Computer Assisted Surgical Planner for Craniofacial Reconstruction – Imaging Techniques

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Abstract

Computer Tomography (CT) and Magnetic Resonance Imagery (MRI) have had an enormous impact in medicine. Using medical imagery, Computer Assisted Surgery (CAS) systems decrease the invasiveness of surgical procedures, increase accuracy and facilitate surgical planning and analysis. Craniofacial anomalies and fine anatomic details of facial traumic injuries can be well studied with such imaging techniques. This research is focused on reconstruction of human hard/soft tissues and anthropometric landmarks for craniofacial surgery. The data capture devices used include CT scanner, 3D Laser Scanner and Close Range Photogrammetry. The visualization of soft tissue superimposed on hard tissue, display of tissue with varying opacity, and cutting of tissues for detailed analysis and planning has been demonstrated in this paper.

Keywords: CAS, surgical planner, soft tissue, hard tissue, cutting

1. Introduction

Radiological science in the last two decades has witnessed a revolutionary progress in medical imaging and computerized medical image processing. The development and advances in multidimensional medical imaging modalities such as X-ray Mammography, X-ray Computed tomography (CT), Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), Ultrasound, Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI) have provided important radiological tools in diagnosis and treatment evaluation and intervention of critical diseases for significant improvement in health care [1][2].

The clinical significance of radiological imaging modalities in diagnostic and treatment of diseases is overwhelming. While planar X-ray imaging was the only radiological imaging method in the early part of the last century, several modern imaging modalities are in practice today to acquire anatomical, physical, metabolic and functional information from the human body. The commonly used medical imaging modalities capable of producing multidimensional images for radiological applications are CT, MRI, SPECT, PET and Ultrasound.

Simple planar radiographic imaging methods such as X-rays and mammograms usually provide images on a film through an external radiation source (X-ray). These planar radiographic imaging methods provide high quality analog images that are shadow or two-dimensional projected images of three-dimensional organs. On the other hand, recent complex medical imaging techniques such as X-ray CT, MRI, SPECT, PET and ultrasound provide multi-dimensional digital images. These multi-dimensional digital images of physiological structures can be manipulated to visualize hidden characteristic diagnostic features that are difficult or impossible to see with planar imaging methods.

In many critical radiological applications, the multi-dimensional visualization and quantitative analysis of physiological structures provide extremely valuable information for diagnosis and treatment. The computerized processing and analysis of medical imaging modalities provide a powerful tool that helps physicians to make important clinical decisions.

The organization of this paper is as follows. First, in section 2, we give an overview of medical imaging modalities. In section 3 we elaborate the imaging methods being used in this research. Section 3.1 discusses Laser Scanning, section 3.2 discusses Close Range

Photogrammetry and section 3.3 discusses X-ray CT imaging. In section 4 we present some of our basic results. Finally, we discuss the imaging modalities and results.

2. Medical Imaging Modalities

The overall objective of medical imaging is to acquire useful information about the physiological processes or organ of the body by using sources of energy. Imaging modalities available for radiological applications may use internal, external or a combination of energy sources. Figure 2.1 identifies medical imaging modalities classified on the basis of imaging energy sources.

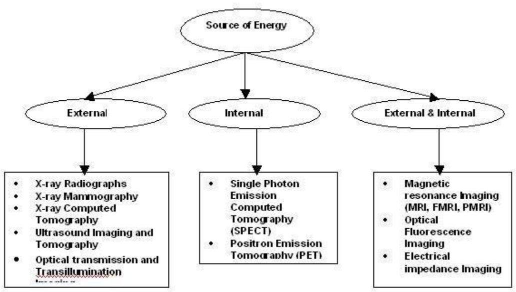

Figure 2.1. Classification of Medical imaging modalities on basis of energy sources

In most commonly used imaging methods, ionized radiations such as X-rays are used as an external energy source primarily for anatomical imaging. These imaging modalities are based on the attenuation of radiation passing through the body. X-ray radiographs and Computed Tomography (CT) measure attenuation coefficients of X-rays that are based on the density of the tissue or part of the body being imaged. Ultrasound is another imaging method that uses external source of energy.

Nuclear Medicine imaging modalities use an external energy source through an emission process to image the human body. For emissive imaging, radioisotope pharmaceuticals are injected into the body to interact with selected body matter or tissue to form an internal source of radioactive energy that is used for imaging.

Magnetic resonance Imaging uses external magnetic energy to stimulate selected atomic nuclei such as hydrogen protons. These excited nuclei become the internal source of energy to provide electromagnetic signals for imaging during the process of relaxation. MRI of the human body provides high-resolution images of the human body with excellent soft-tissue characterization capabilities.

In all the medical imaging modalities, the principle of imaging has great importance. For example, X-ray imaging uses transmission of X-rays through the body as the basis of imaging. On the other hand, in Nuclear Medicine modalities, SPECT uses the emission of gamma rays resulting from the interaction of a radiopharmaceutical substance with the target tissue. The emission process and the energy range of gamma rays cause limitations on the resolution and data acquisition time for imaging. So it is difficult to see same level of anatomical information from both modalities. Therefore, SPECT and PET provide images that are poor in contrast and anatomical details while the X-ray and CT provide sharper images with high-resolution anatomical details. The MRI provides high-resolution anatomical details with excellent soft–tissue contrast.

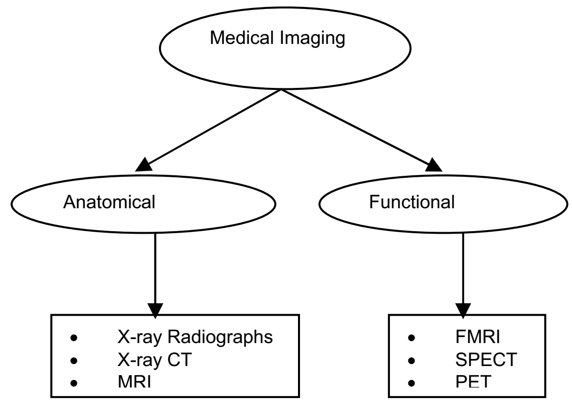

Figure 2.2. Classification of Medical imaging modalities on basis of information

Medical imaging modalities, on the basis of information they provide, can be broadly classified into two classes (Figure-2.2): (1) anatomical or structural, and (2) functional or metabolic [3] [4]. The characteristics of a specific anatomical imaging modality depends upon its ability to discriminate different constituent of the body such as water, bone, soft tissue and other biomedical fluids [5]. The major anatomical modalities include X-ray imaging (R-ray radiographs, X-ray mammography, X-ray CT), ultrasound and MRI. The characteristic of a specific functional imaging modality depends on its ability to discriminate different level of metabolism caused by specific biochemical activity that may be generated by the uptake of a radiopharmaceutical substance. Major functional imaging modalities include functional MRI (FMRI), SPECT, PET and fluorescence imaging. For example, FMRI can be used to measure blood flow or oxygenation level in brain tissue. The change in the blood or oxygen level in the tissue is considered to reflect neural activity in the brain caused by stimulation such as sound or light. In Nuclear Medicine modalities, blood flow in tissue organ can be measured through an emission process of a radioactive tracer that is administered in the blood. For example, a PET image obtained through the administration of flurodeoxyglucose (FDG) may show blood flow and glucose metabolism in the tissue that may be affected by a disease such as tumor or epilepsy [3].

3. 3D Imaging – System Setup

The focus of this research is intended to develop a craniofacial spatial database and information system, and a Craniofacial Surgical Planner for Malaysian people. Figure 3.1 shows the flow diagram of the surgical planner under development. The system is needed for medical and dental practitioners, forensic examiners, protective gear manufacturers and researchers [6].

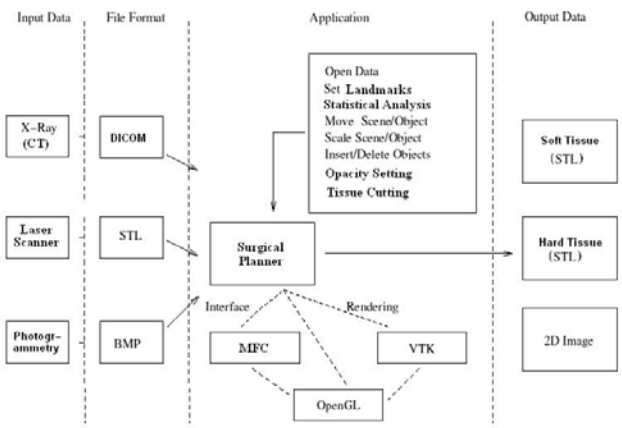

Figure 3.1. Flow diagram for surgical planner

For development of Craniofacial Surgical Planner, a number of imaging modalities are being used to capture soft-tissue data, hard-tissue data, skin-surface soft-tissue data and data for landmarks on skin surface. The imaging modalities used to capture above mentioned types of data include X-ray CT imaging, Laser Scanner imaging and Close Range (CR) Photogrammetry. X-ray CT imaging provides soft and hard tissue data. Laser Scanner imaging captures skin surface soft-tissue data and CR Photogrammetry captures soft skin texture information along with data for anatomical landmarks on skin surface.

This section presents some details about the equipment and system setup to acquire all above-mentioned types of data for Craniofacial Surgical Planner.

3.1. 3D Laser Scanners

In this research, in order to capture three-dimensional skin-surface soft tissue data, two three-dimensional non-contact Minolta VIVID 910 laser-scanning systems have been used. Minolta VIVID family of 3D Laser Scanner is a good choice for various applications such as medical applications (such as surgical planning system in maxillofacial, dental and orthopedic, plastic surgery and measurement of anthropometric landmarks), rapid prototyping input, CAD reverse engineering, machine vision, computer graphics, quality control inspection of production parts and industrial design. [7]. Figure 3.2 shows VIVID 910 3D laser Scanners setup.

Figure 3.2. Setup for scanning process [7]

In this research, two Minolta VIVI-D 910 laser Scanners are used to capture human face. The angle between the two scanners is 90 degree and each scanner is placed at a distance of 0.7m from the human face, a shown in Figure 3.2. There are two operating modes for these scanners classified as fine mode and fast mode. The fine mode scan produces 3D data of 307,000 pixels whereas the fast mode can produce 76,800 pixels with 640x480x24 bits color depth. Both scanning modes record RGB color texture information of the scanned object. The captured data is then transferred to computer for further modeling process. "Polygon Editing Tools" software is used to transfer the data these images to computer. In Figure 3.3, two captured images (left and right image) have been shown side-by-side.

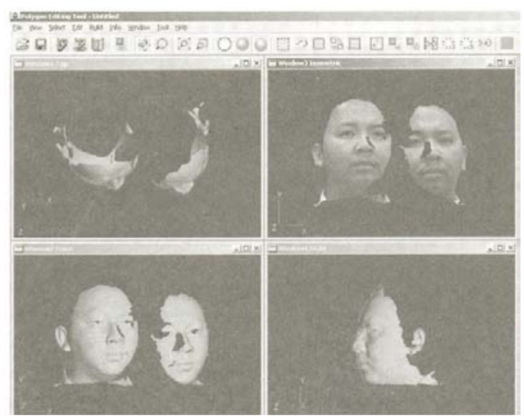

Figure 3.3. Output from the two scanners [7]

In order to build three-dimensional model of the scanned data, both left and right images are registered with RapidForm 2004 software. This registration involves manual selection of three corresponding points on both left and right images. Figure 3.4 shows a 3D model of human face developed from left and right scanned images.

Figure 3.4. 3-D model of a human face

3.2. Close Range Photogrammetry

Figure 3.5. Canon Powershoot S400 digital cameras

Photogrammetry is one of non-invasive data acquisition methods [8]. Speed of capture is important when young and potentially un-cooperative children form the major part of the study population. The photogrammetric technique is significantly quicker than laser-based systems and simultaneously captures the appearance of the whole face [9].

Figure 3.6. Setup for capturing human face

Close range photogrammetry measures objects directly from photographs or digital images captured with a camera at close range. Digital cameras, visualization and automated image measuring software, and desktop computing power, have made close range photogrammetry a useful, practical tool. Multiple, overlapping images taken from different perspectives produce accurate as-built measurements and 3D models.

The close range photogrammetry is selected in this research to achieve good quality soft-tissue data [10]. Six Canon Powershoot S400 digital cameras (Figure 3.5) are used to capture human face. Figure 3.6 shows Close Range photogrammetry setup.

3.3. X-ray Computed Tomography

For acquisition of CT scanner data, this research has collaboration with Hospital University Science Malaysia (HUSM), Kota Bahru, Malaysia. HUSM has good CT scanning facilities and provides CT data for this research. The family of CT scanners used is GE CT scanner. The output from these scanners is in Digital Imaging and Communication in Medicine (DICOM) format. To scan a complete head, the output consists of 204 slices, slice thickness is 1.25mm and data resolution is 12 bit. The DICOM file contains both a header, and the image data (which contains information in two dimension (one slice) or three dimensions (a collection of slices forming a volume) [11].

4. Results

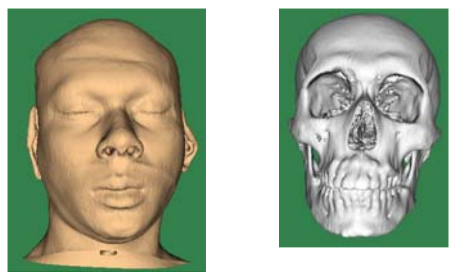

Figure 4.1. 3D model of human skin (left) and skull (right).

The focus of this research is to develop a surgical planner that can be applied for diagnostic visualization, planning surgical procedures and planning approach trajectory in craniofacial reconstruction surgery. Pre-operative data sets (CT data, Laser Scanner data and CR photogrammetry data) are fused with a robust registration process. Then this merged data is visualized in 3-D graphics environment – The Visualization toolkit (VTK).

Figure 4.2. Soft tissue (semitransparent) superimposed on hard tissue (left) and close view (right).

In order to segment skin and skull from CT data, we use Marching Cubes algorithm [12]. This 3D skin and skull reconstruction provides the basis for the diagnostic 3D visualization and pre-operative planning of surgical procedures. Decimation is used to reduce the amount of triangles without sacrificing the visible details. Figure 4.1 shows patient's skin (left) and skull (right) reconstructed from CT data.

Figure 4.2 (left) demonstrates the image in which soft tissue has been superimposed on hard tissue. Soft tissue has been drawn semi-transparent to reveal hard tissues. Figure 4.2 (right) shows a closer view of the left image. In Figure 4.3 (left), the soft tissue has been displayed as points in order to provide a clear view of the underlying hard tissue and right side image shows a closer view. Cutting of soft tissues for diagnostic visualization and detailed planning of surgical procedure has been demonstrated by Figure 4.4.

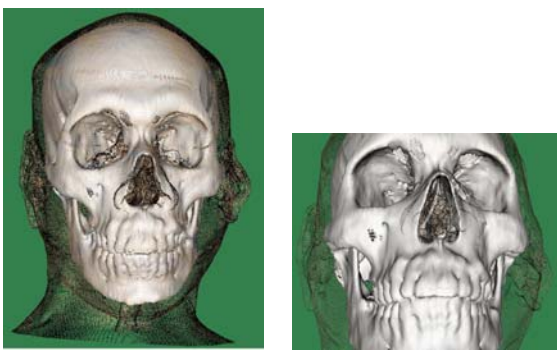

Figure 4.3. Soft tissue displayed as points (left) and close view (right)

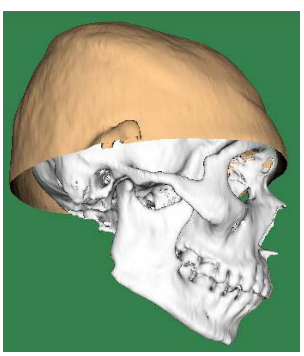

Figure 4.4. Cutting of soft tissue for detailed diagnosis and surgical planning.

5. Discussion

Medical imaging modalities used to get anatomical/structural information includes X-ray radiography, X-ray mammography, X-ray CT, ultrasound and MRI. X-ray radiography is the oldest medical imaging technique that is still one of the most widely used methods in diagnostic radiology because of its simplicity, portability and low cost. It is also being used for breast mammography and is very effective in detection of breast cancer at earlier stage. In case where 3D anatomical information is required, CT, ultrasound or MRI is the choice.

CT images have a very high spatial resolution and provide very good contrast between soft tissues. The major disadvantage of X-ray and CT imaging is the fact that these techniques use radiations that can cause tissue damage and there is a limit on the total radiation dose per year to which a patient can be exposed. MRI gives excellent soft tissue contrast and high spatial resolution. The scanning time is between 3 to 10 minutes and is much more susceptible to patient motion. The cost of MRI scanner is higher than others.

Medical imaging modalities used to get functional information include fMRI, SPECT and PET. SPECT imaging is rich of functional/metabolic information and is a prove tool in the characterization of tumor. However, SPECT images are poor in resolution and anatomical information as compared to CT or MR images. SPECT imaging is a low-cost imaging modality compared to PET because of the lower preparation cost of the radioisotopes used for imaging.

PET imaging is an effective radiological imaging tool in metabolic, blood-flow and functional imaging. The most significant advantage of PET imaging is the ability to tag a very specific biochemical activity and trace it with respect to time. The preparation cost of radiopharmaceuticals used in PET imaging is much more higher than those used in SPECT. Also, compared to CT or MR images, PET images are poor in resolution and anatomical information. However, PET images have better resolution that SPECT.

X-ray CT, being most suitable for anatomical and structural information, and a common imaging modality, is being used to capture hard tissue and soft tissue data of human skull.. We use Marching Cube segmentation algorithm to extract surfaces for soft and soft tissue as shown in Figure 3.7. Soft tissue superimposed on hard tissue is demonstrated in Figure 4.1, which play a key role in diagnosis and surgical planning. Display of soft and hard tissue with a selective opacity (Figure 4.1) helps the surgeons observe hard tissue through hard tissue and compare the two. The display of soft tissue as points or wireframe as demonstrated in Figures 4.2 (left) and 4.2 (right) provides a more clear view of hard tissue and can be helpful. Cutting of soft tissues plays important role for diagnostic visualization and detailed planning of surgical procedure as demonstrated by Figure 4.3.

CT imaging provides sharp anatomical details. But the problem with CT data is that of high radiation dose and only specific patient can go through this scan. Also, CT data does not provide texture information for the facial skin surface.

To get the soft tissue of normal people for our craniofacial database, we use 3D laser scanning system, the scanning time for scanners is 0.6 Sec for low resolution scan and 2.6 Sec for high resolution scan. The texture information captured by 3D laser scanners is of low resolution and the identification of landmarks is difficult and prone to errors. This long exposure time results in patient movements, especially the children and affect the accuracy of the data.

Close Range Photogrmmetry captures high-resolution soft tissue data. The landmark identification is easy and very accurate. The other useful information provided by this data is the texture information of the skin surface. The exposure time for photogrammetry cameras is very short as compared to laser scanning time and is less prone to patient movements.

6. Conclusion

The use of imaging data from CT, 3D laser scanner and Close Range Photogrammetry has been demonstrated and discussed for diagnosis and surgery planning for craniofacial abnormalities. CT data provide sharp anatomical details of organs. But normal people cannot go through this type of imaging due to radiation dose.

To capture soft tissue data of normal people, 3D laser scanning has been used in this research. The skin texture information provided by laser scan is poor, which effects landmark identification process for registration of the data.

The data from Close Range Photogrammetry has been used to capture high-resolution texture information of skin. Landmark identification is easy and accurate with this data. So landmark information captured from this data is used to register 3D laser scanner data.

In future, the focus of this research will be to segment human skull into various sections such as mandible, maxilla etc., cutting of abnormal part to plan post-operative surgery procedures and then realignment of the various segmented parts of the skull to visualize the outcome of the procedures.

Acknowledgement

This research is funded by Ministry of Science, Technology and Innovation (MOSTI). On behalf of Medical Imaging Research Group (MIRG), Faculty of Geoinformation Science & Engineering, Universiti Technologi Malaysia, we would like to acknowledge the MOSTI for the grant, which helped us to carry out this research.

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