Mannequin, (c) Three dimensional Scanned Model of the Mannequin

The measurement is based on seven standard anthropometric landmarks with six types of measurement as suggested by Kolar and Salter (1997). The straight measurement involved the landmarks between ex-ex, en-en, ch-ch and sn-gn while the curve measurement involved the landmarks between obi-sn and obs-ex. Figure 14 shows the selected anthropometric landmarks.



(a) (b)

Figure 14 : Selected Anthropometric Landmarks for the Measurement Test : (a) direct measurement and (b) curve measurement

The measurement of the scanned model was done using RapidForm 2004 software with two methods; the single measurement and measurement using Automatic Measurement function and the mean between them was calculated. Table 1 shows the results of different type of measurement methods and the different between these methods.

Table 1 : Comparison Between Conventional and Digital Method

Linear Measurement	Conventional Method (mm)	Digital Method (mm)	Difference (mm)
ex-ex	81.95	81.44	0.51
en-en	31.95	31.73	0.22
ch-ch	48.45	48.63	-0.18
sn-gn	44.15	44.91	-0.76
obi-sn	109.50	108.93	0.57
obs-ex	60.50	60.57	-0.07

The difference values that showed in Table 1 are calculated between the conventional method and average of the single measurement and automatic measurement methods. The project accuracy requirement was 0.7mm. However, from the table we can see that the difference between the conventional and the digital technique was less than 0.7mm. Therefore, the accuracy of the digital technique satisfies the project requirement. In other words, the laser scanning method can be considered as an excellent method for modeling and measuring human faces. The differences in measurement results could be caused by incorrect digitization of the points (digitizing errors) and incomplete three-dimensional model of some parts of the face. In general, these problems could be solved by identifying correct position of the landmarks by craniofacial experts with the accuracy of ±0.2mm.

4. Conclusion and further works

The used of laser scanning system in modeling human face was found to be excellent and effective. In general, the laser scanning system can be classified as real-time modeling system where the three-dimensional model can be seen directly after the scanning process. One of the disadvantage of the Minolta VIVID 910 laser scanner is that it is sensitive with black feature such as eye-ball, hair, eye-brow and etc, however using the editing functions provide the RapidForm software, these problems could be improved by 70% and the results is closed to real object texture. The scanned images also proved to be 1:1 in scale where the measurement can be done directly and subsequently the measurement can be compared with the conventional measurement techniques such as using calipers.

Further work on this research will be concentrated on the texture mapping of the scanned face using stereo images produce using close-range photogrammetric method. For this task, the patient need to contribute in both scanning and photographing process. To avoid error due to the movement of the object, the laser scanners and the stereo cameras will be synchronized so that they could operate simultaneously.

Acknowledgement

On behalf of Medical Imaging Research Group, Faculty of Geoinformation Science and Engineering and University of Technology Malaysia, we would like to acknowledge the Ministry of Science, Technology and Innovation (MOSTI) Malaysia for the grant and Mr Cheong Beng Huat from Minolta Singapore Pte Ltd for helping us on the scanning and modeling the object. Finally, thanks to individuals in the group.

References

D'Apuzzo N (2002), Modeling Human Faces with Multi-Image Photogrammetry, Three-Dimensional Image Capture and Application V, Proc. Of SPIE, San Jose, California, 2002, Vol. 4661.

Hajeer M.Y (2002), Three-dimensional imaging in orthognathic surgery : The clinical application of a new method, International Journal of Adult Orthodontic Orthognathic Surgery, Vol. 17, No. 4, 2002.

Siebert J.P and Urquhart C.W (1994), C3D : a Novel Vision-Based 3D Data Acquisition System, Proceedings of Monalisa Workshop, Hamburg, 1994.

Kolar J.C and Salter E.M (1997), Craniofacial Anthropometry : Practical Measurement of the Head and Face for Clinical, Surgical and Research Use, Charles C Thomas Publisher Ltd.

Wilson I, Snape L, Fright R and Nixon M (1997), An Investigation of Laser Scanning Techniques for Quantifying Changes in Facial Soft-tissue Volume, New Zealand Dental Journal, 93(414) : 110-3, Dec. 1997.

Cha B.K, Lee J.Y, Cho T.H, Bae S and Lim H (2003), Orthodontic Application using 3D Reverse Engineering Technique : 3-dimensional facial profile evaluation by National Dentistry Association of Korea, http://www.rapidform.com/success/success_3_2.htm.

Mowforth P, Ayoub A, Jin J, Moos K, Niblett T, Siebert P, Urquhart C and Wray D (1995), A Three-dimensional Imaging System for Clinical Applications, The Turing Institute.

Siebert P.J and Marshall S.J (2000), Human Body 3D Imaging by Speckle Texture Projection Photogrammetry, MCB University Press, ISSN 0260-2288, Vol.20, No.3, 2000, pp. 218-226.

Hammond P, Hutton T.J, Allanson J.A, Shaw A and Patton M (2001), Delineation and Visualization of Congenital Abnormality using 3D Facial Images, presented at Intelligent Data Analysis in Medicine and Pharmacology, IMIA Wg3 Workshop at MEDINFO, 2001, London.

Hasegawa K, Hattori K and Sato Y (1999), A High Speed Face Measurement System, Vision Interface 1999, Trois-Rivieres, Canada.

Evison M.P (1999), Computerized 3D Facial Mapping, First International on Forensic Human Identification, London, 23-26 October 1999.

Knyaz V.A (2003), Accurate Photorealistic Texture Mapping for Metric 3D Models, State Research Institute for Aviation System, Moscow, Russia, 2003.

Douglas T.S, Martinez F, Meintjes E.M, Vaughan C.L and Viljoen D.L (2002), A Photogrammetric Method For The Assessment of Facial Morphology in Fetal Alcohol Syndrome Screening, ISPRS Commission III Symposium 2002, Photogrammetric Computer Vision, September 9-13, 2002, Graz, Australia.