THE DEVELOPMENT OF IMAGE CAPTURING SYSTEM AND INFORMATION SYSTEM FOR CRANIOFACIAL RECONSTRUCTION

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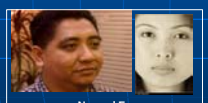
3rd FIG Regional Conference for Asia and the Pacific, Jakarta, 3-7 Oct 2004

Contents

INTRODUCTION

- Human face is a complex surface, with different depth and texture.
- For medical purposes (such as craniofacial reconstruction), human faces need to be measured and modeled accurately.



Normal Faces

Abnormal Faces

INTRODUCTION

•Most surgeons use laborious traditional contact method (for example, calipers) for measuring anthropometric landmarks on human face...not practical!

•Requirements of craniofacial reconstruction: measurement [non-contact, accurate & rapid] of human face [soft tissue] & skull [hard tissue]; 3D model [digital & physical]; Malaysian craniofacial database; surgical planner...inter-disciplinary!

INTRODUCTION

•A multi-disciplinary research (2002-2005) is established between Universiti Teknologi Malaysia (UTM), Standards & Industrial Research Institute Malaysia (SIRIM), and Universiti Sains Malaysia (USM).

•Expertise: UTM (imaging of soft tissue, database), SIRIM (Rapid Prototyping, database), USM (imaging of hard tissue, craniofacial surgeons).

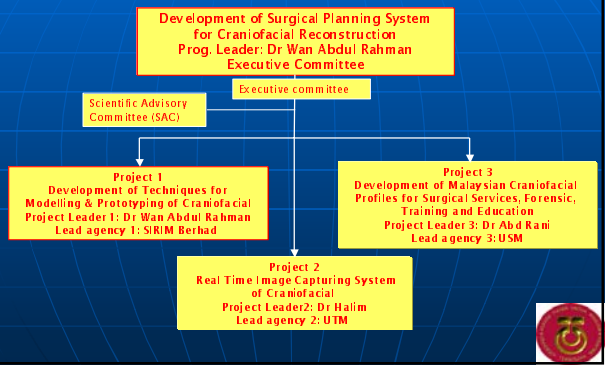
•Research fund: Ministry of Science Technology & Innovation [MOSTI] Malaysia.

•Research focus: The development of surgical planning system for craniofacial reconstruction [for both the soft and hard tissues].

•Deliverables: imaging technology, craniofacial database, surgical planner.

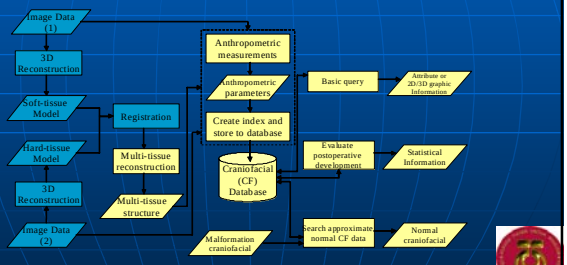
•UTM: Real time image capturing system of craniofacial.

Research Program Structure



UTM: Project 2

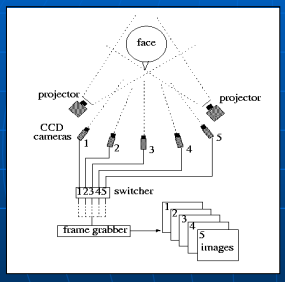
•The focus: Development of real-time image capturing system [close range] & information system for craniofacial soft tissue.

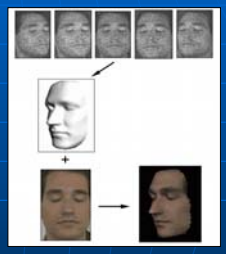


METHOD: IMAGING SYSTEM

- ***3D Modeling of Human Face***
  - On-going research (world wide)
  - Requires modern and advanced technology
  - Modeling of facial soft tissue and hard tissue (skull)
  - Imaging Techniques [soft tissue] : Stereophotogrammetry, Coded Light Range Digitizer, etc
  - Imaging Techniques [hard tissue] : CT Scan, MRI, etc.
  - Application : Craniofacial Planning Surgery, Forensic Study, etc

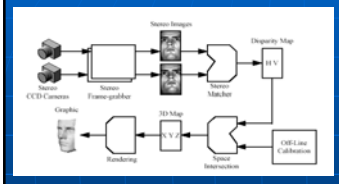
Modeling Human Faces with Multi-Image Photogrammetry





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.

A C3D : A Novel Vision Based 3D Data Acquisition System



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

Objectives: UTM

i. To develop a craniofacial data acquisition system for reconstructive surgery based on stereophotogrammetry and laser scanning technique

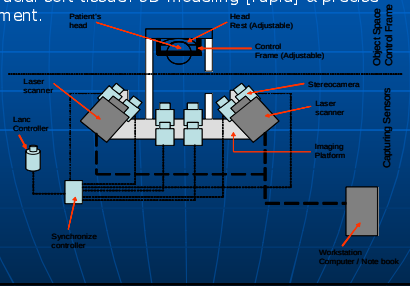
ii. To evaluate the reliability, accuracy and outlier detection of the technique based on advanced statistical deduction

iii. To develop and evaluate a new algorithm for image matching technique between stereophotogrammetry and laser scanning data for a complete 3D craniofacial surface models

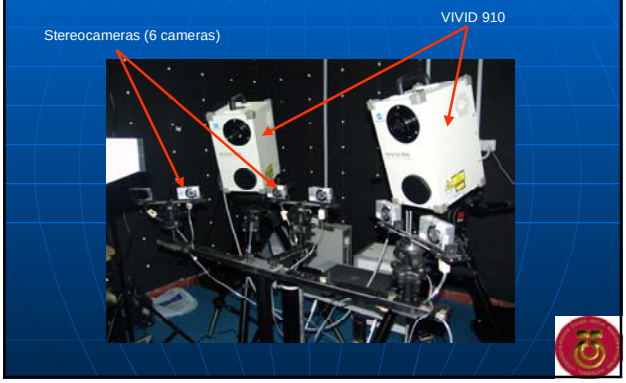
iv. To develop an efficient method for measurement of anthropometric landmarks

IMAGING SYSTEM: UTM

•The developed image capturing system combines the laser scanning (using 2 Minolta Vivid 910) and stereo photogrammetric techniques (6 cameras) for acquiring high-resolution 3D models of craniofacial soft tissue: 3D modeling [rapid] & precise measurement.



Imaging Sensors: UTM



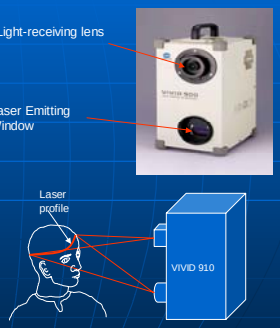
HARDWARE & SOFTWARE

- Minolta Vivid 910 & PET software: 3D model
- Camera: photogrammetric data
- Control frame
- Rapidform software: process scanned data, 3D modeling
- Australis software: camera calibration
- DVP software: process photogrammetric data
- Computer

- In this presentation we report our experience: using Vivid910 in modeling of human face for medical application (craniofacial surgical planning study).
- The study comprises of six steps :
  - *Data Acquisition setup*
  - *Scanning of human face*
  - *3D image registration and merging of scanned images*
  - *3D editing and modeling*
  - *3D smoothing*
  - *3D Measurement of anthropometric landmarks*

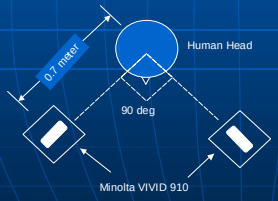
3D Surface Laser Scanning System

- Minolta Vivid 910
- Eye-safe laser scanner
- Exchangeable lens
- Operates using laser triangulation light block method
- Capture mode : fine (2.5 sec) and fast (0.3 sec)
- Point cloud : 300,000 (Fine), 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



Methodology

- ***Data Acquisition Setup***
  - **Two VIVID 910 3D digitizers**
  - **Object distance : 0.7 meter**
  - **Lens : Middle Lens**



- **Running one after another**

Scanning of human face

- Fine mode
- on-line method (via scsi cable)

On-line method
(Control using PET or RapidForm Software)

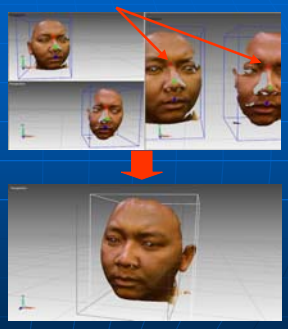
Off-line method
(Using Scan Button and Compact Flash Memory Card)

Scanning output : Polygon Editing Tool Software

3D Registration and Merging Process

- Registered two scanned images automatically using RapidForm software
- Method : initial image registration based on selected corresponding points (Iterative Closest Point Algorithm)
- Merging process : involves 3D merging of scanned images and texture

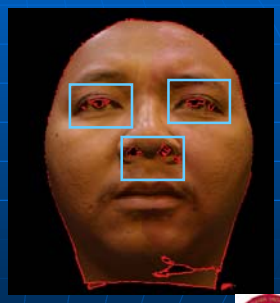
Selecting corresponding points



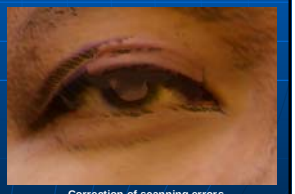
Output after registration and merging process

3D Editing and Modeling

- The scanner is sensitive to black features on the face such as hair, eye brows, eye balls and beard
- This factor will generate an errors in the scanning images and represented as holes
- RapidForm software is capable of finding holes and eliminates them by adding new points and polygon => the local curvature of the mesh is preserved.



Scanning errors (holes)



Correction of scanning errors

- 3D smoothing process

Before Smoothing

After Smoothing

Measurement of anthropometric landmarks

- The measurement of human face soft tissue data is important in planning craniofacial surgery
- The measurement involved straight and curve distances, and an angle
- 46 anthropometric points located on different part of the face
- Conventional method :
  - Uses calipers (tape, sliding caliper, level and angle finder)
  - Disadvantages : contact measurement

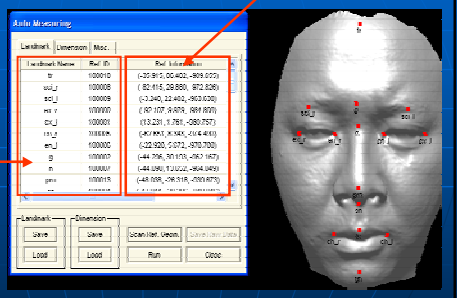
- In RapidForm software, the distances and angles are computed automatically according to the points selected by the user
- Two methods of measurement :
  - (a) **point to point mode**
  - (b) **Automatic Measure Function**

Point to point measurement method

Automatic Measure Function

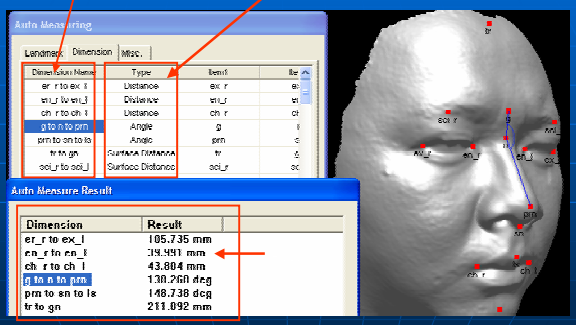
3D coordinates of landmarks

Landmark Name



Dimension

Type of measurement



- **Validation study**
  - To validate the non-contact method in measurement of anthropometric landmarks
  - Number of points involved :
    - 7 points (ex, en, ch, sn, gn, obi, obs)
    - Straight distances : ex-ex, en-en, ch-ch, sn-gn
    - Curve distances : obi-sn, obs-ex
  - Comparison with conventional method

Human Head Mannequin

Results

$$Difference(mm) = Conventional(mm) - \left(\frac{SingleMeas(mm) - AutoMeas(mm)}{2}\right)$$

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	44.65	-0.50
obi-sn	109.50	108.93	0.57
obs-ex	60.50	60.57	-0.07

- The project accuracy requirement was 0.7mm (from literature)
- Table: the difference between the conventional and the digital technique was less than 0.7mm
- Therefore, the accuracy of the digital technique satisfy the project requirement

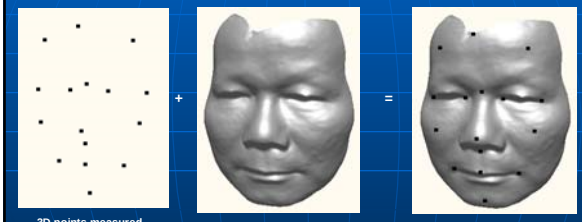
RESULTS

- Comparison: photo, laser, caliper
- Differences within few mm, and mainly due to the inaccuracies of locating the anthropometric landmarks either manually (using caliper) or digitally (using DVP and RAPIDFORM).

Measurement Points	Calipers [A] +/- 0.05 (mm)	Photo [B] (mm)	Laser [C] (mm)	Diff 1 [B-A] (mm)	Diff 2 [C-A] (mm)	Diff 3 [C-B] (mm)
1 ~ 2	96.55	98.26	97.43	1.71	0.88	-0.83
6 ~ 7	60.25	58.68	57.08	-1.57	-3.17	-1.60
10 ~ 11	62.65	63.64	63.50	0.99	0.85	-0.14
4 ~ 3	63.90	61.04	65.94	-2.86	2.04	4.90
3 ~ 9	43.10	41.05	44.05	-2.05	0.95	3.00
1 ~ 3	56.70	54.96	58.52	-1.74	1.82	3.56
2 ~ 3	55.40	54.32	55.88	-1.08	0.48	1.56
10 ~ 3	45.30	44.40	46.40	-0.90	1.10	2.00
11 ~ 3	42.95	41.92	42.15	-1.03	-0.80	0.23
9 ~ 5	20.90	19.80	20.98	-1.10	0.08	1.18

Table 1. Comparison of results

3D Matching between stereophotogrammetry and laser scanning method for development of complete 3D Model of Craniofacial Data



3D points measured by stereophotogrammetric technique (DVP system)

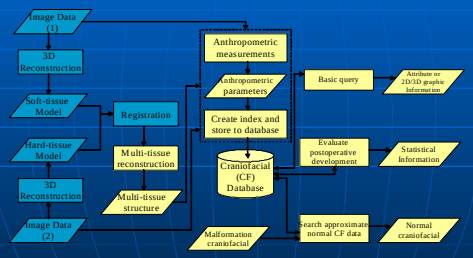
3D surface measured by laser scanning technique

Complete 3D Model of Craniofacial Data

- **Conclusion/imaging**
  - The use of laser scanning system in modeling human face was found to be excellent and effective
  - VIVID 910 :
    - ***Advantage : Fast 3D data collection***
    - ***Disadvantage : Sensitive to black features***
  - The scanning errors can be corrected and improved up to 70% closer to real object
- **On-going Works on laser scanning**
  - Laser Scanner Synchronization (reduce scanning time)
  - Laser Scanner Calibration (evaluate the accuracy)
  - Precise 3D Registration Method (increase accuracy)
  - Texture Mapping (register photorealistic images on 3D data)

METHOD: INFORMATION SYSTEM

- Craniofacial database!



Objectives

1. To develop 3D raster-based and vector-based data models
2. To develop algorithms for the retrieval and manipulation of spatial information for craniofacial reconstruction
3. To evaluate the reliability of the developed craniofacial spatial information system

Outcome of System

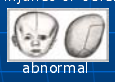
1. To view a patient stereo-craniofacial-images, 3D craniofacial surface model and 3D hard tissue model.
2. To manipulate the data of (1) to obtain 3D vector information, anthropometric measurement and soft tissue data.
3. To view attribute information.
4. To obtain statistical information on postoperative development and quality information on the surgical operation.

Related Works

- Some projects in images medical database (PACS), Anthropometric Databases, Clinical Information System and 3D GIS (Geographic Information Systems) database
- Research in 3D modeling, mesh data structure for elastic surface
- Research in Surgical Planning System, Forensic Science and Product Design.
- Research in 3D object database, similarity search and indexing system
- Research in Shape analysis

What for?

- Surgery (Pre, Intra and Post Operative)
  - Craniofacial surgery consists of operations on the soft tissues and bones in the head and face. These operations are done primarily on children born with abnormal shapes of the head and face. Sometimes such surgery is done to patients suffering with tumors, injuries or other disorders.


abnormal

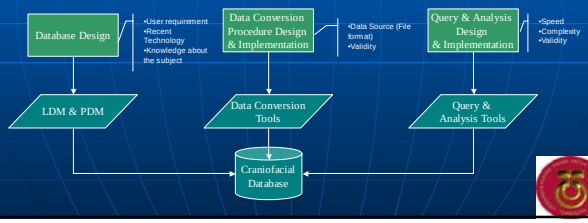

pre


post

- Forensic, medical procedures and scientific testing done for use in court
- Design Product (helmet, oxygen mask, glasses)

Methodology

- Database Design
- Data Conversion Procedure Design & Implementation
- Query/Analysis Design & Implementation
- User interface Design & Implementation



Design Issues

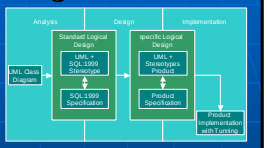
- *Automation*: Every function available to the user must require a minimal amount of user intervention. In particular, functions related to 3D data processing must ideally be completely automated.
- *Ease of use*: The application must incorporate a simple, clear, helpful graphical user interface, as it is meant to be used by semi-expert or non-expert operators.
- *Flexibility*: The application must use simple and standard data formats for input and output, so that it may easily communicate data between other applications available on the market.
- *Reliability*: The application should be capable of processing almost every data set mentioned in its specification. In case of failure it should retain its run-time integrity and inform the user of the nature of and reason for the failure, suggesting possible actions in order to complete an operation successfully.

Design Issues

- *Performance*: Basically, three actions need to be taken in order to improve the performance of the running application (ideally to a response-time of a few seconds per query):
  - Simplification of the 3D Model
  - Off-line pre-calculation of as many quantities as possible at the time of data uploading.
  - Database optimization at the time of design, by use of canonical forms, relational calculus, primary keys and fast indexing mechanisms that speed up the database searches
- *Security*: needs to be taken to protect the database from intruders. Examples of security method are :
  - Centralized control of user access
  - Protection of the subject's personal details.
  - Firewall
- *Working with 3D Data*: Multimedia Databases store not only images, sounds and videos, but could be in 3D geometrics surfaces/solid forms.
  - From Images Processing to Geometrics Processing
  - Craniofacial data is multimedia data
  - Need one representation of shape to simplify the process

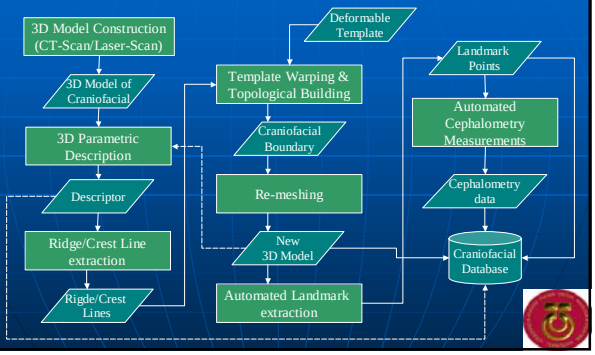
Database Design

- At the **analysis** phase, UML class diagram is used to design the conceptual schema, because UML is the standard language for object-oriented system design.

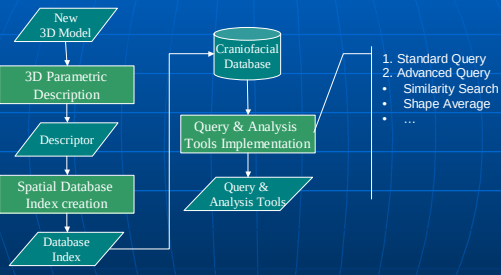


- The **design** phase is divided into two steps:
  - Standard design, that is, a logical design independent of any product.
  - Specific design, that is, the design for a specific product (for example, Oracle8*i*, Informix, Postgres, etc.).
- The **implementation** phase includes the physical design tasks. In this phase the schema obtained in the previous phase are refined to improve the response time and storage space according to the specific needs of the application.

Data Conversion Procedure



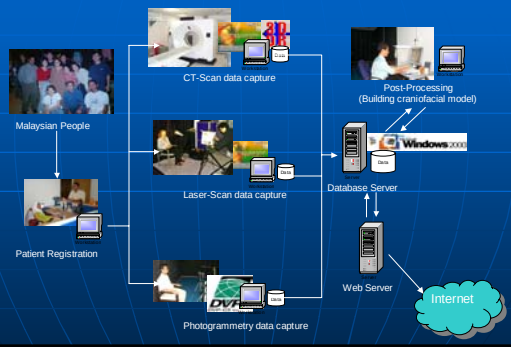
Query and Analysis



User Interface Design

- **Uploading Tool**: a 'Loader' program that copying scans, measurements and patient data onto the database.
- **Query Tool**: Queries in system are structured along the lines of natural language and sentences. Queries are composed by users based on simple multiple hierarchical choices without knowing any low-level concepts such as 'join' and 'selection'.
- **Reporting Tool**: The reporting tool allows the user to navigate an object in a hierarchical fashion. In particular, from a high-level object (e.g. patient) the user can "drill down" to lower-level objects that comprise the higher-level; similarly, from a low-level object the investigator can "roll up" to higher-level objects.
- **Analysis Tool**: The analysis tool aggregates low-level data and provides summary information. In this way the user can gather data from multiple tests and view them graphically on one form, or request aggregate data on group of patients.

Overview of prototype system



Data set

- Data for information system: 3D soft & hard tissue models, measurement & patient's information.
- 3D craniofacial skin surface scan using laser scanner [3D soft tissue model]...UTM.
- 3D craniofacial skull surface from CT scanner [3D hard tissue model]...SIRIM.
- Anthropometric landmark measurement with stereo-photogrammetry...UTM.
- Hard tissue landmark measurement from CT scans...SIRIM.
- Landmark measurement from the lateral and frontal cephalograms...SIRIM.
- Dental landmark measurement of the dental cast...UTM

Data Base Management System

- PostgreSQL is an open-source descendant of the original Berkeley (University of California) code. It supports SQL92 and SQL99 and offers many modern features: complex queries, foreign keys, triggers, views, transactional integrity, and multiversion concurrency control.
- Also, PostgreSQL can be extended by the user in many ways, for example by adding new data types, functions, operators, aggregate functions, index methods and procedural languages.
- And because of the liberal license, PostgreSQL can be used, modified, and distributed by everyone free of charge for any purpose, be it private, commercial, or academic research

Thin Client Application

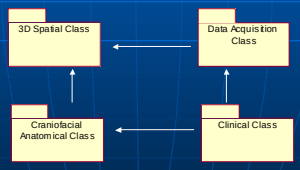
- The application connects to the database via local area network (LAN) or private TCP/IP connections.
- Purposes:
  - Loading data from some data sources to database.
  - Query
  - Visualization
  - Editing, either textual or spatial data
  - Anthropometry measurement at 3D model
- Tools for development
  - Borland Delphi
  - GLScene (open source). GLScene is an OpenGL based 3D library for Delphi or Borland C++ Builder.
  - ZeosDB (open source). ZeosLib is an Open Source project supporting application developers with technologies for high-performance native database access across different platforms.

Web-based Client Application

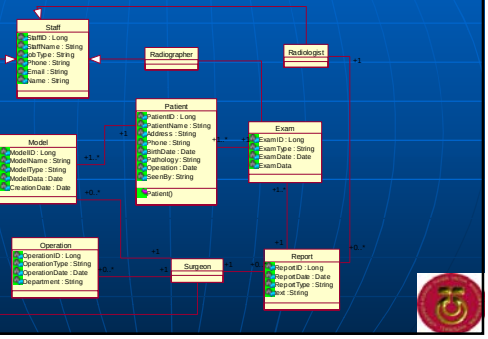
- Purposes:
  - Query
  - Visualization
  - Data distribution.
- Tools for development:
  - PHP scripting language, PHP is a widely-used general-purpose scripting language that is especially suited for Web development and can be embedded into HTML.
  - Apache web server software

Class Objects Package

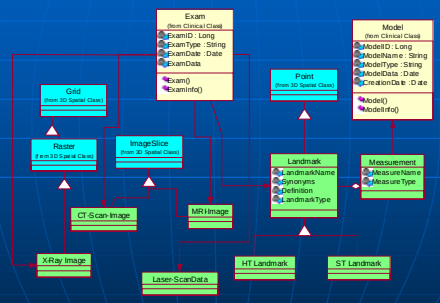
- There are four groups of class objects that support the database; they are 3D spatial, craniofacial anatomical, data acquisition and clinical class objects group. 3D Spatial group has own independency structure from others group and this take as a super group in global diagram. Classes in this group are 3D graphic/geometric primitive and there are some topological relationships between them.



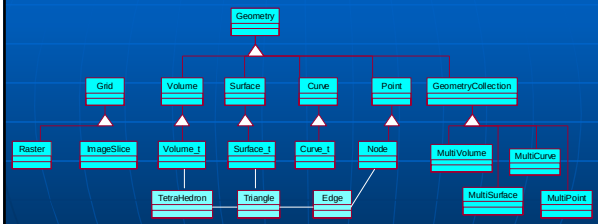
Clinical Classes



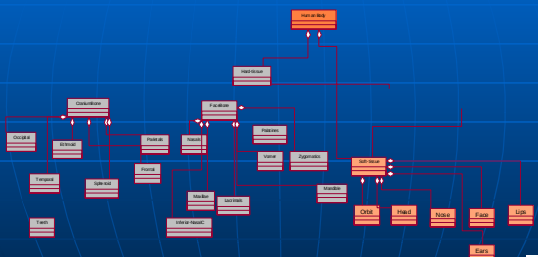
Data Acquisition Classes

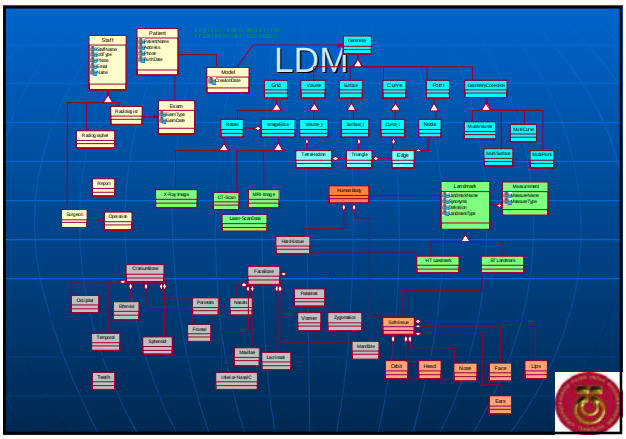


3D Spatial Classes

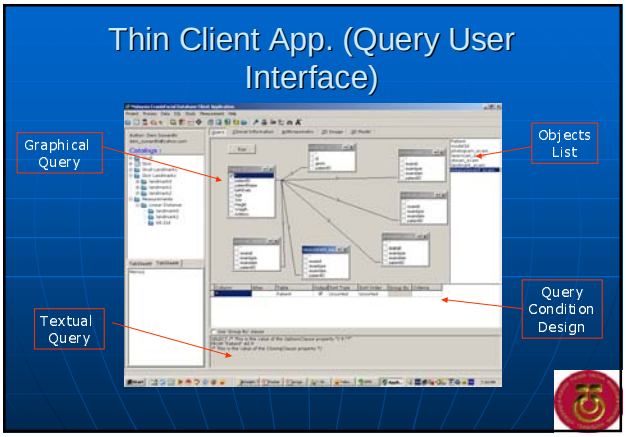


Craniofacial Anatomical Classes

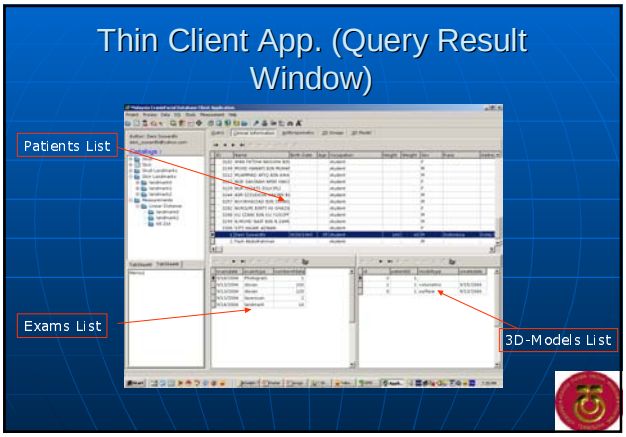




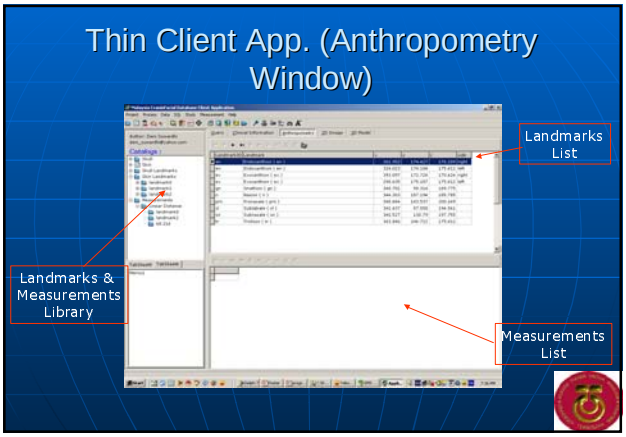
Thin Client App. (Query User Interface)



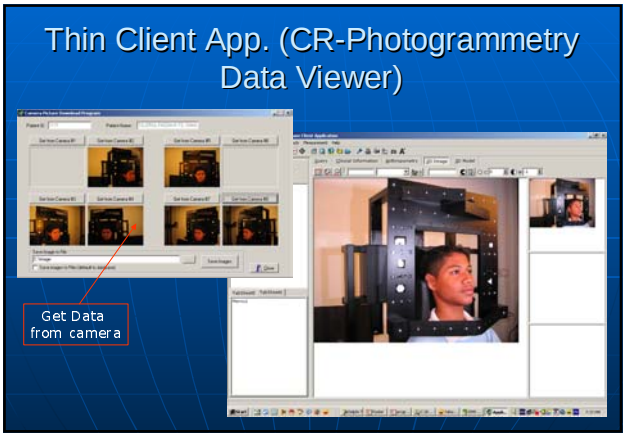
Thin Client App. (Query Result Window)



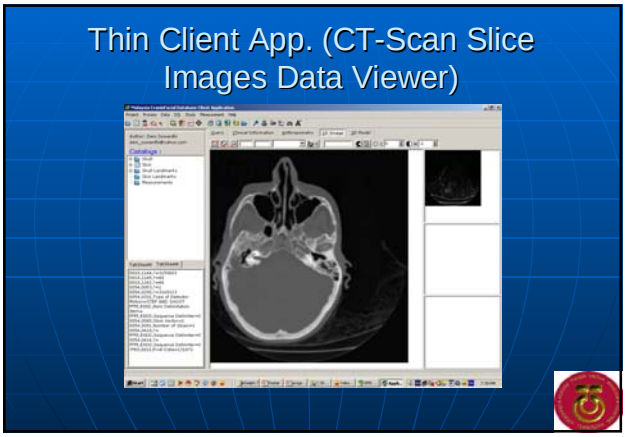
Thin Client App. (Anthropometry Window)



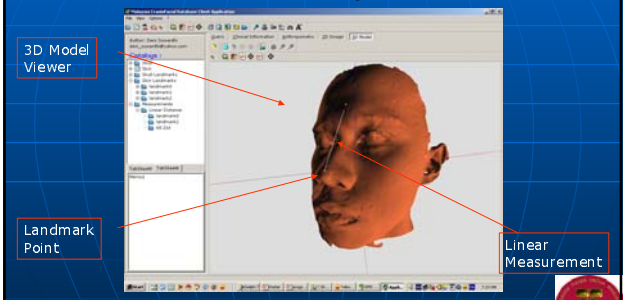
Thin Client App. (CR-Photogrammetry Data Viewer)



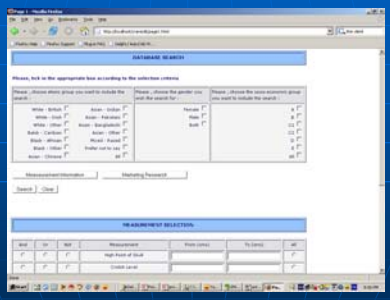
Thin Client App. (CT-Scan Slice Images Data Viewer)



Thin Client App. (3D-Model Data Viewer)



Web Client App. (Query Interface)



CONCLUSIONS

- A multi-disciplinary research is established between UTM, SIRIM & USM.
- Research focus: The development of surgical planning system for craniofacial reconstruction [for both the soft and hard tissues].
- This presentation [UTM]: research works on the development of a close range image capturing system and information system for craniofacial.
- The image capturing system combines the laser scanning and photogrammetric techniques for acquiring high-resolution 3D models of craniofacial soft tissue.
- The information system is used for managing and visualizing the craniofacial data.
- On-going multi-disciplinary research works

The progress!

- Imaging system, calibration, 3D modeling, database design

THANK YOU!

This research is sponsored by
Ministry of Science, Technology &
Innovation [MOSTI] Malaysia