An Integrated System and Framework for Development of Medical Applications and Products Based on Medical Imaging Data

C.H. Le, B.M. Pham, D.T. Tran, K. Lam, T.H. Le, D.L. Vo, S. Mengistu, and M.S. Packianather

Abstract

The Computerised Tomography and Magnetic Resonance Imaging (CT/MRI) technologies have been playing important roles in medical diagnosis and treatments. With the advancements of computer graphics, design and manufacturing technologies in recent decades, medical imaging data such as CT/MRI has been used for personalized design and development of medical models, surgical tools, implants and medical devices, as well as development of databases and 3D models for anthropology and anatomy study, medical education and training. In this paper, an integrated system and framework for development of medical applications based on CT/MRI data is introduced and discussed; it is aimed to target the medical applications in the developing countries, including (1) construction of population-specific 3D anatomical databases, (2) design and development of personalized (patient-specific) medical products, and (3) development of medical training models and education tools. The proposed system and framework is also aimed to help overcoming difficulties and obstacles surrounding the multidisciplinary collaborations, and high cost of software and tools for medical image processing, design and development of medical products and services.

Keywords

CT/MRI • Medical image processing • Implants • Surgical tools • Medical devices

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1 Introduction

Magnetic Resonance Imaging (MRI) and Computerised Tomography (CT) plays a very important role in diagnosis and treatment as well as applications and visualisation related to 2D/3D modelling of anatomical structures. There are a huge number of applications based on CT/MRI data, from the fundamental tools for Medical Image Processing (MIP) for medical diagnosis and surgical planning, for the design and development of surgical training models, biomodels, implants, surgical tools or guides and medical devices [1–8]. Further, CT/MRI imaging and related technologies such as Reverse Engineering (RE), 3D computer graphics and modeling, 3D simulation and animation, cover a wide range of applications, not only limited to the area of medicine, but also applied in many related areas, including biomedical and healthcare engineering, sport science, anthropology [9, 10] and entertainment industries [11]. Furthermore, CT/MRI and related imaging technologies allow developing accurate 3D anatomical models for diagnosis, surgical planning and analysis [2, 3], controlling advanced medical devices for diagnosis and treatment such as radiosurgery (Gamma Knife or CyberKnife treatment), and robot-assisted surgery (da Vinci Surgical System) which enables surgeons to operate with enhanced vision, precision and control [12–14]. Together with Virtual Reality (VR), 3D visualisations and animations based on the 3D models of anatomical structures constructed from CT/MRI data also play an important role in medical educations and surgical training [7, 8, 13, 15–17]. Recently, Reverse Engineering and 3D surface-imaging systems have been commercially available and applied for the plastic surgical set-ups, to provide surgeons an effective communication with patients as well as working on surgical planning and outcome evaluation [18].

There have been also lots of studies and applications about the morphological parameters of the human skeletons based on medical imaging data [19, 20]. *Population-specific* 3D database of anatomical structures are very necessary and important for the design and development of medical products with the sizes and shapes that meet well both technical and clinical requirements, to maximise the life and functions of medical products such as implants, surgical tools or guides and medical devices. These databases are also important for forensic medicine and anthropology [21]. In addition, there are a lot of efforts worldwide to develop Virtual Physiological Human (VPH) models which provide the human body atlas as well as 3D database for medical education and training as well as research and development (R&D) of medical products [6–8, 14].

This R&D project is aimed to investigate and propose cost-effective and population-specific solutions for development of medical applications and products based on medical imaging data. The focus of a project includes the following objectives: (1) construction of *population-specific* 3D anatomical databases, (2) design and development of personalised (patient-specific) medical products, and (3) development of medical training models and education tools. An integrated system and framework for development of medical applications and products based on medical imaging data is proposed, with demonstrations of the key primary results which are then further used for in-house development of medical products and services.

This paper is organised in 4 main sections. The first section provides a brief introduction to Medical Image Processing (MIP) applications and the main objectives of this study. The materials and methods used for creating an integrated system and framework for the development of medical applications and products based on medical imaging data are presented in the second section. The third section presents the results and findings that lead to the proposed integrated system and framework; and the latest development, challenges and difficulties in MIP as well as applications and services based on medical imaging data are also discussed in this section. Finally, the fourth section presents the conclusions.

2 Materials and Methods

An integrated system and framework for the development of medical applications and products based on medical imaging data is presented in Fig. 1. This proposed system and framework is based on the results and applications that have been successfully implemented (see Sect. 3).

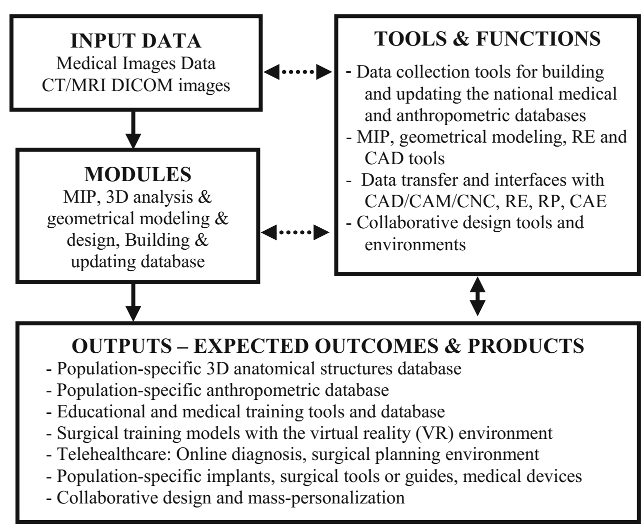

Fig. 1 An integrated system and framework for the development of medical applications and products based on medical imaging data

The inputs for the system are medical imaging data (CT, MRI, micro-CT, CBCT, 3D Ultrasound, and Confocal Microscopy). There are series of open-source software tools and packages which are developed for different specific applications, focusing on the three main modules: (1) *Medical image processing*: segmentation, 3D reconstruction, visualisation; (2) *Geometrical modeling & design*: 3D meshes modeling and editing, Computer Aided Design (CAD) modeling and editing, data transfer and interfaces, collaborative design tools and environments; and (3) *Building & updating database*: Data collection tools for building and updating the national medical and anthropometric databases, including geometric measurements and data collection, 2D/3D data analysis, and statistical data analysis. The expected outcome and products of a proposed system include the following: (1) *Population-specific 3D anatomical structures database*: 3D models of anatomical structures such as hip, femur, tibia, heart, etc. in the form of 3D mesh or NURBS CAD formats; (2) *Population-specific anthropometric database*: 2D/3D mean geometries and statistical data of anatomical structures; (3) *Educational and medical training tools and database*: Software tools and environments for 3D visualization of human anatomy, diagnosis and treatment expert systems; (4) *Surgical training models with the virtual reality (VR) environment*: Available as the software tools or packages for surgical training such as Laparoscopic (keyhole) surgeries; (5) *Telehealthcare*: Online diagnosis, surgical planning environment, software tools and packages for medical diagnosis, records and rehabilitation; and (6) *Population-specific implants, surgical tools or guides, medical devices*: Development of high-value added products such as implants, surgical guides and medical devices (screws, bone plates, etc.), especially the Population-specific ones; and (7) *Collaborative design and mass-personalisation*: These tools and functions allow engineers, medical doctors or surgeons as well as patients to communicate and work together to develop personalised and mass-personalised products.

Via the data transfer to interface with CAD/CAM/CNC, RE, RP, FEA, and CFD, outputs of the proposed system can be relevantly and optimally used to develop different medical applications; and when necessary, additional resources could be cost-effectively used to meet the design and manufacturing constraints as well as to meet clinical requirements.

3 Result and Discussion

Figure 2 presents results and applications that have been successfully implemented. These are the base and methods for building an integrated system and framework for the development of medical image based products and services. With the use of 3D models of bone structures (defective skulls) which are reconstructed from CT images, personalised implants are accurately designed and developed. These in turn help to reduce the surgery time from 3 to 5 h to maximum 2 h [2, 4] (Fig. 2a). The 3D models of skulls are used to generate the mean skull geometry that is then used to develop standardised implant templates [3] (Fig. 2b, e). The 3D skull database and templates can be used to design personalised implants, especially for cases of complex bone defects where the symmetrical features of a skull can not be used for the design (Fig. 2d). The use of the 3D skull database to develop the standardised implant templates, the implant cost for cranioplasty treatments can be reduced to 25–30 USD, compared to 300–350 USD for the personalized implants [3] (Fig. 2e).

RE and MIP methods can be used for 3D modeling of eye shapes which are then used to develop the mean geometry of the eyes for developing population-specific contact lens (Fig. 2c). Figure 2f presents the surgical training models and software with 3D visualization and animation for medical education and training that were successfully developed from CT/MRI data. Finally, Fig. 2 (g) presents the software for MIP with the fundamental functions, including image segmentations and 3D reconstruction of the anatomical structure.

As mentioned in Sect. 1, with the rapid advancement in computer graphics, CAD, and MIP technologies in recent decades, there have been lots of software and tools available for CT/MRI image processing and 3D design and modeling based on CT/MRI data. The following are the most common and commercially available MIP and RE software that are used for MIP, and design and development of medical applications based on CT/MRI and scanned data: (1) Mimics® Innovation Suite: Mimics, 3-matic (Materialise NV: www.materialise.com), (2) ScanIP (Simpleware: www.simpleware.com), and (3) Geomagic Wrap, Design X & Freeform (Geomagic: www.geomagic.com). The key functions and tools for MIP and developing medical products such as implants, surgical tools or guides, and medical devices (bone plates, screws, etc.) are as follows: Image segmentation, 3D medical modeling, 3D mesh (STL) construction and editing, CAD operations and editing, Interfaces with CAD/CAM, RE, RP and CAE packages. Although these state-of-the-art MIP and RE software may provide powerful 2D/3D image processing, 3D mesh editing, and CAD modeling functions, the use of traditional CAD/CAM packages such as Inventor (Autodesk, Inc.), Creo (PTC) and NX (Siemens PLM) are still required and necessary for many applications. In addition, one software alone cannot provide all tools and functions for different requirements of MIP, CAD and RE projects, and of cause, this depends on the complexity of products and applications. Especially, the above mentioned software packages are expensive. Engineers and designers

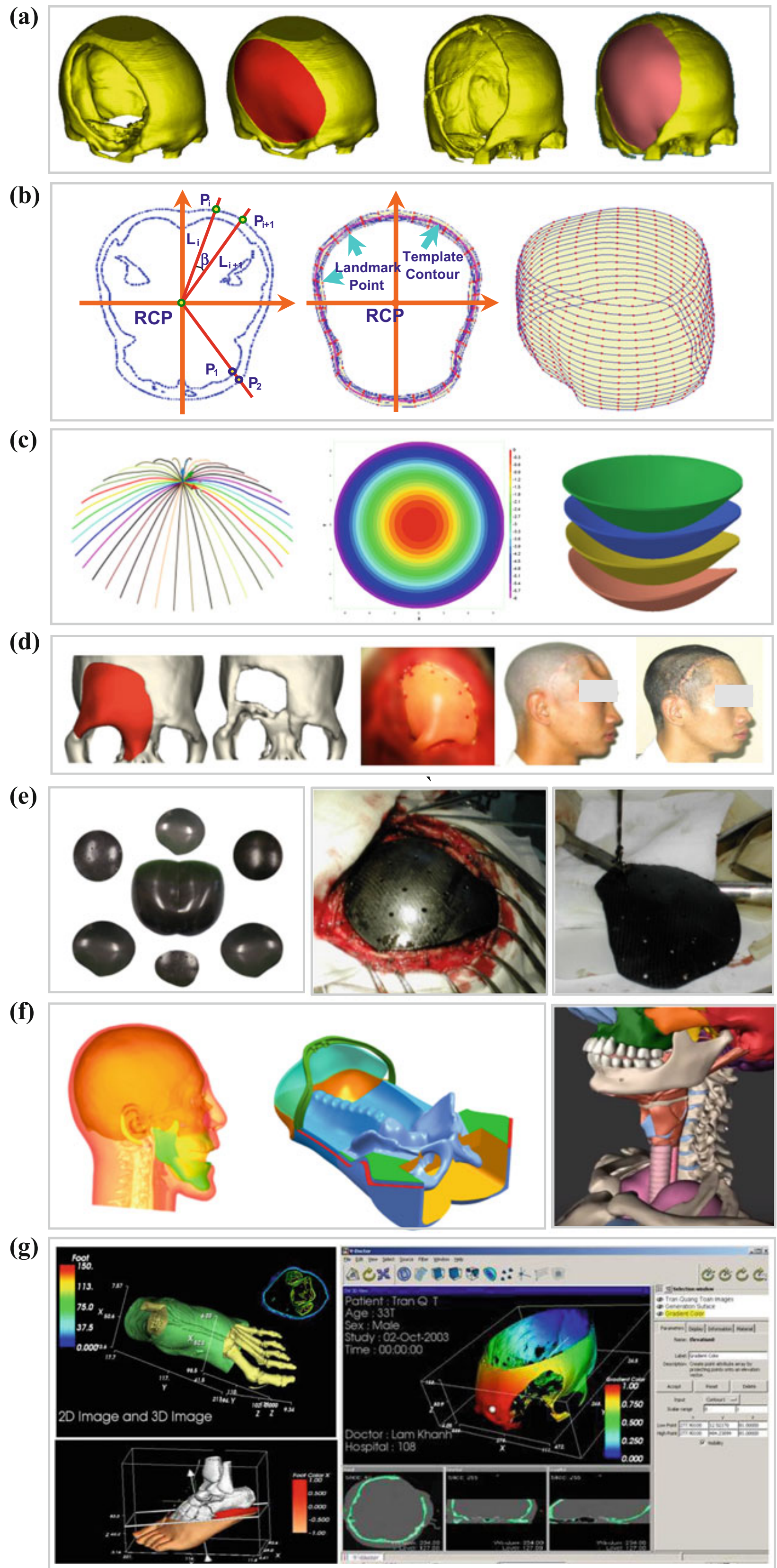

Fig. 2 The results and studies about medical image based applications and products that have been successfully developed and implemented

need to optimally use the available CAD, RE and MIP tools to obtain the cost-effective design solutions.

Our investigations showed that, with the relevant and effective use of available CAD, RE and 3D modeling software and tools, in-house development of MIP tools based on the available toolkit and open-source packages may be an optimal solution. In this way, companies and research and development (R&D) centre of a small scale, are able to develop high-value added products and services without the need of using expensive MIP and RE software packages. The following are the typical open-source packages and tools that can be used for developing customised medical IP applications:(1) *The Visualization Toolkit* (VTK, www.vtk.org) (2) *Insight Segmentation and Registration Toolkit* (ITK, www.itk.org; (3) *The Medical Imaging Interaction Toolkit* (MITK, www.mitk.org); and (4) *3D Slicer* (www.slicer.org).

4 Conclusion

Although the benefits of medical products which are developed based on CT/MRI data such as personalised implants, surgical tools or guides, and medical devices (bone plates, screws, etc.) are well recognised [1–5] the technology has not been widely applied for diagnosis and treatment due to the following challenges and difficulties: (1) the complexity of the design, (2) requirements of the multi-disciplinary collaboration and communication, and (3) high cost of technology [1]. In addition, investments for a complete set of MIP, RE and CAD software packages are always expensive, especially for developing countries. Most of the medical products require the multi-disciplinary knowledge and high technical skills to be developed. Moreover, developments of MIP software packages that are suitable to be used for multi-applications require a huge effort, time and resources. Therefore, there is an emerging need of a cost-effective integrated system and framework for developing medical applications and products based on medical imaging data. There is also an emerging need to build up *population-specific* medical and anthropometric databases for countries or regions, that are important and necessary for design and development of the medical products with the sizes and shapes that meet well both technical and clinical requirements to maximise the life and functions of medical products such as implants, surgical tools or guides and medical devices. These national databases and MIP systems are also beneficial and crucial for the research in forensic medicine and anthropology, as well as for medical education and training purposes. In this paper, an integrated system and framework for the development of medical applications and products based on medical imaging data has been proposed and presented; it is aimed to target the medical applications in the developing and low-income countries where people are not able to gain access to the high-quality healthcare products and services, including (1) construction of population-specific 3D anatomical databases, (2) design and development of personalised (patient-specific) medical products, and (3) development of medical training models and education tools. The results and findings from the clinical cases and medical applications that were successfully implemented have also been discussed and highlighted as the base for in-house developments of the proposed MIP system and framework.

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