THREE DIMENSIONAL CRANIOFACIAL ANTHROPOMETRY USING STEREOPHOTOGRAMMETRY: VALIDATION OF THE TECHNIQUE

Zulkepli Majid[1], Albert Chong[2], [1]Halim Setan[1] and Anuar Ahmad[1]

[1]Faculty of Geoinformation Science & Engineering, Universiti Teknologi Malaysia
[2]School of Surveying, University of Otago, Dunedin, New Zealand
Tel: 60 7 5530829
Fax: 60 7 5566163
E-mail: zulkepli@fksg.utm.my

Abstract

Craniofacial anthropometric mark mapping was performed using stereo-photogrammetry technique. Various size and shape of control frames were designed to provide three-dimensional object-space control for stereo images. A research was carried out to determine whether the accuracy could be further enhanced using natural points. In the research, control points and natural points were measured using precision software and their coordinates computed via bundle adjustment technique. In addition, the six-camera stereo-photogrammetric system was electronically synchronized for optimum accuracy. Subsequently, Digital Video Plotter (DVP) digital photogrammetric workstation was used for stereo orientation and stereo-digitizing of the anthropometric landmarks. For the accuracy assessment of the 'natural point' technique, absolute orientation was performed on the stereo-model using control-frame control and natural points respectively. The results show that the developed technique improves the accuracy of 0.6mm with one standard deviation. The optimum accuracy of the setup stereophotogrammetric cameras was 0.25mm.

INTRODUCTION

Craniofacial anthropometric measurements required high quality measuring tools in order to get the highest possible measurement accuracy (Farkas et. al, 1996). Among the methods used, Stereophotogrammetry was promised to be familiar as a non-contact, non-invasive, reproducible, fast, high-accuracy, practical and cost-effective technique measurement of facial morphology (Naftel et al. 2004; Burke et al.1983; Hay et al. 1985; Majid et al 2005, Meintjes et al. 2002, Ras et al. 1995, Wagner et al. 2005, Johnston et al. 2003).

Generally, photogrammetric control frame is required for the stereo orientation of the craniofacial stereo-photographs. The control is needed to allow scaling and orientation of the spatial model during the later analysis (Newton, 1986). The control frame may be placed over the patient's head (Savara and George, 1984); near both side of the head (Peterson, 1993) and in Schewe and Ifert (2000) the control targets were placed on a helmet. These three designs almost certainly covered in all published photogrammetric control configurations (Majid et al, 2005). However, tests show that the recommended location of the control targets on the frame was not suitable for high accuracy stereo-orientation. The accuracy in the Z (along the optical axis) does not satisfy the project requirement of 0.7 mm. It becomes clear that the control targets are too far from the front facial surface. Consequently, the accuracy of the z differs between the left-face and the front model and the worst accuracy of 2.0 mm for the latter. However, the accuracy between the left and the right face is similar. The problem can be solved by using natural points which may be birth mark, acne or scar. In certain cases, points may be tattooed on the object for the duration of the investigation (Newton, 1986).

A method was developed to obtain accurate coordinate of the natural points. It involves a bundle adjustment of photographs from the three stereo-models using the control frame targets. The bundle adjustment computes the coordinate of the natural points. Subsequently, the natural points are used to carry out absolute orientation of the stereo-models.

METHODS

The design of the photography is based on three stereo-pairs of photograph. Six Sony DSC F828 digital cameras were set up 600 mm from the object (mannequin and human face) to capture the stereo images. The cameras were electronically synchronized using a lanc shepherd controller (Graphic Media Research, Minnesota, USA). Figure 1 show the setup of the stereo-photographic system at School of Surveying, University of Otago.

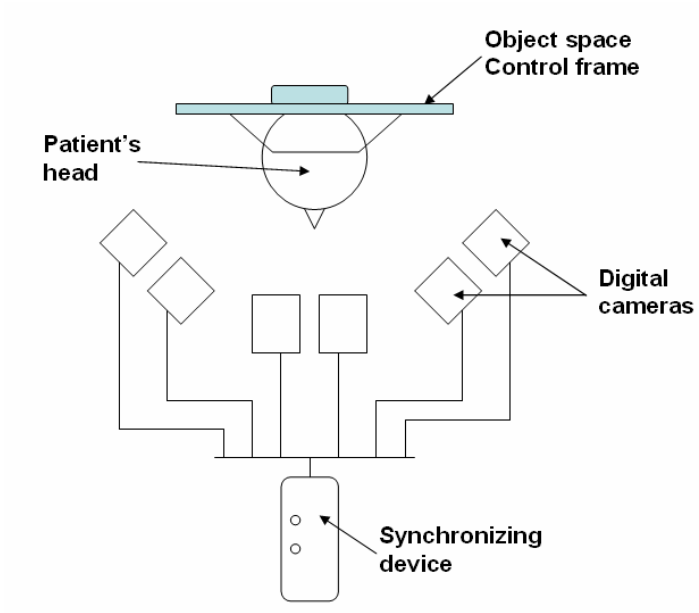

Figure 1: Stereo-photographic system used in the study

Individual camera was calibrated independently using a three dimensional calibration device. The device consists of a camera mount and a 3D test field. Retro-targets are placed in row and column as shown in the figure. The calibration procedure is discussed in Chong and Scarfe; Majid et al. 2005.

A unique control frame was built to provide an accurate control for the research (Figure 2). Again, retro-targets were used to highlight the control points. The control frame also requires accurate calibration. The x, y and z coordinates of the targets were determined using convergent photographs and a bundle adjustment **(**Chong and P. Strafford 2002). The coordinates would be used for the absolute orientation of the stereo models and for computing natural point's coordinates.

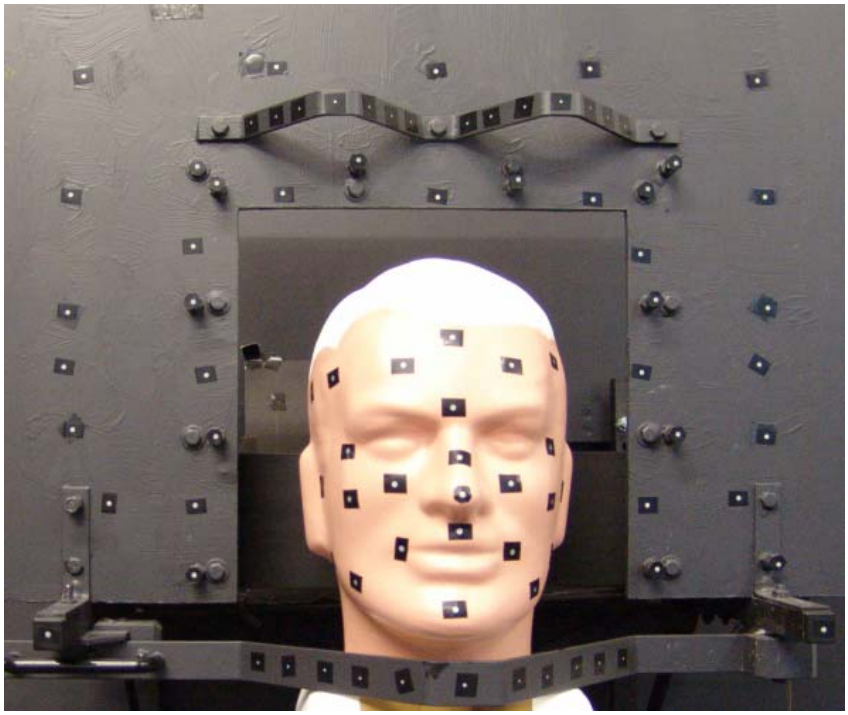

Figure 2: The unique control frame with control points and the simulated natural points (both marked with reflective retro targets). Note that the simulated natural points were also used as a test point for distance and angle measurements.

The photography consists of two stages: (a) a set of convergent photographs of the mannequin to determine coordinates of the simulated natural points and (b) a set of six stereo-photographs of the mannequin for stereo-digitizing of the anthropometric marks and 3D surface. In stage (a), six convergent photographs were captured. Stage (b) involved the capturing of 60% stereophotogrammetric overlap of the mannequin from three different stereo camera positions which covered the craniofacial area. The lens to object distance was 600 mm.

The digital caliper with the accuracy of 0.1mm was used to measure directly the distances between the selected test points on the craniofacial surface. The caliper was calibrated where the value of zero (0) was always started at the accurate scaling designed on the caliper. Each distance was measured three times and the average of the distances was calculated. Figure 3 shows the digital caliper used in the measurements.

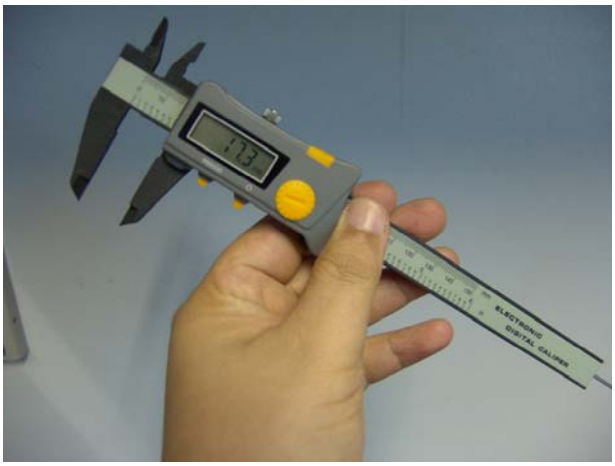

Figure 3: A digital caliper used for direct measurement on the mannequin

RESULTS

Results of the stereophotogrammetric measurements

The results consists of two sets of average three-dimensional coordinates of the test points (for each mannequin's stereo models) gained from three sets of repeated stereophotogrammetric measurements using the control frame method and natural point method, respectively. The preliminary accuracy of the stereophotogrammetric measurements of both methods was determined by the standard errors of the absolute orientation process in x, y and z axis. For both method, the standard error of absolute orientation depends on the accuracy of three-dimensional ground control coordinates and the location of the control on the craniofacial surface. Table I show the optimum absolute orientation standard errors gained from both method. Note that the control was well distributed on the craniofacial surface.

Table I: Optimum standard error of stereophotogrammetric absolute orientation

Methods	***Absolute orientation standard errors in x, y and z axis. Note that the unit is mm.***
Control frame method	Front model (0.347, 0.303, 0.533) Left model (0.364, 0.225, 0.266) Right model (0.304, 0.222, 0.237)
Natural point method	Front model (0.063, 0.117, 0.246) Left model (0.125, 0.112, 0.310) Right model (0.216, 0.112, 0.320)

ANALYSIS

The preliminary analysis involved the vector analysis which deals with the comparison study of craniofacial anthropometry *(distance and angle measurements)* between the set of the test points on the mannequin craniofacial surface. In this analysis, the distances and angles gained from bundle adjustment method was used as a *gold standard* to verify the accuracy of the other method. Advanced analysis involved the study of the depth factor in the stereophotogrammetric measurements by control frame method and natural point method.

The vector analysis involved with sixteen three dimensional anthropometric points which were marked with signalized target (see Figure 4). There are four types of measurement results gained from four

methods which is bundle adjustment method, caliper method, natural point method and control frame method. For each method, the accuracy was determined by the mean, variance and standard deviation of the differences between all the methods with the *gold standard*. Table II and III show the results of the analysis.

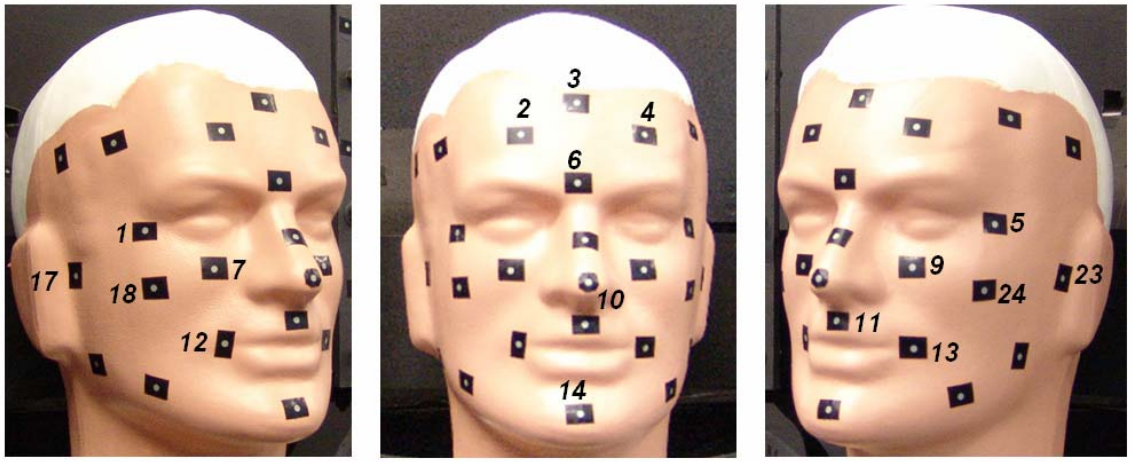

Figure 4: Distribution of three-dimensional anthropometric points on the mannequin's craniofacial surface used in the study

Table II: Differences in distance between the test points

From point	***To point***	***Caliper vs. bundle method (mm)***	***Natural point method vs. bundle method (mm)***	***Control frame method vs. bundle method (mm)***
2	4	0.18	0.08	1.72
3	6	0.35	0.44	0.36
6	10	0.21	1.44	0.5
12	13	0.11	0.50	4.85
1	5	0.11	0.61	7.66
17	7	0.20	0.37	10.20
9	23	0.15	2.00	12.22
4	24	0.11	0.12	0.90
2	18	0.17	0.34	2.16
3	14	0.32	0.22	3.86
Statistics	*Mean*	***0.19***	***0.61***	***4.43***
	Variance	***0.01***	***0.38***	***18.07***
	Std Dev	***0.08***	***0.62***	***4.25***

Table III: Differences in angle measurements between the selected test points

Three points involved (first – middle – last)	***Natural point method vs. bundle method (deg)***	***Control frame method vs. bundle method (deg)***
5-23-13	2.04	1.81
1-17-12	2.08	2.44
3-17-14	2.08	6.61
3-23-14	1.13	6.15
Mean	***1.83***	***4.25***
Variance	***0.16***	***4.60***
Std Dev	***0.40***	***2.14***

The study of the depth factor in the research were being the advance analysis method to prove that the use of natural points as ground coordinates for craniofacial stereophotogrammetric mapping will enhanced the accuracy of anthropometric landmark measurements. The *depth* is defined as the distances between the datum (average distance from camera lens to ground control points) to the selected test points (measured anthropometric landmarks) in z axis. In aerial photogrammetric method, the depth value should not be more than 10% of the flying height in order to gain accurate and precise measurements in z coordinates (actual height of features). The similar formula can be successfully applied in close-range photogrammetry where the depth of all measured points in stereo model will gained higher accuracy in depth if the depth is about $\pm$ 10% of the object distance. For example, for the object distance of 600mm, the maximum depth is 60mm. In this research, which involved the comparison of two methods (control frame and natural point method) in the measurement of anthropometric landmarks, the location of the landmarks from the datum is different (Figure 5).

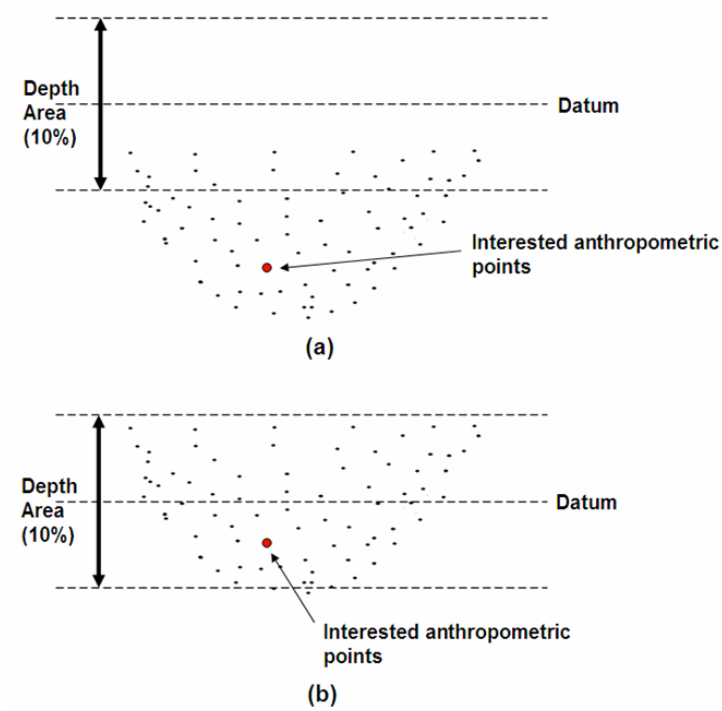

Figure 5: Location of craniofacial landmarks and the photogrammetric measurement datum of (a) control point method and (b) natural point method

The statistical analysis involved the two variable regressions between the errors in z coordinates versus the percentage of depth for each test points in both method and the plots of both results are provided in Figure 6 and Figure 7. As general, both plots show the logical results where the increase of depth value (percentage of depth), will increase the error in z coordinates of the anthropometric landmarks. The results also show that the natural point method is more accurate and more precise than the control frame method. The optimum accuracy for the configuration of the stereo cameras is 0.25mm. The depth percentages of the project accuracy (0.7mm) are less than 10% which is highly accepted for 50%-60% overlap of the stereo model.

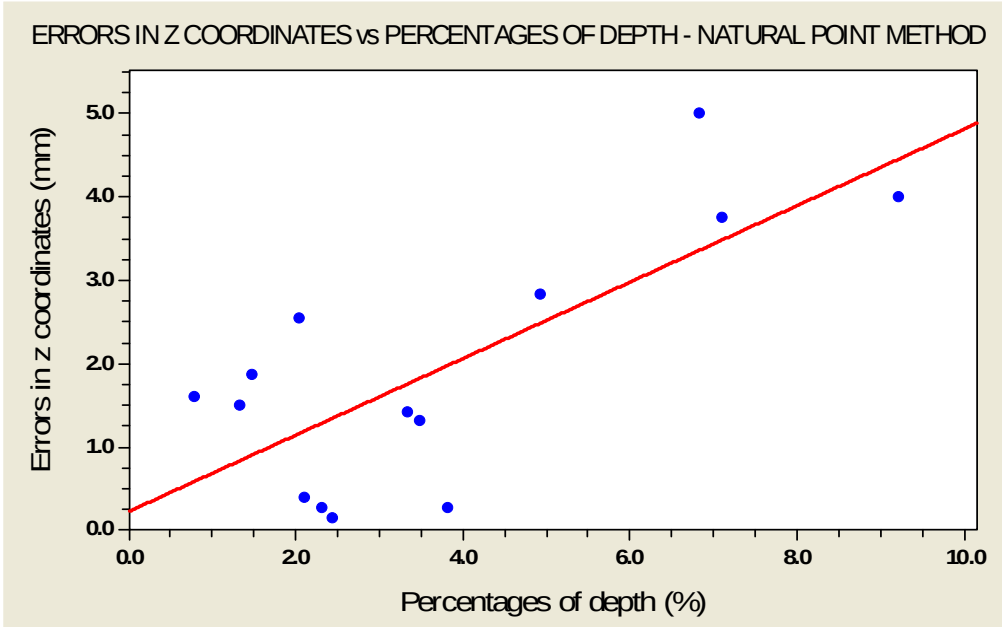

Figure 6: Depth analysis – natural point method

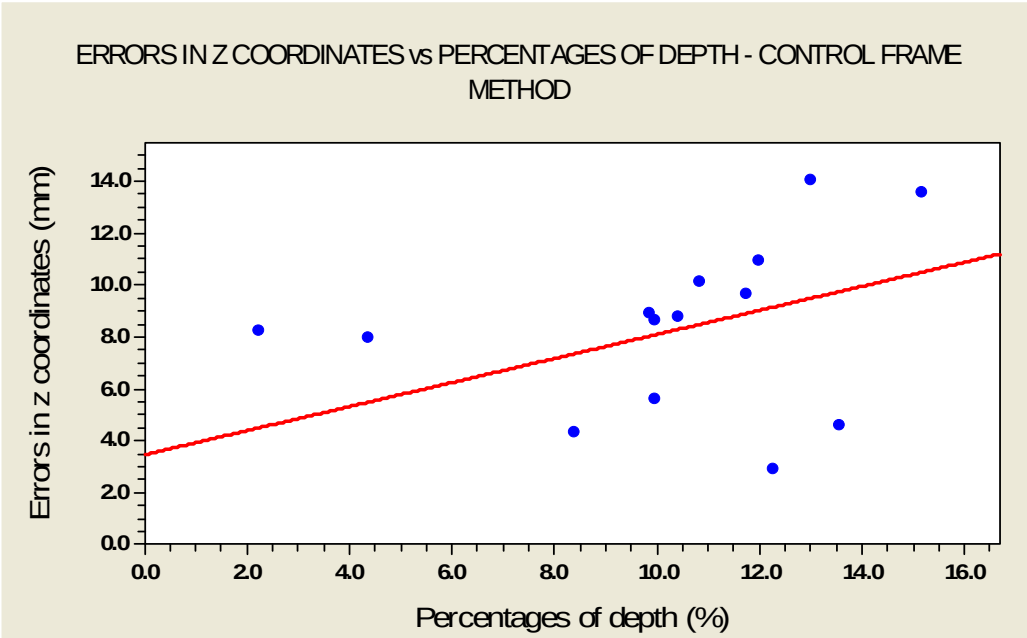

Figure 7: Depth analysis – control frame method

The *F test statistic* was also used to verify the accuracy of the natural point method. The test involved the analysis of population variance to test the significance of differences among the two methods. The null hypothesis H_o (the accuracy of the two methods are the same) was tested against the alternative hypothesis H_A. The F-test for two population variances (variance ratio test) is suitable for testing the hypothesis since the accuracy of both methods is considered into account. The value is computed from the following formula:

$$F = \frac{S_1^2}{S_2^2}$$

Where S_1^2 represent variance of the errors in z coordinates for control frame method and S_2^2 represent variance of the errors in z coordinates for natural point method. The results of the test are provided in Table IV.

Table IV: *F variance ratio test* results

Method	***Variance***	***Degree of freedom***	***F value (calculated)***	***Critical F value (Table)***
Control Frame	10.04033	12		
Natural Point	2.234681	12		
			4.492958	2.686637
		Decision	Reject Ho	

The results show that with 12 degree of freedom, the calculated *F* value is 4.492958. The critical value for *F* (from *F*-Table) is 2.686637. With these results, we rejected the null hypothesis and it is statistically proved that the accuracy of the two methods is not the same. It's also proving that the natural point's method was the accurate method for the measurements of the anthropometric points on the facial surface.

VALIDATION OF PROPOSED METHOD

In order to verify that the proposed method was really accurate to support the craniofacial anthropometric job, a facial surface with signalized target (representing natural points and test points) was used (see Figure 8). The face was posed at the middle of the control frame and photograph using the six synchronization digital cameras (Figure 1). The photogrammetric triangulation method was used to calculate the three dimensional coordinates of the signalized target accurately using Australis software. Both control frame and natural point method was applied separately in the photogrammetric absolute orientation of three pairs of stereo models. Nine linear measurements were performed between the signalized targets. The direct measurements were also performed using caliper as a comparison with the proposed method. All the measurements were repeated three times in order to make sure that each technique was reproducible.

Figure 8: Real human face with signalized targets to represent the natural points and test points.

Table V show the results of the measurements. The natural point method was proved to be accurate with standard deviation of 0.65 mm compared to the control frame method.

Table V: Results of the test. Note that the distances calculated from the triangulation method was selected as a "gold standard".

From point	***To point***	***Caliper vs. triangulation (mm)***	***Natural point method vs. triangulation (mm)***	***Control frame method vs. triangulation (mm)***
2	4	0.11	1.36	3.57
3	6	0.03	0.77	1.61
6	13	0.56	2.01	1.87
16	17	1.60	0.20	0.81
1	5	0.30	0.70	7.64
7	8	0.66	2.00	1.67
10	11	0.63	0.66	2.87
4	14	1.09	1.10	3.56
2	12	0.31	0.15	1.44
Statistics	*Mean*	***0.59***	***0.99***	***2.78***
	Variance	***0.22***	***0.42***	***3.77***
	Std Dev	***0.50***	***0.65***	***1.94***

The natural point method was successfully applied to real craniofacial anthropometric measurements which involved real human craniofacial surfaces. The patient's head was placed at the middle of the control frame. Six Sony DSC F828 digital cameras was setup 600mm in-front of the patient. The patient was asked to be in relaxing mode during the photography period. All the cameras are synchronized and the synchronizing time was 0.2 milliseconds.

The six images from six cameras (Figure 1) were then used to measure the three-dimensional coordinates of selected natural points on the facial surface. Again, the Australis software was used to perform the triangulation process of the natural points. The calibration parameters of all the six cameras are fixed during the calculation.

For the purposed of anthropometric measurements, nine anthropometric landmarks were measured from the stereo models. The measurements of the three dimensional coordinates of each landmarks was repeated three times (one after half an hour) and the average of the coordinates was calculated. Figure 9 show the selected landmarks for the measurements and Table VI show the results of the measurements. All measurements are linear.

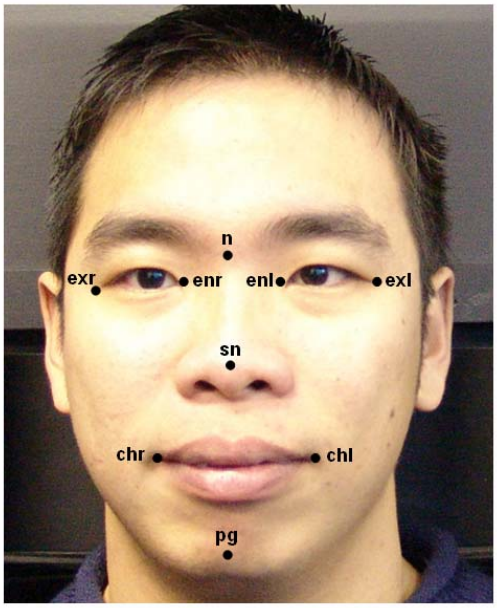

Figure 9: Craniofacial anthropometric landmarks used for the anthropometric measurements

Table VI: Craniofacial anthropometric measurement results

From landmark	***To landmark***	***Distance (mm)***
chr	chl	64.837
enr	enl	41.545
n	sn	43.211
exr	pg	127.182
exl	pg	125.160
exr	exl	113.151
n	pg	115.734

CONCLUSION

In the paper, the use of digital photogrammetry has been discussed for measurements of craniofacial landmarks. The use of natural point's method as a ground control was statistically approved and found to be an effective method to improve the accuracy of the craniofacial stereo mapping by comparing the results with the control frame method. By using the natural point's method, there is no need to shorter the camera to object distance and the optimum coverage of the stereo mapping were maintained. The shape and location of the natural points was found to be easily obtained since the setup of the camera system covered the craniofacial measurement area. For high accuracy absolute orientation of the stereo models, the selected natural points as ground control need to be well distributed in the overlapping area. The number of six natural points was needed for optimum accuracy of absolute orientation.

In the research, the proposed method need medium extra time to proceed since the additional time was needed on the triangulation process to obtain the 3D coordinates of the selected natural points. The Australis camera calibration was used to run the bundle adjustment process. Since the similar software was used for calibrating the stereo cameras and measuring the 3D coordinates of the test points, there is no additional cost for obtaining the natural points coordinates using other third party software.

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