

INTEGRATION OF STEREPHOTOGRAMMETRY AND TRIANGULATION-BASED LASER SCANNING SYSTEM FOR PRECISE MAPPING OF CRANIOFACIAL MORPHOLOGY

Z.Majid^a, H. Setan^a, A. Chong^b

^a Faculty of Geoinformation Science & Engineering, University Technology Malaysia - zulkepli@fkg.utm.my

^b School of Surveying, University of Otago, Dunedin, New Zealand - albert.chong@surveying.otago.ac.nz

Commission V, WG V/6

KEY WORDS: Photogrammetry, Laser Scanning, Integration, Medicine, Precision

ABSTRACT:

The paper describes the first Malaysian Craniofacial soft tissue 3D imaging system which was developed based on the integration of stereophotogrammetry and triangulation-based laser scanning system. The main purposes of developing the imaging system are to provide a non-contact method for craniofacial anthropometric measurement and fast and radiation free 3D modelling of craniofacial soft tissue. The stereophotogrammetric system consists of high resolution digital cameras setup as three stereo cameras placed at the left, front and right sides of the patient. The system was also add-up with another extra two digital cameras setup in convergent mode at bottom left and bottom right of the patient. The combination of all the cameras allowed for the accuracy improvement of craniofacial anthropometry through a novel technique called "natural features technique". In the natural features technique, the images acquired from the camera system were used to digitize the natural features on the human face. Photogrammetric triangulation method was used to calculate the 3D coordinates of the features. The cameras was highly synchronized (0.2miliseconds) using a new external shutter controller. The stereophotogrammetric system was designed to be operated in battery system for mobile data capturing purposes. Apart from the camera system, the developed stereophotogrammetric system was completely designed with the object space control frame. The new patient's chair and photogrammetric control frame has been designed and developed. The object distance is 700mm. Special-built camera calibration device was designed and developed to calibrate each camera individually. The camera was placed at the camera platform to capture eight convergent images of the 3D test field. The self calibration bundle adjustment process was carried out using Australis software to calculate the calibration parameters. The developed stereophotogrammetric system was integrated with the triangulation-based laser scanning system. Two eye-safe Minolta VI-910 laser scanners was setup at right and left side of the patient and near to the stereophotogrammetric system with object distance of 1000mm. For the purposes of scanning the craniofacial morphology, the scanners was setup with middle lens (focal length = 14mm) and fine mode resolution with one scan mode. The scanners scanned one after another with 19 seconds scan period (complete scan). With the optimum setup, two scan images was acquired which covered the craniofacial area (from right ear to left ear and the hair line to bottom part of the chin). The texture data of the craniofacial area was also captured. Both scanners were calibrated using calibrated object. In the data collection session, the patient sited on the chair with the head placed at the middle of the control frame. The complete system was firstly tested using mannequin to determine the accuracy and precision. Both stereo images and scans data was processes separately. The DVP digital stereophotogrammetric workstation was used to carry out the photogrammetric orientation of the stereo images. The vectorization module was used to measure the 3D coordinates of the craniofacial landmarks. The laser scan datasets involved with few data processing steps which included the registration process, merging process, editing process, smoothing process and texturing process. The processing tasks were carried out using the RapidForm 2004 software. At final stage, the craniofacial landmarks measured from stereophotogrammetric system were registered onto the 3D model developed from the laser scanners. The research also involved with the development of the craniofacial database system which used to store the captured datasets. The results show that both stereophotogrammetry and laser scanning system was an effective system to be used in craniofacial mapping. Both systems provide high accuracy non-contact measurement method. The accuracy of the craniofacial landmark measurement is 0.2mm with one standard deviation, while the accuracy of the 3D model is 0.3mm with one standard deviation.

1. INTRODUCTION

1.1 Introduction

A prototype craniofacial imaging system has been developed in the study. As 3D photogrammetry system for acquiring craniofacial spatial data, the developed system completely consisted of *data acquisition system* and *data reduction system*.

2. CRANIOFACIAL SPATIAL DATA ACQUISITION SYSTEM

2.1 General

The developed prototype craniofacial spatial data acquisition system is the combination of two 3D photogrammetry systems namely stereophotogrammetry and 3D laser scanner. The prototype system also involved with the special built object space control. The object space control consists of special built craniofacial chair and calibrated photogrammetric control frame. Figure 1 show the conceptual design of the system, while Figure 2 shows the physical design of the prototype system.

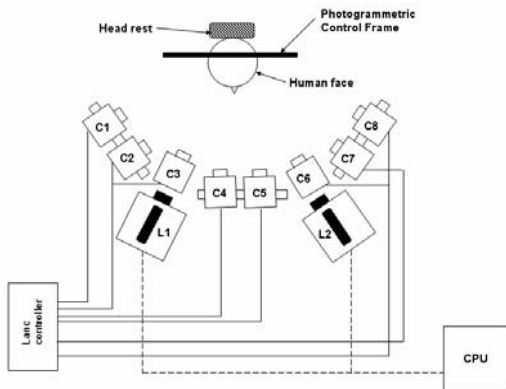


Figure 1. Craniofacial Spatial Data Acquisition System – Conceptual Design

In Figure, C1 to C8 shows the location of camera 1 to camera 8, while L1 and L2 show the location of laser scanner 1 and laser scanner 2 (Figure 3). Camera 3 and camera 6 (Figure 4) was setup in convergent mode at lower position to allow the scanner to emit the laser light onto craniofacial surface. Both cameras were also rotated 90° to allow the implementation of role diversity rule in the system.

The approach implemented in the developed system is unique. Existing and previous data acquisition system for modelling and measuring human faces does not involve with the integration or combination of more than one system. Most of the system only implement one sensor either stereophotogrammetry or 3D laser scanner. The combination of the two system will enhanced the accuracy, geometry and visual quality of the craniofacial spatial data.

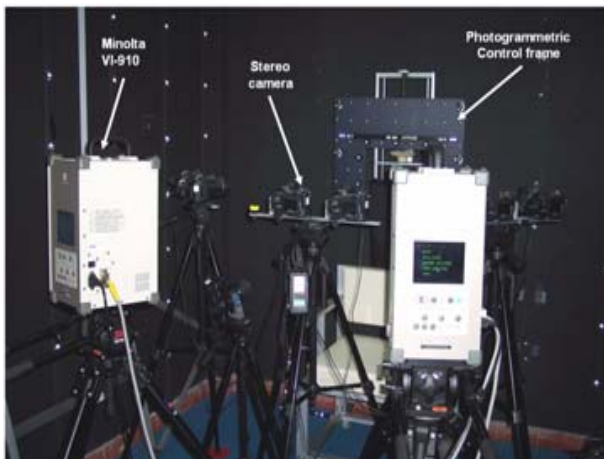


Figure 2. Craniofacial Spatial Data Acquisition System – Physical Design

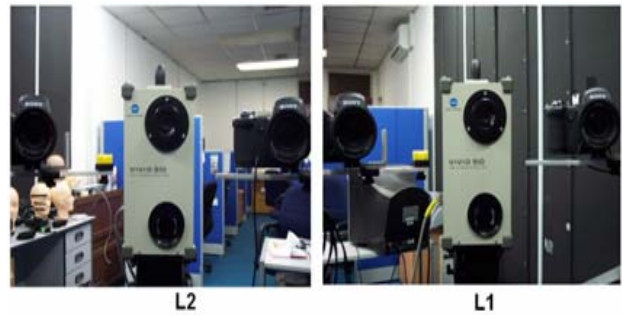


Figure 3. The location of laser scanner L1 and L2



Figure 4. The location of camera C3 and camera C6

Both sensors (stereocameras and 3D laser scanners) were operated one after another. The stereocamera system was operated using battery while the scanner was operated via computer and Polygon Editing Tools (PET) software. The details information regarding the system is discussed below:

2.2 Stereophotogrammetric System

The objective of having a stereophotogrammetric system in the prototype system is to acquire high resolution stereo images of craniofacial morphology. The implementation of the system followed the basic stereophotogrammetry operation that has been applied in aerial photo mapping. The developed stereophotogrammetric system consists of eight high resolution (8.0 Mega Pixels Sony DSC F828 – as in Figure 5) professional digital cameras. Six of the cameras were setup in stereo mode with calculated stereo base distances. The six cameras captured 70% stereo-overlapping images and setup 800mm in-front of the patient. The last two cameras was setup in convergent mode to capture two convergent images. The cameras were control and synchronized using new special built camera lanc controller (as in Figure 6). The user can switch on/off and release the shutter of the camera easily using the controller. All the cameras can be accurately synchronized within 0.2 milliseconds. The stereo and the convergent images of the craniofacial morphology was stored in the compact flash memory card and was downloaded into CPU using multi-card reader device for further processing tasks.



Figure 5. The Sony CyberShot F828 professional digital camera



Figure 6. External shutter device to control the stereo cameras

The cameras were setup at 200mm stereo base distance with 70% stereo overlapping area. The camera system was setup at 700mm object distance (distance between camera to subject). Table 1 shows the full specifications of Sony DSC F828 professional digital camera.

| | |
|-----------------------|--|
| Imaging Device | 2/3" 8.0 Megapixel Effective Super HAD™ CCD |
| Recording Media | Memory Stick® Media, Memory Stick PRO™ Media, Microdrive and CompactFlash® Type I/II Media |
| Zoom | 7X Optical, 2X Digital, 0 -5X Smart Zoom™ Feature1, Up to 35X Total Zoom1 |
| Filter Diameter | 58mm |
| Focal Length | 7.1mm – 51mm |
| 35mm Equivalent | 28mm – 200mm |
| Aperture | f2.0 – 2.8 |
| Shutter Speed | Auto (1/8–1/3200 sec), Program Auto (1–1/3200 sec) Shutter Priority (30–1/2000), Manual (30– 1/3200) |
| Manual Exposure | ±2.0 EV, 1/3 EV Step |
| Color LCD | 1.8" 134K Pixels Low Temperature Polysilicon TFT |
| Eye-Level Finder | Hi-Speed TTL 0.44" 235K Pixels Precision TFT LCD |
| Flash Modes | Auto/Forced On/Forced Off/Slow Synchro |
| Flash Effective Range | 19 3/4" - 14' 9 3/4" (0.5m - 4.5m) |
| White Balance | Auto, Daylight, Cloudy, Fluorescent, Incandescent, Flash, One-Push Manual |
| Picture Effects | Solarize, Sepia, Negative Art |
| Still Image Modes | JPEG (Fine/Standard), TIFF, RAW, Burst, Auto Bracketing, Email, Voice Memo |
| USB Terminal | Supports USB 2.02 High Speed |
| Battery Type/Capacity | InfoLithium® NP-FM50 1180mAh Rated |
| Dimensions | 5 5/16" x 3 9/16" x 6 3/16" (134.4 x 91.1 x 156.7mm) |
| Weight | 2.12 lbs (955g) with accessories |

Table 1. Sony Cybershot F828 full specifications

2.3 Three dimensional (3D) Laser Scanning System

The basis idea to involve the 3D laser scanning system in the development of craniofacial spatial data is to capture the craniofacial surface model in fast and high accuracy data

capturing mode. The 3D surface laser scanning system was generally designed in two method of operations; time flight method and triangulation method. For short distance scanning case (like scanning human face), most of the 3D laser scanners in the market was design and built using the triangulation method. The triangulation method is based on triangle concept that linked the laser device, charge couple device (CCD) camera and the scanning object.

After the initial evaluation of a few laser scanning products, the Minolta VI-910 3D laser scanner (as in Figure 7) was selected and two of these scanners were used to scan the whole craniofacial area. Each of these laser scanners emits an eye safe Class I laser (FDA) with $\lambda=690\text{nm}$ at 30mW with an object to scanner distance of 600-2500mm. The scanner can be operated in two types of scanning modes; fast mode and fine mode. The fast mode scanning period is 0.3s while the fine mode scanning period is 2.5s. Minolta VI-910 used charge couple device (CCD) camera that can acquire 300,000 3D data points (fine mode scan) and 78,000 3D data points (fast mode scan). The scanner output data is the 3D surface of scanning object with 640 x 480 pixel RGB texture data. The scanner provide three types of CCD lenses with different focal length(f); wide(f =8mm), middle (f =14mm) and tele(f =25mm). The chose of the lens normally based on the size of the object to be scan and the object distance. Both scanners were setup at 1200mm from the patient. Table 2 show full specifications of VI-910 laser scanner.



Figure 7. The Minolta VI-910 3D laser scanning system

The Minolta VI-910 can operate the scanning job in two modes of measurements either “on-line” mode or “off-line” mode. The “on-line” mode allowed the user to control the scanners from the computer via Polygon Editing Tool (PET) software (software that purchased along with the scanner system). The scanning data can be stored directly to hard disk. While the offline scanning approach allowed the user to scan object by using the built in scanning button designed at the back of the scanner and the scanning data was stored in the memory compact flash card and can easily downloaded using digital card reader that available in the market. For the purposed of capturing craniofacial 3D spatial data, the on-line measurement mode was used, look forward that the job was done in the laboratory (Figure 8).

| | |
|--|--|
| Model | Non-contact 3D digitizer VIVID 910 |
| Measurement method | Triangulation light block method |
| Light-receiving (Exchangeable) lenses | TELE: Focal distance $f=25mm$ MIDDLE: Focal distance $f=14mm$ WIDE: Focal distance $f=8mm$ |
| Scan range (depth of field) | 0.6 to 2.5m (2m for WIDE lens) |
| Optimal 3D measurement range | 0.6 to 1.2m |
| Laser class | Class 2 (IEC60825-1), Class 1 (FDA) |
| Laser scan method | Galvanometer-driven rotating mirror |
| X-direction input range (varies with distance) | 111 to 463mm (TELE), 198 to 823mm (MIDDLE), 359 to 1196mm (WIDE) |
| Y-direction input range (varies with distance) | 83 to 347mm (TELE), 148 to 618mm (MIDDLE), 269 to 897mm (WIDE) |
| Z-direction input range (varies with distance) | 40 to 500mm (TELE), 70 to 800mm (MIDDLE), 110 to 750mm (WIDE/FINE mode) |
| Accuracy | X: $\pm 0.22mm$, Y: $\pm 0.16mm$, Z: $\pm 0.10mm$ to the Z reference plane (Conditions: TELE/FINE mode, Konica Minolta's standard) |

Table 2. Full specifications of VI-910 3D Laser Scanning System

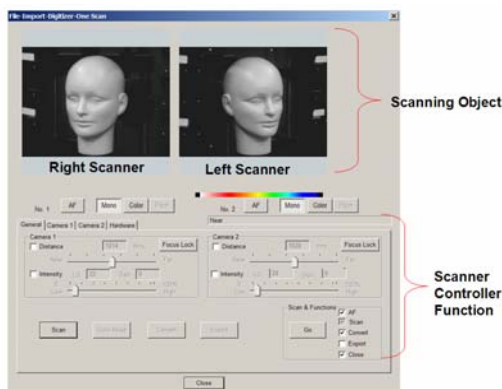


Figure 8. "On-line" scanning mode using PET software

The on-line scanning mode offered by the PET software was operated using "Import Digitizer One Scan" interface. The interface window was divided in two parts, namely the view of scanning object and the scanner controller function (Figure 8). In the first part, the scanning object from both laser scanners was displayed. The second part allowed the user to control both scanners to performed scanning task. If the scanning project required the used of two VI-910s 3D digitizer system,

the basic information of both laser scanners was shown in the "Hardware" module (Figure 9 and Figure 10). The setting of the scanning mode for each laser scanner can also be done using "Camera 1" and "Camera 2" modules.

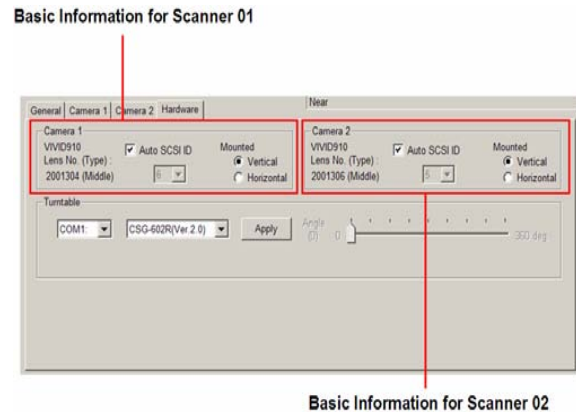


Figure 9. Basic Information of Both Laser Scanners in the "Hardware" Module

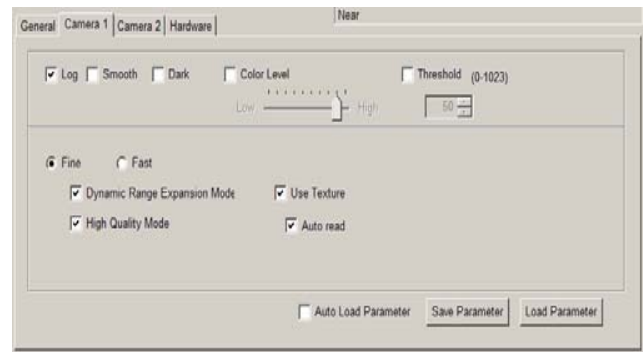


Figure 10. The Setting of the Scanning Mode for each Laser Scanner using "Camera 1" and "Camera 2" Modules.

The interface also provided the preliminary scanning accuracy information by colour coding method (Figure 11). The function was fully utilized just after the scanning task finished. The accuracy was early evaluated using the colour coding scale which shows the effectiveness of the scanning on the surface of the object.

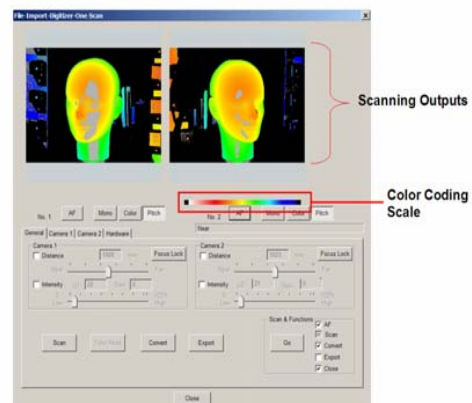


Figure 11. Preliminary Scanning Accuracy Information by Colour Coding Method

2.4 Object Space Control Frame

The 3D object space control is an important part in the development of craniofacial spatial data acquisition system. The 3D object space control consists of a special designed chair with adjustable head rest and high accuracy photogrammetric control frame. The photogrammetric control frame used to provide high accuracy 3D ground control to the stereo images via signalized retro-reflective targets. Figure 12 shows the side view of the photogrammetric control frame.

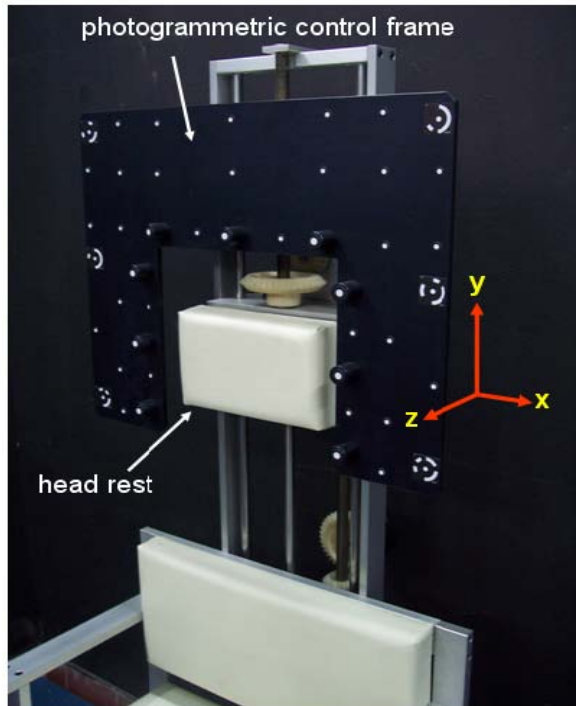


Figure 12. Object space control frame

The photogrammetric control frame requires photogrammetric calibration in order to determine the 3D coordinates of the paper targets. To calibrate the control frame four or more convergent photographs are taken with a high precision invar scale bar placed in the middle of the control frame. A bundle adjustment process is needed to determine the 3D coordinates of the targets. It is not necessary to have any previous known control point in the adjustment as in the case of an absolute orientation of a stereo-model. During data collection process, the patient will sit down on the chair with the head placed at the middle of the photogrammetric control frame. The level of the eye is parallel to x-axis and z-axis (Figure 13).

The photogrammetric control frame consists of 39 control points with 6mm diameter paper targets and 6 photogrammetric coded targets arranged in grid form. The big number of control points is fully needed to increase the accuracy of relative orientation of the stereo images, where all the points were digitized accurately. The control frame can be moved precisely using built-in moveable gear along the y-axis.

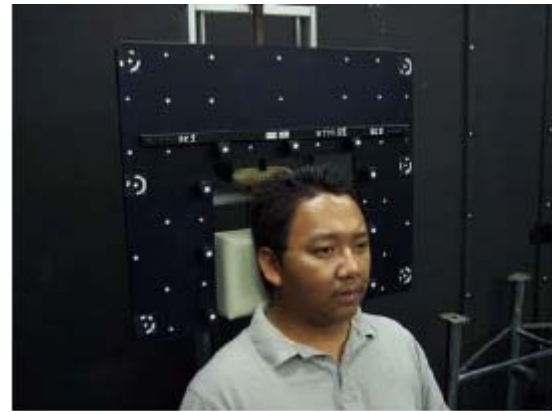


Figure 13. The position of patient's head during data acquisition

2.5 The Craniofacial Raw Datasets

As mentioned elsewhere in the report, the data collection task involved the collection of two types of craniofacial spatial data, the stereo images and the 3D laser scan surfaces. This means that for each individual that involved as samples or/and populations was photographed using stereo camera and scanned by using the laser scanners. The data collection process was done one after another where most of the cases, the stereo images were captured first because the data collection period of the stereo camera system was very fast (0.2 milli-seconds) compare to the scanning period which took about 19 seconds to complete the scanning process from two scanners. A complete datasets will consist of three stereo images, two convergent images and two 3D surfaces (which also known as shells). Figure 14 shows the image datasets, while Figure 15 shows the laser scanner dataset.

As seen in both Figure 14 and Figure 15, the photogrammetric control frame image was included in the raw datasets.



Figure 14. Image datasets from camera system

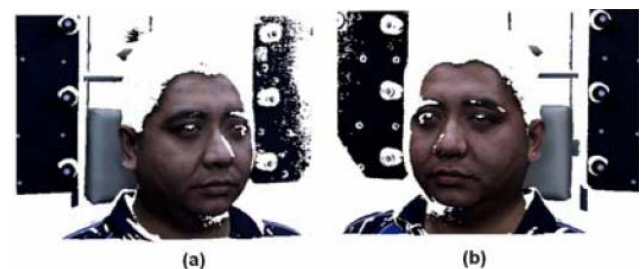


Figure 15. 3D laser scanner raw datasets – (a) right shell, (b) left shell

3. CRANIOFACIAL SPATIAL DATA REDUCTION SYSTEM

The data reduction system involved with the method used to process the raw data (as acquired using data acquisition system). The method used consisted of pre and post processing of the raw data. There are two types of data pre and post processing tasks involved in the project. The first pre and post processing task involved the processing of image datasets (as acquired using camera system), while the second one involved with the processing of 3D laser scanner point clouds data. The details of the data processing are as below:

3.1 Pre and Post Processing of Images Acquired from the Camera System

The acquired stereo and convergent images involved with two pre-processing tasks. The first task involved with photogrammetric triangulation process. The aim of the process is to measure the 3D coordinates of the natural landmarks on the craniofacial surface. The 3D coordinates were then use as control points in photogrammetric absolute orientation process (Figure 16 and Figure 18).

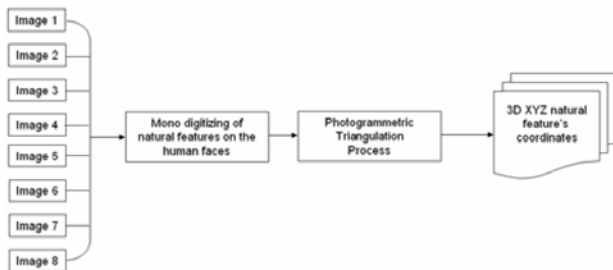


Figure 16. The flowchart to show the measurement of natural features 3D XYZ coordinates using Photogrammetric Triangulation process

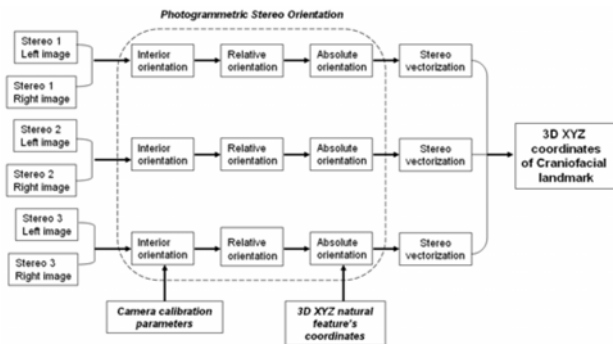


Figure 17. The flowchart to show the stereophotogrammetric measurement process of stereo images using DVP Photogrammetric System



Figure 18. Measurement of natural features using convergent photogrammetric method

The stereo images were then proceed with the photogrammetric stereo orientation which involved interior, relative and absolute orientation process to generate the stereo model. The stereo vectorization was then applied to digitize the 3D XYZ coordinates of the craniofacial landmarks (see Figure 17 and Figure 19). The accuracy of the stereo digitizing process was evaluated using the RMS value of the absolute orientation. Most of the cases in craniofacial mapping required the RMS value of 0.5mm for X, Y and Z coordinates, respectively.



Figure 19. Post processing of stereo images using DVP system.

3.2 Pre and Post Processing of 3D Laser Scanning Datasets

The data processing of the 3D laser scanning datasets involved with six common 3D modeling process which consists of filtering noise, initial registration and fine registration of the two shells, merging, holes filling and smoothing (as in Figure 20 and Figure 21). The common processing steps mentioned above was offered by most of the laser scanning data processing software such as RapidForm 2004 (INUS Technology, Korea) and Polygon Editing Tools (PET) software (Konica Minolta, Japan).

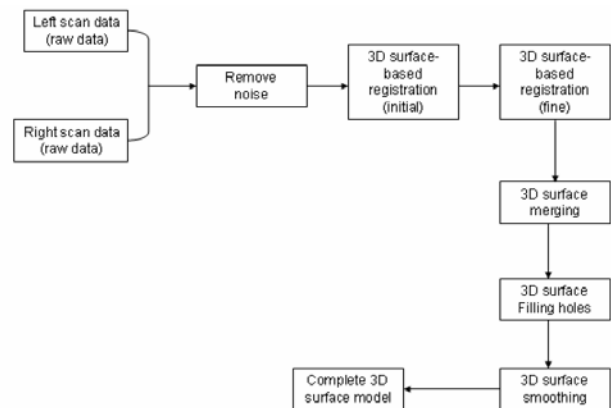


Figure 20. The flowchart show the pre-processing steps to process the 3D laser scanning datasets

The post processing involved with the measurement of craniofacial landmarks on the 3D craniofacial surface model. The process required the user to identify the location of the landmarks on the 3D surface based on the terrain (DTM) of the surface and the break-surface, and finally the location was digitized. RapidForm 2004 software offered auto-measure function to measure slope distance, along surface distance and angle between the selected landmarks.

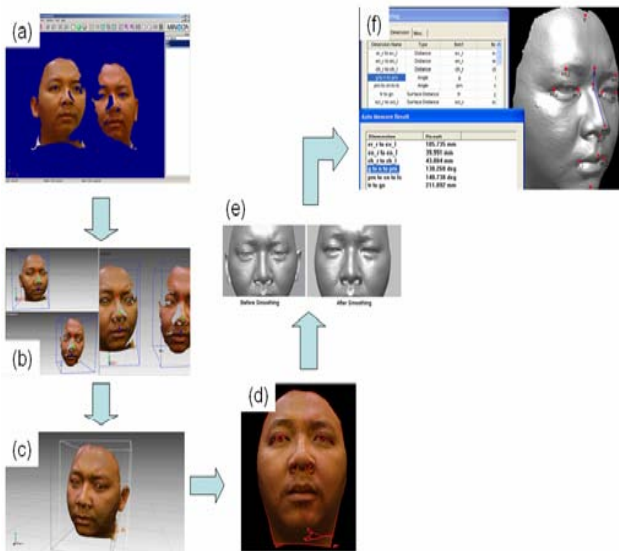


Figure 21. Pre and post processing of 3D laser scanning datasets – (a) raw datasets, (b) registration process, (c) merging process, (d) filling holes, (e) smoothing process and (f) measurement of craniofacial landmarks

4. CONCLUSION

4.1 Advantages of a Prototype 3D Craniofacial Imaging System for Craniofacial Soft Tissue Mapping

The developed prototype 3D craniofacial imaging system is the first system developed in Malaysia for the purpose of craniofacial mapping. In term of 3D measurement of craniofacial soft tissue, the prototype 3D craniofacial imaging system developed in the study offered a non-contact method with better accuracy compare to the conventional method which used callipers for measuring craniofacial landmarks. Instead of acquiring one type of data which was implemented in most of craniofacial data acquisition system (which was published in journals), the developed system can be used to acquire two types of craniofacial spatial data which are (a) stereo images of craniofacial soft tissue, and (b) 3D surface model of corresponding craniofacial soft tissue captured in (a). Both data was acquired with patient remain seated for a few seconds. The acquired data (both stereo images and 3D laser surface) was process using appropriate software and the measurement of the landmarks was successfully obtained in 3D environment in the software, which was similar to conventional method using

callipers. With the total weight of 30 kilograms, the imaging system was fully portable as mobile craniofacial imaging system. These were proved by a series of data collections at USM Hospital in Kota Bahru, Kelantan.

REFERENCES

- Albert K. Chong, Zulkepli Majid, Anuar Ahmad, Halim Setan and Abdul Rani Samsudin, THE USE OF A NATIONAL CRANIOFACIAL DATABASE, *The New Zealand Surveyor Journal*, No. 294, June 2004.
- Zulkepli Majid, Albert Chong and Halim Setan (2006). Calibrating Minolta Vivid 810 3D Laser scanner for medical mapping. *The New Zealand Surveyor*. December 2006.
- Zulkepli Majid, Albert Chong and Halim Setan (2007). Important Considerations for Craniofacial Mapping using Laser Scanners. *The photogrammetric record*, December 2007. Vol. 22, No 120, p 1-19.
- Zulkepli Majid, Albert Chong, Anuar Ahmad, Halim Setan and Abd. Rani Samsudin (2005), Photogrammetry and 3D laser scanning as spatial data capture techniques for a national craniofacial database. *The photogrammetric record*, March 2005. Vol. 20, No 109, p 48-68.
- Zulkepli Majid, Albert Chong, Halim Setan and Anuar Ahmad (2005). Craniofacial stereo mapping: Improving accuracy with natural points. *The New Zealand Surveyor*. No 295, December 2005.
- Zulkepli Majid, Albert Chong, Halim Setan, Anuar Ahmad and Zainol Ahmad Rajion (2006). Natural Features Technique for Non-Contact Three dimensional Craniofacial Anthropometry using Stereophotogrammetry. *Archives of Orofacial Sciences*. 2006 1(1). p 42-50.
- Zulkepli Majid, Halim Setan and Albert Chong (2004). Modeling human faces with non-contact three dimensional digitizer: preliminary results. *Geoinformation Science Journal*, Vol. 4 No 1.

ACKNOWLEDGEMENTS

The research has been fully funded by the Ministry of Science, Technology and Innovation, Malaysia.

