
Silvia Bessa
silvia.n.bessa@inesctec.pt
Jaime S. Cardoso
jaime.cardoso@inesctec.pt
Hélder P. Oliveira
helder.f.oliveira@inesctec.pt

INESC TEC
Porto, Portugal

Abstract

Image registration is an important research topic in medical imaging, with applications such as computer-aided diagnosis and surgery planning. However, medical images are usually obtained from different modalities and describe anatomical structures that are deformed during acquisition, which makes the registration task challenging. Many solutions have been proposed, but the maturity of these algorithms still remains an open problem. This is the case of breast imaging registration. Breast image registration is a key task in creating complete 3D models of the breast, which combines multi-modal images, but few works have been published regarding the field of matching surface and interior radiological information of the breast. This is a drawback that limits the development of tools for planning breast cancer surgeries and predict breast deformities caused by cancer treatment. In this paper, some breast image registration techniques and approaches are described.

1 Introduction

Breast cancer is a public health disease affecting over 1.6 millions of women every year. In Portugal, every day 11 new cases are detected and another 4 women die. While a few decades ago the primary goal of breast cancer treatments was to eliminate cancer, with newer techniques, the aesthetic results now play a special role in the treatment decision process, and an increasing number of women have to live with the consequences of treatments for many years [13]. The involvement of women in the treatment decision process has been proven beneficial to accept the resulting outcomes, highlighting the necessity of creating tools that predict the outcomes of each possible option, providing patients with visual clues of the expected results for more conscientious decisions. To develop a breast surgery planning tool, it is necessary to create complete 3D models of the patient’s breasts. Attempts to model the breast include the use of Magnetic Resonance Image (MRI), Computed Tomography (CT), Ultrasound (US) and 3D models. But in order to obtain a complete 3D model of the breast for planning surgery interventions, the complementary information of different image modalities has to be combined. Breast images are often acquired with different views, modalities or at different times, which makes image registration an important step to convey multiple and complementary information into a single coordinate system to ease the understand and analysis of data [2]. In the next sections, some prominent breast image registration techniques are described, which are used to combine multi-modal radiological exams or reconstruct surface models of the breast. The main goal of this paper is to provide knowledge about the main advances in breast image registration techniques, while highlighting some limitations that have to be overcome to properly create complete 3D models of the breast.

2 Multi-modal Breast Image Registration

Several methods have been proposed to solve the problem of image registration, but this task is particularly hard for breast data, due to the inhomogeneous, anisotropic nature of the soft-tissue within the breast, and its inherent non-rigidity characteristics [2]. The success of registration methodologies depends on the choice of the geometric transformation, which highly depends on the nature of the data to be registered. Registration techniques can use rigid or nonrigid transformations, but most medical image registration approaches are based on the latter, given the deformable nature of most of the anatomical parts of the human body. Research in the field of breast image registration has been primarily focused on combining mono and multi-modal radiological images, but few attention has been given to the task of matching surface and interior radiological information of the breast. Combining this information would lead to the generation of patient-specific 3D models of the women breast that can be used in visualization and planning of breast cancer surgeries. The registration of multi-modal radiological exams allows the best characterization of the tumour (location, size and volume) and other characteristics as the glandular density, which combined with the 3D external model of the breast, results in a complete model of the breast, useful to predict the risk of deformity and quantify the aesthetic result after surgical removal of the tumour. However, considering that interior and surface data of the breast are acquired in different poses (prone position for interior data, and upright position for surface data acquisition), it is necessary to determine the transformation between the two models. Despite the developments in multi-modal breast image registration algorithms, there is gap for algorithms that match interior and surface data of breast.

3 3D Interior Model of the Breast

Early detection of breast cancer is key to its successful treatment and improvement of survival rates. Consequently, routine mammogram screenings are recommended for a large percentage of female populations, which justifies the large number of breast image registration techniques focused on X-ray mammogram alignment, either for combining bilateral or temporal images. These strategies provide aid to better visualization of breast lesions, as well as improvements in the detection and diagnosis rates of computer assisted diagnosis systems.

However, different breast imaging modalities bring complementary information that can be advantageously used for these tasks. More recently, strategies have been developed which focus on multi-modal registration of breast images. These methodologies usually map the information of MRI, a 3D and nearly undeformable information, to mammograms, and the dual information is subsequently used in the general pipeline of detection and diagnosis of breast lesions. This mapping is accomplished using transformation models based on synthetic deformations [5, 10], or finding corresponding control points in images, such as anatomical regions as breast boundaries, nipple and pectoral muscle. These control points are then aligned either by iterative optimization [7], or by direct computation of the transformation function [4]. Additionally, deformable finite element methods (FEM) have been specially investigated as physical models to register intra and inter-modality images and model the interior of the breast [4, 5, 7, 10], but these methods present high computational cost. Therefore, alternatives based on parametric models have been explored to reduce the complexity of the models to be registered, while preserving the ability to properly align them. Examples of this strategy include the use of Non Uniform Rational Basis Spline (NURBS) [1, 11], or a combination with Free Form Deformation (FFD) to obtain deformable models of the breast [3, 9].

In spite of the encouraging results accomplished by combining multi-modal breast images in the detection and diagnosis of breast lesions, there is no follow up of this task to the planning of breast cancer surgery. Surgery planning still relies on manual drawings, and rude marks drawn in the patient’s body, and would benefit from the inclusion of image registration outputs in a model suitable for visualization.
4 Surface Model of the Breast

To have a complete representation of the breast, it is necessary to obtain a surface model of the breast. 3D information of the surface of the breast can be acquired using active or passive methods. The first act by projecting energy onto the breast and use its reflection to retrieve the surface information, while in the second 3D reconstructions of the breast are obtained by combining information of multiple images acquired with simple cameras. Among active methods, high resolution systems such as the 3MD [14], which acquires multiple high-resolution images from several angles simultaneously, or other 3D laser scanning systems have been used to model breast surface. But these systems have an inherent disadvantage in the clinical set: they are expensive, large or have to be fixed in one place. They require a dedicated space to be properly operated and non-clinical specialized staff. As a consequence, low-cost and easy to use alternatives have been explored, with examples using either more affordable active methods such as RGB-D cameras [8], or passive methods such as stereoscopy [6]. Breast surface representations can also be obtained from radar-based systems, in which the attenuation of a wideband pulse transmitted towards the breast is received by antennas. The received signals consist of two major contributions: the signal attributed to the skin reflection, and the signal from the internal structure of the breast. The skin reflection signal is used for the 3D breast surface reconstruction [12].

Regardless of the selected method to retrieve the surface information of the breast, registration algorithms have to be used to generate 3D representations of the breast surface. For instance, one of the challenges of using RGB-D cameras is the conversion of depth-map information to close meshes. In these strategies, breasts are usually imaged with the patient in a standing position, which frequently results in the lack of depth information for infra-mammary regions, particularly in the case of breasts with large curvatures. On the other hand, for stereoscopy-based methods, the challenge is to find corresponding points in multiple views images: occlusions may appear, and the lack of texture and salient features on the surface of the skin hinders the mapping process. This shows that despite the numerous available registration techniques, there is still room for improvement. Moreover, 3D breast reconstructed data are usually 3D point clouds, which difficult subsequent attempts of mapping surface information with breast interior data extracted from image radiological registration.

5 Conclusions and Future Work

Advances in imaging techniques have resulted in an increasing number of breast images. However, these images are often acquired with different vintages modalities or at different times, which makes image registration an important step to convey multiple and complementary information into a single coordinate system to ease the understand and analysis of data. Yet, literature review evidences a gap for 3D breast image registration methods that combine interior and surface data of breast, and the use of 3D point clouds representing the breast surface can also pose extra registration challenges. Besides, the mapping of interior and surface information is a fundamental step in the creation of patient-specific complete models of the breast, which can be used for planning breast cancer surgeries and predict breast deformations arising from breast cancer treatments. Therefore, future research in the area of matching 3D interior and surface breast models would not only result in contributions in the field of computer vision, namely with new methodologies for 3D registration from multimodal images, but would also allow researchers to move ahead in the creation of 3D planning tools for visualization, to better understand the effect of surgical removal of cancerous tissue. Such tool would help the communication between the physician and the patient, ultimately empowering patients to take an active role in a shared decision making process.

6 Acknowledgements

This work was funded by the Project "NanoSTIMA: Macro-to-Nano Human Sensing: Towards Integrated Multimodal Health Monitoring and Analytics"(NORTE-01-0145-FEDER-000016” financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

References