SPECIALIZED IMAGING AND INFORMATION SYSTEMS FOR CRANIOFACIAL RECONSTRUCTION

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ABSTRACT

For specific medical purposes (such as craniofacial reconstruction), human faces and skulls (i.e. soft and hard tissues) need to be modeled and measured accurately. This multi-disciplinary research focuses on the development of surgical planning system for craniofacial reconstruction, for both the soft and hard tissues. The craniofacial reconstruction requires the following: imaging and measurement (non-contact, precise, rapid), 3D models (digital and physical), database, and surgical planner. In this research, the main data are the soft tissue (face) and hard tissue (skull) of craniofacial. This paper discusses the research works undertaken by UTM on the development of specialized imaging system (close range, non-contact, precise, and real time) for capturing soft tissue spatial data, and the development of specialized information system (called MyCIS) for craniofacial applications. The developed real time imaging system combines laser scanning (via MINOLTA VIVID910 scanner) and stereo photogrammetric techniques for acquiring high-resolution 3D models of craniofacial soft tissue. All these 3 types of data (laser scanning, stereo photogrammetric, and CT scan) were processed separately using RAPIDFORM, DVP, and 3DSLICER respectively. MyCIS or Malaysian Craniofacial Information System is developed in-house, and consists of three main components: Data input and pre-processing; Database management; Data analysis and manipulation. MyCIS uses ORDBMS for managing anthropometric/morphometric craniofacial spatial data. MyCIS integrates various inputs (soft tissue from laser scan and photogrammetry, hard tissue from CT-scan, measurement, patient's information, etc) for managing and visualizing the craniofacial data. The actual results to date (with measurement accuracy of sub-mm) indicate the suitability of the adopted procedure for practical craniofacial applications. This research has produced the latest approach for imaging of soft tissue and managing of local craniofacial database. The results from this research are useful for many multi-disciplinary applications (both local and abroad) requiring craniofacial data.

1.0 INTRODUCTION

To date, craniofacial surgery in Malaysia uses reference (normal) data from abroad, as the local craniofacial database is not available yet. Moreover, special medical applications (such as craniofacial reconstruction) need precise measurement (and 3D computer model) of normal human faces (or soft tissue) and skulls (or hard tissue) (Figure 1).

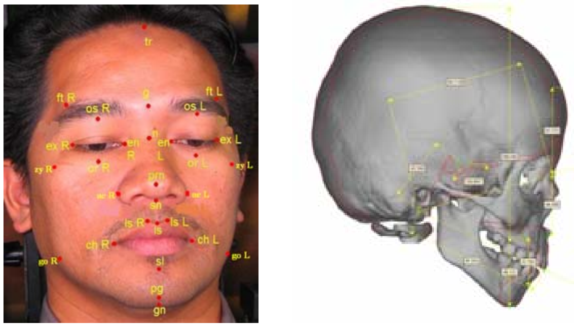


Figure 1. Landmarks on human face and skull (craniofacial)

Most surgeons (in Malaysia) are still relying on laborious traditional contact method (for example, calipers) for measuring anthropometric landmarks on human face and skull (Halim et al, 2004; Figure 2). The traditional contact method (Farkas, 1994) is slow, time-consuming, not practical, subject to significant errors, and not efficient to build the database.

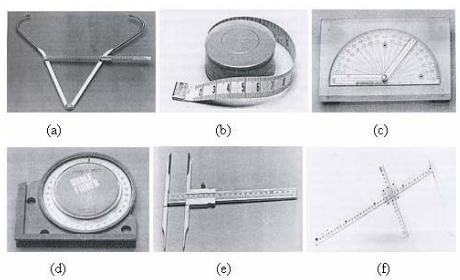


Figure 2. Traditional contact measurement method

Since 2002, a multi-disciplinary Prioritised Research (PR) under IRPA mechanism is established between Universiti Teknologi Malaysia (UTM), Standards & Industrial Research Institute Malaysia (SIRIM), and Universiti Sains Malaysia (USM) & Hospital USM (HUSM) Kelantan. This multi-disciplinary research focuses on the development of surgical planning system for craniofacial reconstruction, for both the soft and hard tissues.

The craniofacial reconstruction requires the following: precise automated imaging and measurement (to sub-mm accuracy) of soft and hard tissues (i.e. non-contact, close range, real time, fast, precise), 3D models (digital and physical), craniofacial database, and surgical planner.

This paper discusses the research works undertaken by UTM on the development of specialized precise imaging system (close range, non-contact, and real time) for capturing soft tissue spatial data, and development of specialized information system (called Malaysian Craniofacial Information System or MyCIS) for managing local craniofacial database.

2.0 IMAGING SYSTEM

In this research, the main data are the soft tissue (face) and hard tissue (skull) of craniofacial.

2.1 Soft tissue imaging

To date, most imaging systems of soft tissue use either single laser or convergent photogrammetric techniques. The developed prototype real time imaging system at UTM is unique (Figure 3), and combines the eye-safe 3D laser scanners (2 units) and stereo photogrammetric techniques (with 8 digital cameras together with special built craniofacial chair/object space control frame) for acquiring high-resolution spatial data and 3D models of craniofacial soft tissue (Halim et al, 2004, 2006; Zulkepli, 2007; Zulkepli et al, 2004, 2005b).

Figure 3. Real time imaging system (laser, camera, control frame)

Both data sensors (two MINOLTA VIVID910 3D laser scanners and eight 8.0MP SONY F828 digital cameras) were operated one after another, i.e. stereo camera system (off line, capture time=0.2msecs) followed by scanner system (on line, fine mode, capture time=19 secs). All SONY cameras were controlled and synchronized using a special built camera lanc controller, to enable simultaneous photogrammetric imaging (Zulkepli, 2007).

The UTM imaging system produces three pairs of stereo images, two convergent images and two 3D surfaces for each face/patient (Figure 4).

Figure 4. Direct output from imaging system

The main features of MINOLTA VIVID910 include: eye-safe laser scanner; operates using laser triangulation light block method; exchangeable lens; on line/off line; capture mode: fine (2.5 sec) and fast (0.3 sec); point cloud: 300,000 (Fine) and 77,000 (Fast);

precision in depth: ±0.008mm; scanning accuracy: X(±0.22mm), Y(±0.16mm), Z(±0.10mm); object distance: 0.6m to 2.5m. In this research, the typical configurations are on line, fine mode, and middle lens (Halim et al, 2004).

The combination of laser and photogrammetry techniques provides fast 3D computer model (via laser scanning) and precise landmark measurement (via stereo photogrammetric) of the soft tissue.

2.2 Hard tissue imaging

The hard tissue data (Figure 5), obtained via Computed Tomography (CT) scan, are provided by HUSM.

Figure 5. CT scan for hard tissue imaging

3.0 DATA PROCESSING

All the data (from laser scanning, digital photogrammetry and CT scan) are processed separately using specialized software, to generate inputs (i.e. 3D computer models and measurement of landmarks) for further manipulation and analysis by MyCIS (section 4).

The procedures for processing of data from the laser scanning (via RAPIDFORM2004), photogrammetry (via DVP) and CT-scan (via 3DSLICER) are summarized in Figure 6 to Figure 8 (Halim et al, 2005).

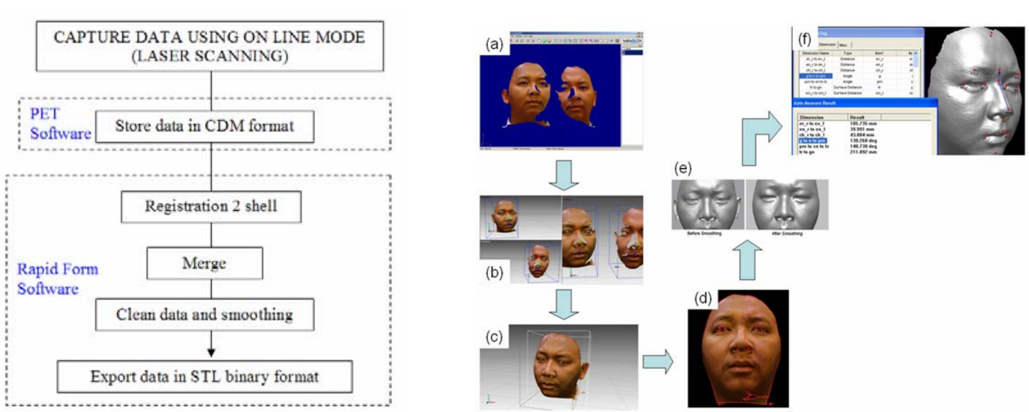


Figure 6. Laser scanning: data processing

The pre-processing of the 3D laser scanning datasets (Figure 6) consists of filtering noise, initial registration and fine registration of the two shells, merging, holes filling and smoothing (Halim et al, 2004; Mohd Sharuddin et al, 2005; Zulkepli, 2007). The post-processing (Figure 6) focuses on the measurement of craniofacial landmarks on the 3D craniofacial surface model. The process required the user to identify and digitize the location of the landmarks on the 3D surface. RAPIDFORM 2004 software offers auto-measure function to measure slope distance, along surface distance and angle between the selected landmarks.

The photogrammetric data are pre-processed first (i.e. photogrammetric triangulation process via AUSTRALIS) to determine the 3D coordinates of the natural landmarks on the craniofacial surface. The 3D coordinates were used as control points in photogrammetric orientation process via DVP. The stereo images were then post-processed (Figure 7) with the photogrammetric stereo orientation process (i.e. interior, relative and absolute orientation) to generate the stereo model. The stereo vectorization was then applied to digitize the 3D XYZ coordinates of the craniofacial landmarks (Mohd Farid et al, 2005).

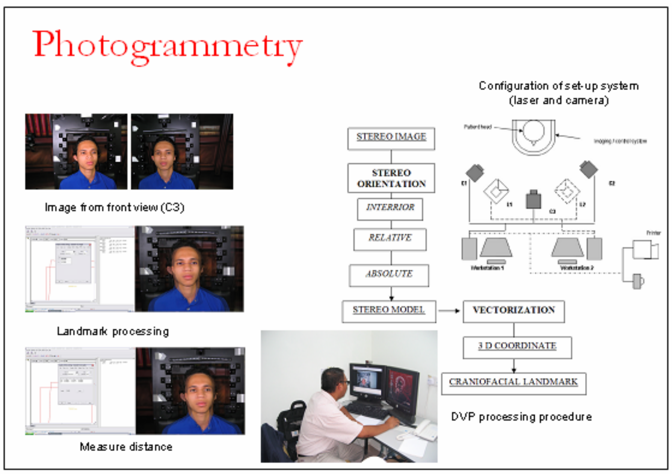


Figure 7. Stereo Photogrammetry: data processing

The integration of close-range photogrammetry and 3D laser scanning is essential for high accuracy 3D modeling of craniofacial spatial data (soft tissue). Consequently, a new 3D alignment technique was developed (Zulkepli et al, 2006) for precise alignment of 3D laser scanner data using photogrammetric targets.

The data processing of CT scan data used 3DSLICER open-source software to generate the 3D model of human skull from CT scan raw data. RAPIDFORM2004 is also used for editing, landmark identification and measurement of the human skull. Figure 8 shows the process to generate the 3D skull model (Zakiah et al, 2006). The image pixels (grayscale and color) from CT scan raw data in Digital Imaging and Communications in Medicine (DICOM) format are classified into separate colour groups based on their colour and textured information using a clustering algorithm. Image segmentation is then performed. Segmentation is the process that separates an image into its important features (primitives) so that each of them can be addressed separately. The segmentation process to generate the 3D skull model craniofacial is carried out using threshold technique. Then, image contouring is performed before the 3D model was generated (Figure 8). After all the processes were done, the 3D skull model will be displayed and editing process will be done for post processing.

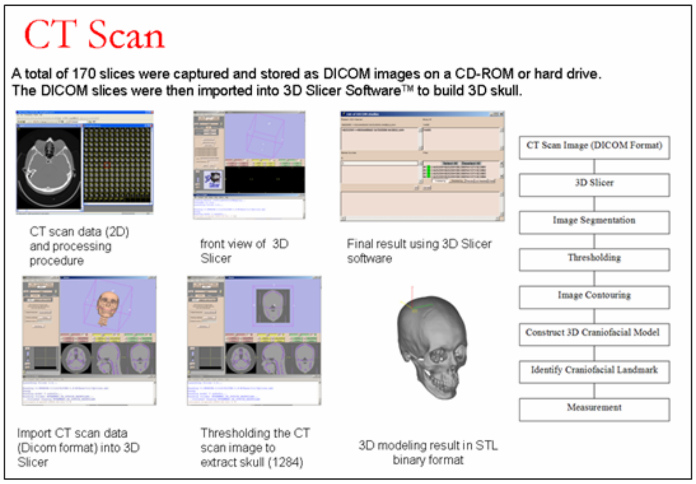


Figure 8. CT scan: data processing

In this research, a total of 24 landmarks (Kolar & Salter, 1997) are used for measurement on both soft and hard tissues (Figure 9).

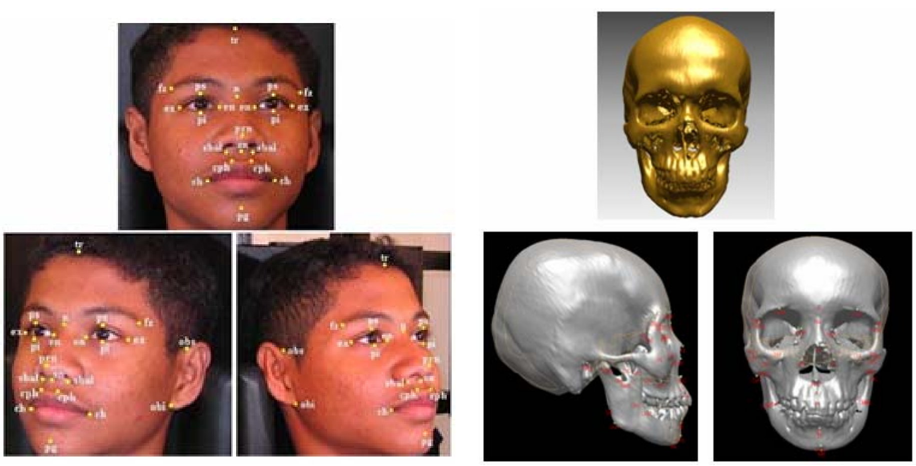


Figure 9. Landmarks on the face and skull

4.0 DATABASE

In this research, it is required to develop a spatial craniofacial database (Chong et al, 2004) and its software (Halim et al, 2004) for input, query, manipulate, analysis, and visualize the database. Such database is useful for surgical planning. Consequently, a prototype information system known as Malaysian Craniofacial Information System (MyCIS) is developed (Deni, 2007).

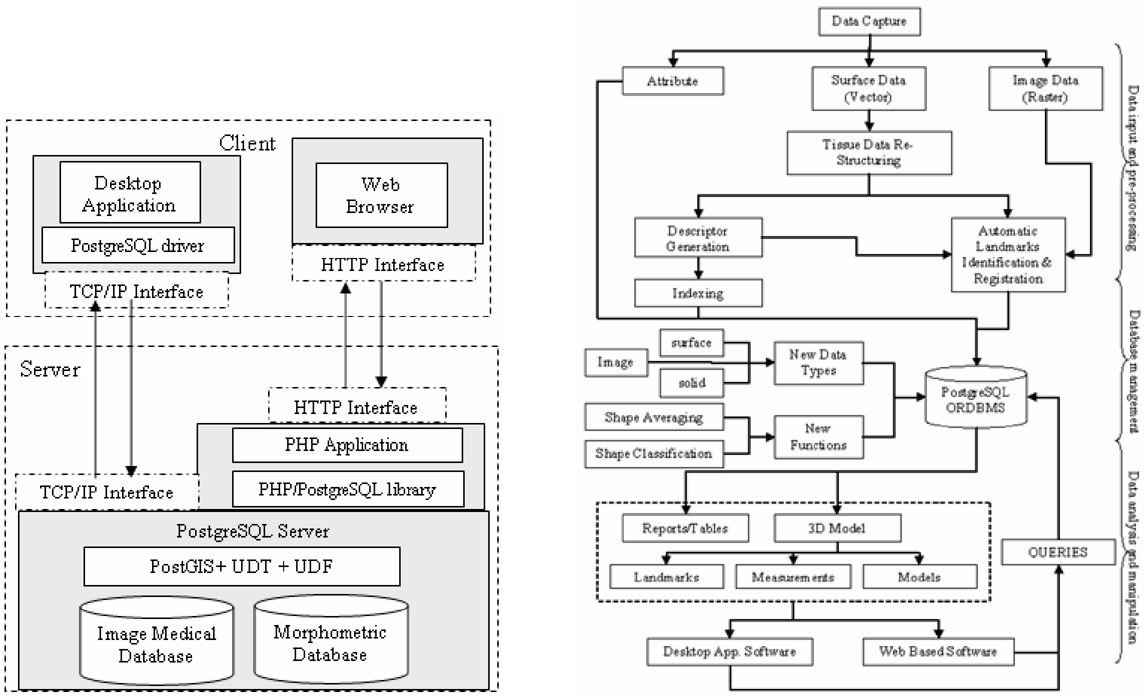


Figure 10. MyCIS: System Architecture & components (Deni, 2007)

Figure 10 shows two conceptual databases (i.e. Image Medical and Morphometric), both represent the same database (Deni & Halim, 2006). Image Medical Database stores raw data from multimodal devices (i.e. CT scan, Laser-Scan and Photogrammetry). Morphometric or Anthropometric Database store models, landmarks and measurements created from raw data after some pre-preprocessing stages. The system's architecture offers a user-interface that enables non-specialist users' easy and effective access to (complex) 3D geometry/morphometric database. Functions for browsing the database, interactive querying and querying by an existing 3D object are also available.

MyCIS is developed in-house using POSTGRESQL and other software (e.g. VISUAL C++, DELPHI, OPENGL, etc), and consists of three main components (Figure 10): Data input and pre-processing; database management; data analysis and manipulation (Deni et al, 2005). Traditional Relational Database Management System (RDBMS) is not suitable for storing, managing and retrieval complex data such as image, video, sound, or spatial data. MyCIS uses Object-Relational Database Management System (ORDBMS) for managing anthropometric/morphometric craniofacial spatial data. MyCIS integrates various inputs (soft tissue from laser scan and photogrammetry, hard tissue from CT-scan, measurement, patient's information, etc) for managing and visualizing the craniofacial data (Figure 11).

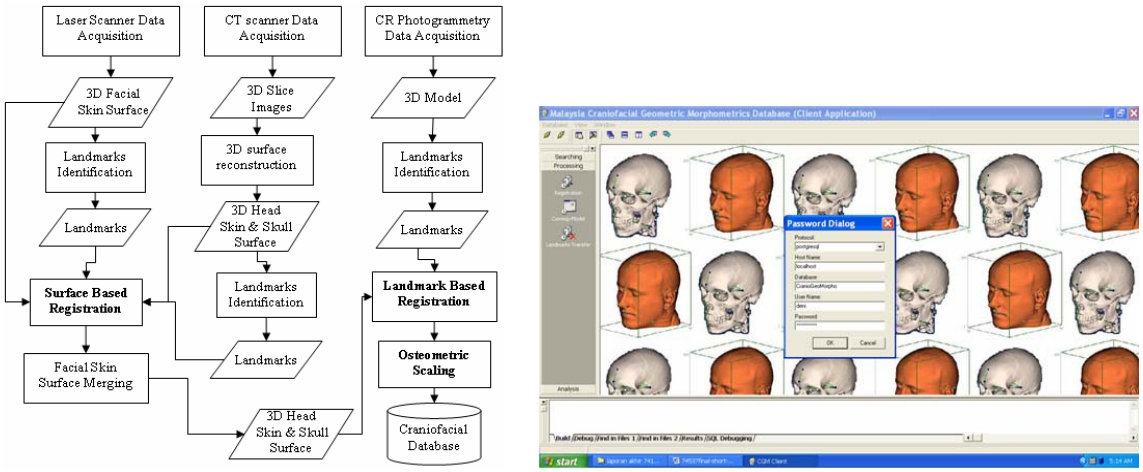


Figure 11. MyCIS: data integration & start menu

5.0 RESULTS

This section highlights the main results of the research. More detail results are given in Zulkepli (2007) and Deni (2007).

A comparison test on soft tissue measurement was performed using 3 sensors: Caliper, Scanner and Microscribe (i.e. micro-CMM). In this test, a mannequin was marked with landmarks (Figure 12), and 41 measurements were performed. The results are compared and tabulated in Table 1. Almost all the differences are within sub-mm (i.e. less than 0.7mm). The differences for Caliper-Laser range between 0.0mm to 0.7mm, for Laser-Micro range between 0.0mm to 1.2mm, and for Micro-Caliper range between 0.0mm to 0.7mm.

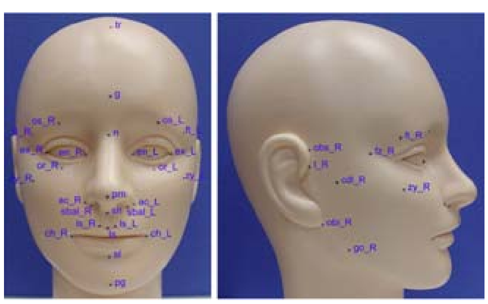


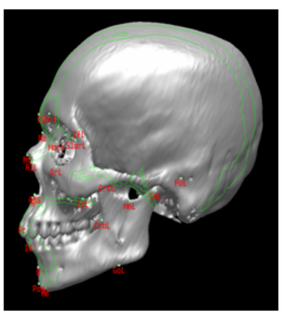
Figure 12. Mannequin

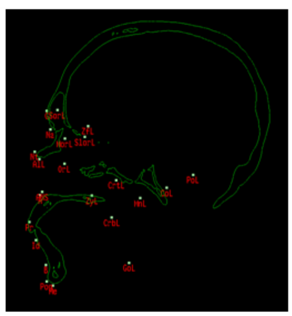
Comprehensive tests were performed on the optimization of laser system (on-line mode). The results indicate that the accuracy of the laser scanning system for craniofacial mapping is the function of the following parameters (Zulkepli et al, 2007; Mohd Kamil et al, 2006): capture mode (optimum value=fine mode with 2.5sec); point cloud=300,000 for fine mode; scan distance (optimum value=1000mm); focal length of lens (middle-angle lens, optimum value f=14mm); scanning resolution (optimum value=medium/high resolution); laser beam intensity (optimum value between 20 to 40 bands); the number of scan per face (optimum value=2-scan); and scan angle (optimum value between 80^0 to 90^0).

No	Measurement	Cal vs Micro	Cal vs Laser	Micro vs Laser
1	ftR - ftL	0.453	0.291	0.743
2	tr - g	0.311	0.312	0.002
3	tr - n	0.497	0.169	0.329
4	fzR - fzL	0.138	0.088	0.225
5	fzR - g	0.247	0.188	0.059
6	fzL - g	0.475	0.742	0.267
7	zyR - zyL	0.558	0.038	0.520
8	goR - goL	0.080	0.026	0.106
9	g - tR	0.466	0.165	0.631
10	g - tL	0.498	0.109	0.389
11	n - tR	0.417	0.431	0.847
12	n - tL	0.580	0.086	0.495
13	exR - tR	0.083	0.020	0.062
14	exL - tL	0.576	0.669	1.245
15	sn - tR	0.258	0.167	0.426
16	sn - tL	0.540	0.530	1.071
17	exR - goR	0.657	0.697	0.040
18	exL - goL	0.565	0.120	0.685
19	goR - cdlR	0.049	0.241	0.192
20	goL - cdlL	0.128	0.321	0.194
21	g - sn	0.229	0.326	0.097
22	sn - pg	0.050	0.051	0.001
23	sl - pg	0.015	0.357	0.341
24	g - pg	0.320	0.494	0.175
25	enR - enL	0.694	0.025	0.719
26	exR - exL	0.335	0.151	0.485
27	enR - exR	0.105	0.296	0.401
28	enL - exL	0.346	0.230	0.116
29	sbalR - sn	0.086	0.147	0.061
30	sbalL - sn	0.323	0.453	0.130
31	sn - prn	0.460	0.019	0.479
32	acR - prn	0.129	0.134	0.263
33	acL - prn	0.473	0.106	0.367
34	n - sn	0.049	0.386	0.337
35	n - prn	0.085	0.133	0.218
36	chR - chL	0.310	0.273	0.037
37	sn - ls	0.137	0.099	0.039
38	sbalR - lsR	0.131	0.070	0.201
39	sbalL - lsL	0.082	0.256	0.174
40	obsR - obiR	0.040	0.404	0.443
41	obsL - obiL	0.196	0.160	0.037

Table 1. Comparison of measurement between laser, caliper & Microscribe (unit mm)

The verification of hard tissue measurement was performed by comparing the results from 3D digital model (via 3DSLICER) and physical model, as illustrated in Figure 13. The differences were very close, within sub-mm.





Measurement	Digital Model (mm)	Physical Model (mm)	difference (mm)
ANS - Pr	13.50	14.19	0.69
AIR - AIL	16.63	17.05	0.43
ANS - Me	66.54	66.62	0.08
GoR - Me	88.31	87.47	0.84
Id - CrbR	63.75	63.57	0.19
Id - Pog	19.06	19.55	0.49
MorL - MorR	19.79	19.37	0.42
Na - ANS	55.52	55.09	0.43
OrL - OrR	66.54	67.22	0.68
OrL - SorL	36.44	36.89	0.45
OrR - SorR	36.29	37.09	0.80
Pog - Me	10.51	10.59	0.08
Pr - Id	25.92	26.07	0.15
SlorL - MorL	39.29	39.98	0.70
SlorR - MorR	39.72	40.64	0.92
ZyR - ZyL	89.52	89.01	0.51
ZfR - ZfL	102.57	103.4	0.83
SlorR - SlorL	94.71	95.08	0.38
SorR - SorL	62.34	62.43	0.09

Figure 13. Hard tissue: 3D model and measurement

To date the following actual data were collected from 105 patients at Hospital Universiti Sains Malaysia (HUSM), Kelantan: Laser scan (105 patients, MDL format), Photogrammetry (105 patients, JPG format), CT scan (26 patients, DICOM format). Most of the samples are from School of Dental Sciences USM, and parts of the subjects are selected from the patients with potential malformation related to craniofacial. There are 79 males (aged from 1 to 73 years old) and 44 females (aged from 1 to 69 years old). All the above informations were obtained from query via MyCIS. All these 3 types of data were processed separately (section 3), and the appropriate results are used as input for MyCIS (Figure 14).

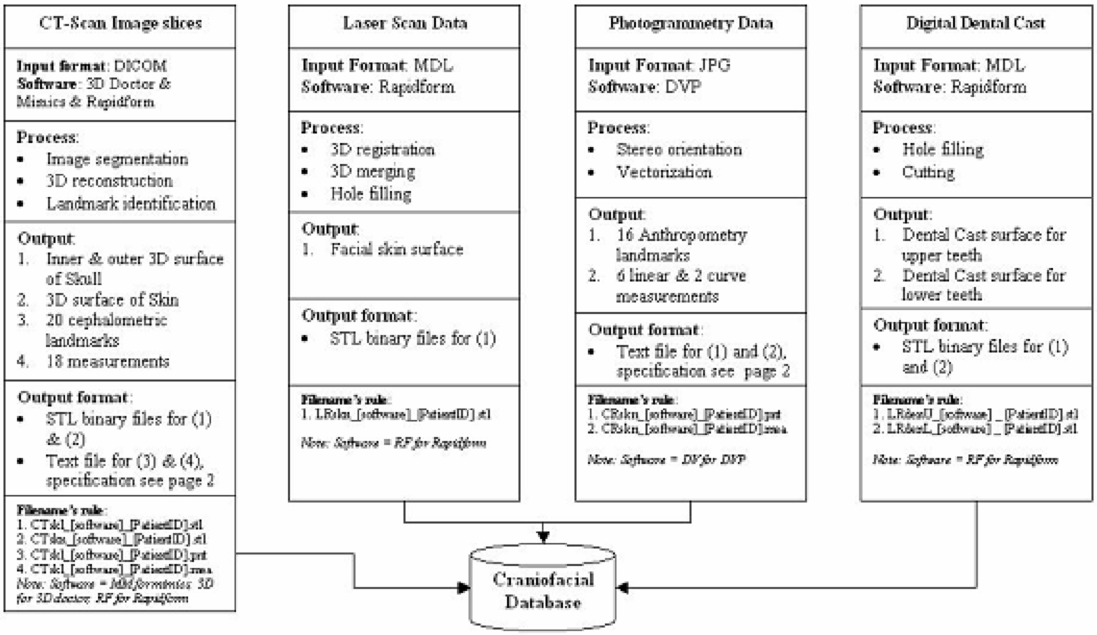


Figure 14. MyCIS: Data integration

MyCIS capabilities are shown in Figure 15 and Figure 16. The main menu of MyCIS (Figure 15) shows the available criterion for query such as key search (person name/id), sex (male/female), race, age, diagnosis category, and observation/data (laser/photogrammetry/CT). The query results could be sorted according to the selected criterion. More information (i.e. general info, models and measurements, 2D image viewer, and 3D image viewer) for a particular patient/person could be viewed by double clicking the name. In addition, some advanced processing options (registration, landmark measurement, multi resolution dense correspondence model, realistic modeling, etc) are available too. Figure 16 shows an integrated 3D model by combining data from CT (i.e. skull), laser (i.e. face) and photogrammetry (landmarks).

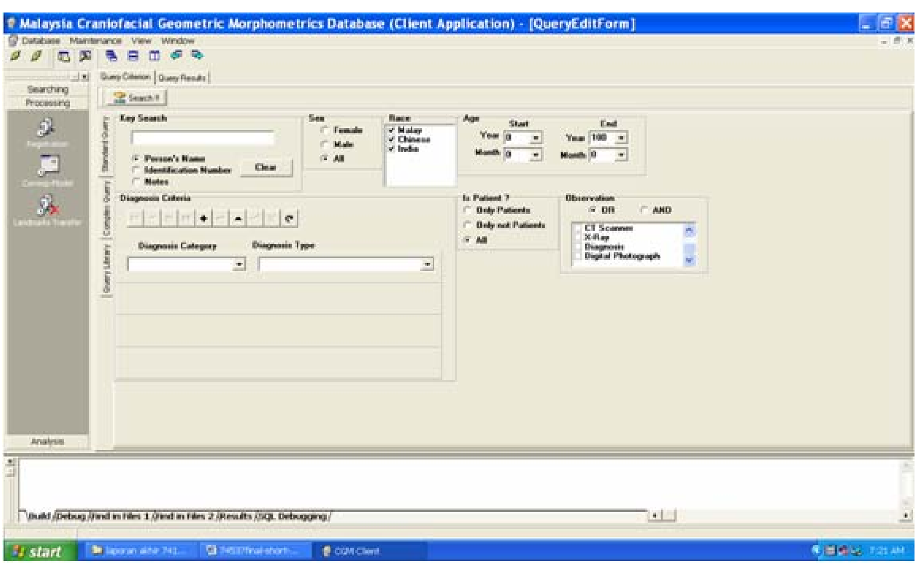


Figure 15. MyCIS main menu

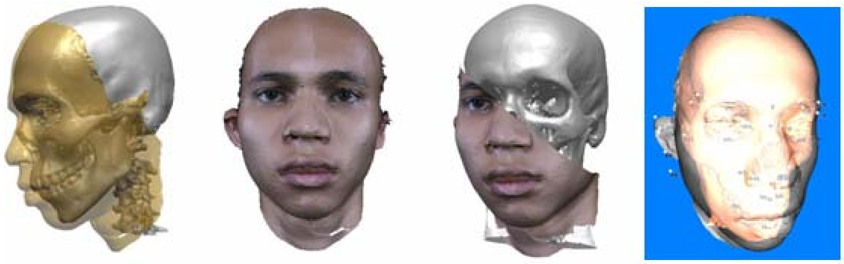


Figure 16. Integrated 3D model

The actual results to date (with measurement accuracy of less than 0.7mm) indicate the suitability of the adopted procedure for practical craniofacial applications.

6.0 CONCLUSION

This paper discusses the development of specialized imaging system for capturing soft tissue spatial data (close range, non-contact, and real time), and specialized craniofacial information system (i.e. MyCIS) for managing of local craniofacial database.

The results to date indicate the suitability of the adopted procedure for practical craniofacial applications. This research has produced the latest approach for imaging of soft tissue and managing of local craniofacial data. The results from this research are useful for many multi discipline applications (both local and abroad) requiring craniofacial data.

Currently, the research works at UTM also concentrates on the following on-going craniofacial-related research works: 3D planning and modeling techniques for craniofacial reconstruction surgery, optimization of imaging and 3D measurement procedure, craniofacial classification via statistical shape analysis method, cephalometric measurement and analysis, and dental cast measurement and analysis.

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