ALIGNMENT OF 3D LASER SCANNER POINT CLOUDS USING PHOTOGRAMMETRIC TARGETS

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Abstract

3D laser scanning technology has found to be an excellent method for the modeling and measuring 3D objects (rigid and real life). The 3D point clouds of an object can be acquired within less than one second (0.6s for Minolta VI-910 3D laser scanner) and stored digitally for pre-processing task. Complex mapping of 3D object such as human faces required at least two scanning images to cover the complete facial area (from right ear to left ear, and from hair line to bottom part of the chin) with optimum 3D modeling accuracy. For complete 3D model generation, the scanning images is needed to be registered (combined) and merged together. Existing registration method used corresponding features between the two scanned images as registration primitive and finally 3D transformation algorithm was applied to combine the images. This paper described the use of photogrammetric targets, as registration primitive to combine two scanning images of human face. The so called "paper targets" were setup on the special design photogrammetric control frame where the human face was placed at the middle of the frame during scanning process. The photogrammetric control frame was calibrated using close-range convergent photogrammetry with coded targets and high precision scale bars to determine the precise 3D coordinate of such targets. The targets was also included in the scanning images and represented as point clouds datasets. Via laser scanning images, the centroid of the targets was measured and the 3D transformation algorithm was successfully applied to transform the scanning point clouds from laser scanning coordinate system to photogrammetric coordinate system. The output of the registered point clouds was displayed and processed in reverse engineering RapidForm 2004 software. The accuracy of the method was evaluated using shell-shell deviation analysis technique where the average deviation of the two scanning images was calculated. The results show that the accuracy of existing 3D registration method was recorded as 0.3-0.5mm, while the proposed 3D registration using photogrammetric targets was recorded to be 0.129-0.285mm. The reliability of the photogrammetric targets method was also evaluated and the measured accuracy is from 0.216-0.741mm with one standard deviation.

Keywords: 3D registration, laser scanning, photogrammetric targets, point clouds

1.0 Introduction

The paper described the details on the integration of close-range photogrammetry and 3D laser scanning for high accuracy 3D modeling of craniofacial spatial data (soft tissue) by improving the accuracy of the alignment process of 3D point clouds data. The needs for precise alignment of 3D laser scanner data using photogrammetric targets is essential to solve the problem when the lacked of corresponding features on two laser scanner dataset are happened. The 3D alignment process using Iterative Closest Point method (as practice in RapidForm 2004 3D modeling software) required the user to digitized at least three corresponding points that appeared on the 3D surfaces in triangle form. As seen in Figure 1, it is difficult to select the corresponding features since the features were not accurately modeled by the laser scanners. Both models was failed to align together and the error of the alignment process was shown in Figure 2.

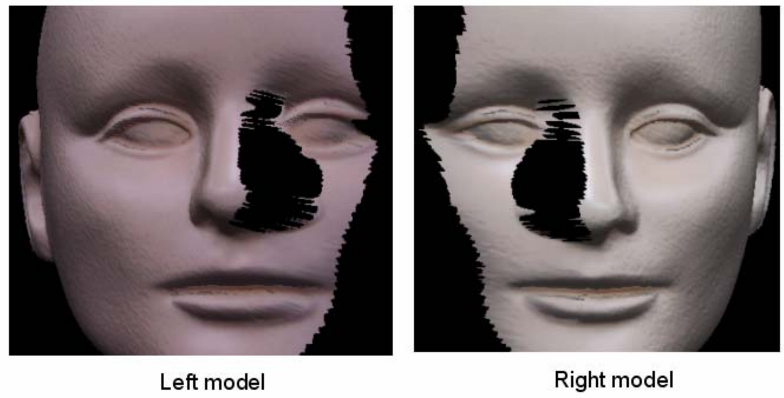

Figure 1: The lacked of corresponding features on 3D laser scanner surface model

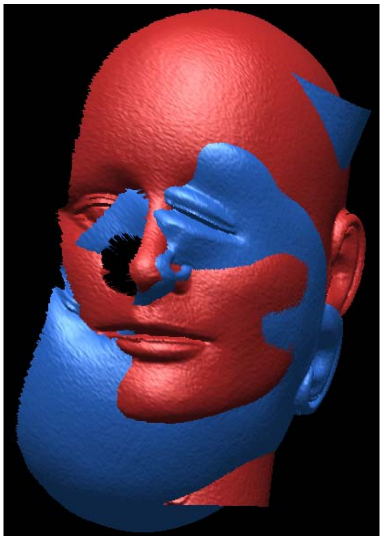

Figure 2: Error in 3D alignment process – effect from the lacked of corresponding features

Therefore, the new technique was developed to overcome the alignment problem. The technique applied the close-range photogrammetric targets as a tool to align the laser scanner point clouds datasets. The details of the new 3D alignment technique were described in the following sub-chapters.

2.0 Setup of the test

The test was carried out using the Imetric System (Imetric, Switzerland) consisted of hardware and software. The process started with the calibration of the so-called "photo-laser control frame" which was specially designed for craniofacial mapping task. The "photo-laser control frame" consisted of close-range photogrammetric targets (see Figure 3). The control frame was designed to have different in depth value by using 30mm diameter cylindrical rod attached on the plate. Four coded targets were stick-on the plate for automatic calibration process. Two scale bars with coded and paper targets was used to supply scaling on the measurements. Fifty convergent images (normal and roll views) were captured using Minolta A200, eight million pixels digital cameras within 1 meter object distances.

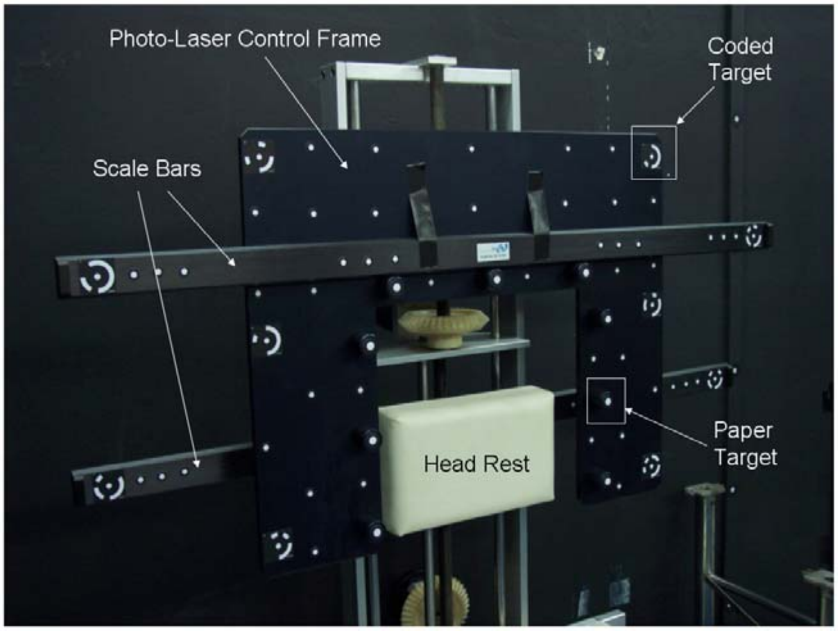

Figure 3: The "Photo-Laser Control Frame" – setup during the calibration process

The photogrammetric image processing (using IMetric Software System) started with relative orientation (RO) measurements to predict the preliminary 3D coordinates of the targets. By using coded targets, the RO processes allowed automatic measurement of the targets in each images. The bundle adjustment method was finally performed to refine the 3D coordinates of the targets. The overall accuracy of measured 3D coordinates was 0.018mm, 0.025mm and 0.028mm for X, Y and Z, respectively. The targets were than used as a control for the 3D alignment process of the point clouds datasets. Table 1 show the X, Y and Z coordinates of the targets.

Table 1: X, Y and Z coordinates of the targets

ID	**X (mm)**	**Y (mm)**	**Z (mm)**
701	141.3276	34.9785	19.3886
702	141.3956	125.8587	-0.5542
703	141.3602	215.448	19.3843
704	200.1451	273.2141	-0.6870
705	290.2756	274.6969	19.3047
706	380.5301	273.3969	-0.3822
707	441.6218	214.2141	19.7036
708	440.0886	125.1733	-0.0980
709	441.5747	35.5981	19.7020

Second steps of the case study involved with the scanning process of the test objects using Minolta VIVID 910 three-dimensional laser scanners. The case study involved with two test objects; (a) the mannequins (as in Figure 4) and (b) real-life human faces (as in Figure 5). Both test objects was placed at the middle of the photo-laser control frame. The mannequin was used to determine the accuracy, reliability and error in the proposed method. The test on real-life human face involved with the scanned of ten normal faces.

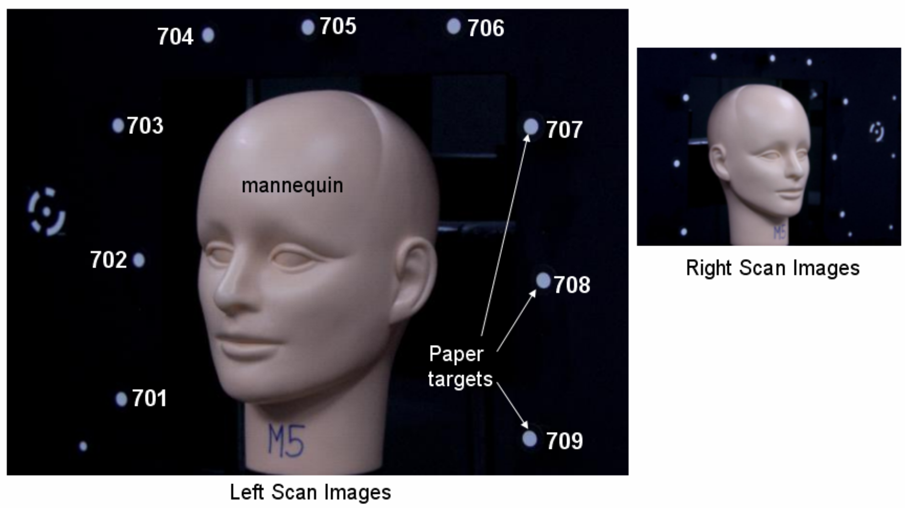

Figure 4: Mannequin as test object for accuracy testing of the new technique

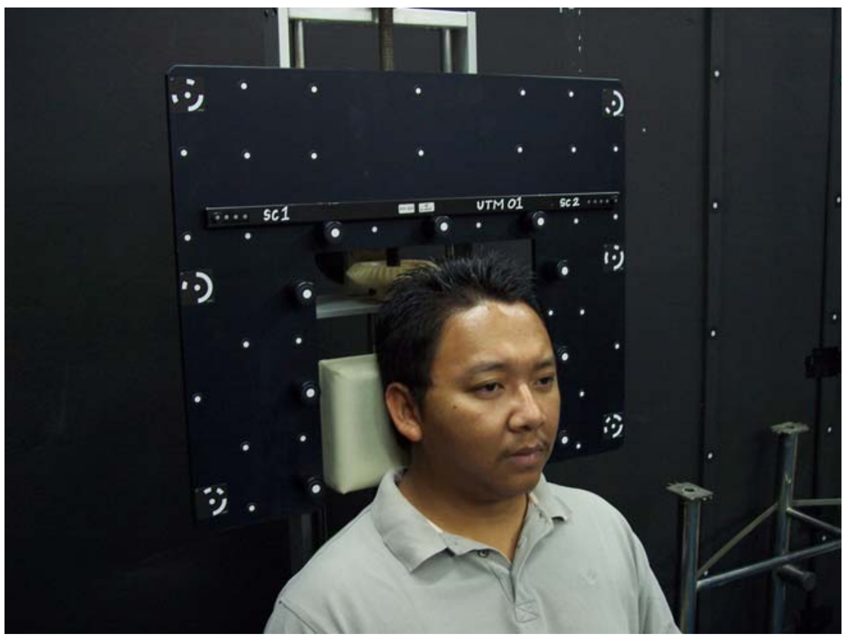

Figure 5: Position of the real-life human head during data capture

3.0 Pre-processing of laser scanning datasets

The input data for the alignment process is the 3D coordinate of the targets (determined by photogrammetric method) and the laser scanner point clouds datasets (cdm format). The cdm format consists of two laser scanner data, the 3D point clouds and the color images taken by the CCD camera (built-in the laser scanner system). For the purpose of measuring the targets in laser scanner data, the color images were used and the sub pixel target measurement method was applied. The centroid of the photogrammetric targets in the images is similar centroid on such targets in point clouds datasets. Figure 6 shows the pre-processing tasks involved in the development of final craniofacial 3D model using the proposed precise 3D alignment method.

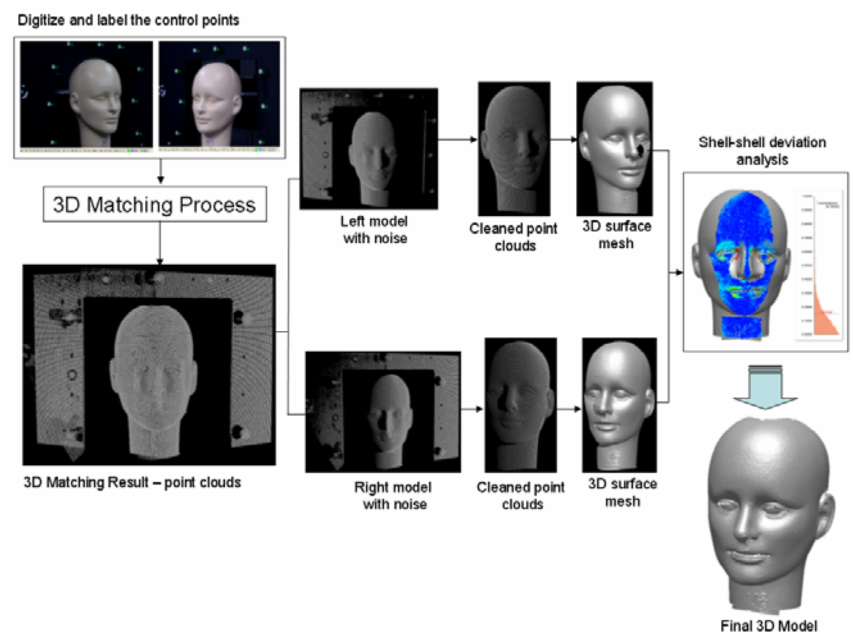

Figure 6: Pre-processing tasks for the development of final 3D model of craniofacial

4.0 Reliability of proposed method – test on the mannequin

The reliability of the proposed technique was evaluated using three different mannequins. Each mannequin was scanned at five different periods (range in 5 minutes) with fixed scanning configuration (high resolution with 300,000 point clouds per scanning, scanning angle at 90 degree and scanning distance at 850mm). For each scanning datasets, nine photogrammetric targets was used and manually digitized and labeled. The reliability of the proposed technique was determined by the matching accuracy, average distances accuracy between the point clouds and the standard deviation of the deviations. The results of the reliability test were shown in Table 2, 3 and 4.

Table 2: Reliability test results of the proposed 3D alignment technique – Test on mannequin 1

Test on Mannequin 1	Left Model Matching Accuracy (mm)	Right Model Matching Accuracy (mm)	Average Distances (mm)	Standard Deviation (mm)
Test 1	Vx = 0.535 Vy = 0.378 Vz = 0.223	Vx = 0.295 Vy = 0.214 Vz = 0.182	0.285	0.741
Test 2	Vx = 0.536 Vy = 0.379 Vz = 0.237	Vx = 0.304 Vy = 0.220 Vz = 0.191	0.251	0.624
Test 3	Vx = 0.536 Vy = 0.378 Vz = 0.238	Vx = 0.303 Vy = 0.218 Vz = 0.189	0.271	0.660
Test 4	Vx = 0.543 Vy = 0.382 Vz = 0.253	Vx = 0.322 Vy = 0.194 Vz = 0.131	0.267	0.701
Test 5	Vx = 0.530 Vy = 0.377 Vz = 0.230	Vx = 0.296 Vy = 0.214 Vz = 0.185	0.272	0.693

Table 3: Reliability test results of the proposed 3D alignment technique – Test on mannequin 2

Test on Mannequin 2	**Left Model Matching Accuracy (mm)**	**Right Model Matching Accuracy (mm)**	**Average Distances (mm)**	**Standard Deviation (mm)**
Test 1	Vx = 0.535 Vy = 0.376 Vz = 0.244	Vx = 0.316 Vy = 0.222 Vz = 0.195	0.261	0.637
Test 2	Vx = 0.531 Vy = 0.375 Vz = 0.238	Vx = 0.305 Vy = 0.217 Vz = 0.196	0.209	0.478
Test 3	Vx = 0.526 Vy = 0.370 Vz = 0.247	Vx = 0.313 Vy = 0.226 Vz = 0.191	0.221	0.482
Test 4	Vx = 0.530 Vy = 0.375 Vz = 0.238	Vx = 0.299 Vy = 0.212 Vz = 0.196	0.274	0.673
Test 5	Vx = 0.532 Vy = 0.373 Vz = 0.238	Vx = 0.304 Vy = 0.227 Vz = 0.166	0.234	0.538

Table 4: Reliability test results of the proposed 3D alignment technique – Test on mannequin 3

Test on Mannequin 3	**Left Model Matching Accuracy (mm)**	**Right Model Matching Accuracy (mm)**	**Average Distances (mm)**	**Standard Deviation (mm)**
Test 1	Vx = 0.438 Vy = 0.310 Vz = 0.256	Vx = 0.325 Vy = 0.144 Vz = 0.141	0.129	0.216
Test 2	Vx = 0.438 Vy = 0.306 Vz = 0.259	Vx = 0.240 Vy = 0.143 Vz = 0.134	0.137	0.248
Test 3	Vx = 0.434 Vy = 0.306 Vz = 0.252	Vx = 0.237 Vy = 0.140 Vz = 0.138	0.241	0.615
Test 4	Vx = 0.434 Vy = 0.304 Vz = 0.277	Vx = 0.237 Vy = 0.144 Vz = 0.145	0.236	0.604
Test 5	Vx = 0.433 Vy = 0.300 Vz = 0.284	Vx = 0.238 Vy = 0.144 Vz = 0.143	0.200	0.440

5.0 Reliability of proposed method – testing on real-life human faces

The similar approach was test on real life human faces and the reliability of such method was evaluated using shell-shell deviation analysis (as seen in Figure 7). The test on real life human faces shows that the accuracy of the 3D craniofacial surface model was increased with deviation analysis between the scan images is between 0.21mm to 0.27mm compare to 0.30mm by using the corresponding features method (as reported in many publications). The RMS accuracy of the 3D matching of both laser scanner and photogrammetric targets was below than the project accuracy (0.7mm) and considered to be an acceptable accuracy for craniofacial mapping task.

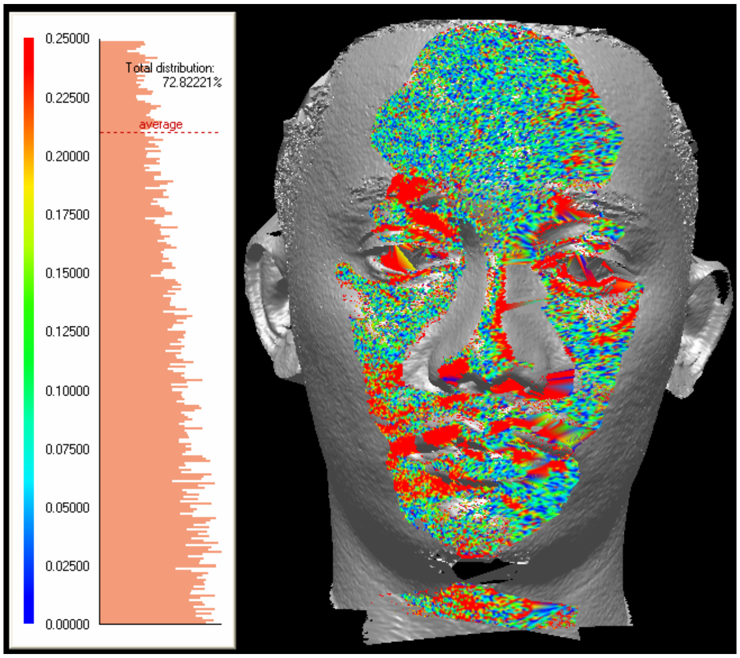

Figure 7: Shell-shell deviation analysis of real life human face 3D model

6.0 Advantages and disadvantages of the technique

The advantages of the proposed method are the method increased the accuracy of the alignment of 3D laser scanner datasets. The average shell-shell deviation accuracy is recorded to be less than 0.30mm. The test on the mannequins shows that the deviation accuracy is from 0.12mm to 0.26mm, while testing on real-life human faces shows the accuracy of 0.21mm. Apart from the accuracy aspect, the percentages of the coverage of the scanning area was increased without having a problem with the lacked of corresponding scanning area, since the alignment process is based on photogrammetric targets which was attached on the photo-laser control frame and where the modeling from left ear to right ear and from the hair line to the bottom part of the chin can easily be captured.

The disadvantages of the proposed method are the aligned laser scanner datasets is in 3D point clouds form. The texture data, triangle mesh data and 3D surface mesh data, which was captured during the scanning task, was terminated from the datasets. The final output is a set of x, y and z coordinates of the point clouds written in ASCII format. The problems required the user to re-generate the triangulation mesh and 3D surface mesh of the laser scanner datasets based on raw 3D point clouds. The texture mapping of the data required extra images from other sources such as digital images captured from digital camera or video camera that setup along with the laser system.

7.0 Bibliography

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