Engineering a 3D Ultrasound Robotic System

J.C. Seabra
ISR - Instituto Superior Técnico
Lisboa, Portugal
jseabra@isr.ist.utl.pt

J.M. Sanches
ISR - Instituto Superior Técnico
Lisboa, Portugal
jmrs@isr.ist.utl.pt

Abstract

Three-dimensional (3D) Medical Ultrasound (US) can definitely improve the diagnosis of several pathologies by providing a better view and analysis over tissues and organs than 2D Ultrasound. Depending on the organ or tissue to be scanned, it is necessary to apply different scanning strategies or protocols which comprise linear, rotatory and free-hand scanning, just to name the most common ones. Most imaging systems are not optimally adapted for such a wide range of applications. A new 3D US prototype robotic system which can control, standardize and accurately perform the acquisition process is presented. This system may assist the operator in defining suitable scanning paths for each patient according to the region of interest (ROI) to be scanned. Different acquisition properties can be assigned in each examination, such as the duration and rate of image acquisition. Moreover, each image is assigned with its spatial information allowing to further perform following-up studies or to reconstruct and segment the tissues or organs scanned with higher degree of confidence.

1. Introduction

Medical US has benefited from major advances in technology and is considered an indispensable imaging modality due to its flexibility and non-invasive character. Although all anatomy is 3D in form, the vast majority of US imaging is 2D. Most of the times, this technique provides sufficient information for diagnosis but there are clearly identifiable limitations, such as, non-ability to perform quantitative volume measurements or to obtain optimal 2D scan views of the anatomical ROI.

Thus, 3D US is a logical solution to allow better, more complete and objective diagnostic results. In this imaging modality, the 2D US images are combined by a computer to form an objective 3D image of the anatomy and pathology. This data can be manipulated and measured in 3D both in real time or later offline. Moreover, unlike CT and MR imaging, in which 2D images are usually acquired at a slow rate as a stack of parallel slices, in a fixed orientation, US provides images at a high rate (15 to 60 s^-1) and in arbitrary orientations.

Most 3D US systems make use of a conventional transducer to obtain a sequence of images by sweeping the probe along the anatomical ROI, and differ only in acquisition and position sensing [1]. In this way, images can be acquired mechanically, free-handed with or without an optical or electromagnetic spatial locator and using 2D arrays. Some of these systems were validated in various clinical applications, such as obstetrics, cardiology and vascular imaging in order to increase the diagnosis confidence [2].

Robotic systems can be regarded as an important diagnosis tool because they can simultaneously control and standardize the image acquisition process. Thus, they can be very suitable for quantifying and accurately monitor the development of cardiovascular diseases, namely, the progression of atheromatous plaques by scanning the carotid or coronary arteries [3]. In addition, the ability to remotely position the US probe with the robotic arm could also be used in telemedicine [4].

In this paper it is described a prototype medical robot which can easily be integrated with common ultrasound scanning equipment and provides clinicians with their regular scanning operations.

2. System overview

The prototype medical robot presented in this paper is schematically shown in Fig. 1 and has four principal components. The first unit is the robotic arm (Scorbot-ER VII, Intelitek, USA) with six degrees of freedom which is operated from the robot controller. The second element is an US portable scanner (Echo Blaster 128, Telemed, LT), equipped with a linear array probe. This probe is attached to the tip of the robotic arm, together with an electromagnetic position sensing device (Fastrak, Polhemus, VT). The last component of the system is the computer workstation, which holds a joystick and the interface to control the medical robot and the US scanner.

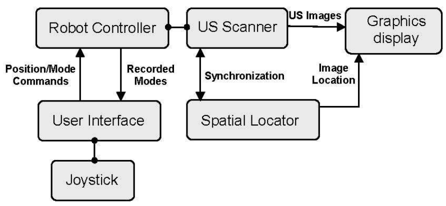

Figure 1. Block diagram of the Medical Robot system.

This interface, developed in-house, permits access and setting of the robotic arm controls and movements as well as to view and tune the acquisition results. The robotic arm is manipulated using a joystick which allows to move the US probe towards the ROI to be scanned. Moreover, the robot has a teach mode that enables the learning of a suitable scan path, and a replay mode to reproduce the manually taught path. This feature is suitable to guarantee clinical reproducibility of the results because a scan path can be assigned for each patient with controlled speed and accurate position information provided by the spatial locator.

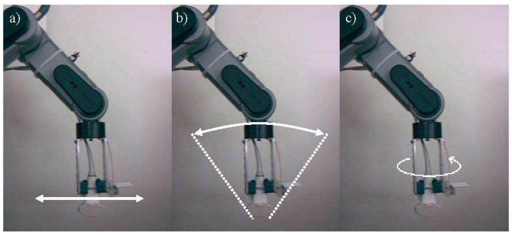

Figure 2. Acquisition modes: linear (a), fan-like (b) and rotatory (c) scans.

The robot integrates several acquisition modes (see Fig. 2), providing free-hand, linear, fan-like and rotatory scans. This should be flexible enough to allow image acquisition from different organs and tissues, where different scanning operations are needed. The system allows to capture B-mode images at uniform spacing and user-defined sampling rate. These images are synchronized with the spatial locator and sent with their corresponding probe positions to the workstation for storage and future 3D reconstruction.

Fig. 3 shows the experimental robot setup for US image acquisition. A cross-section of a cylindrical latex-made phantom, which resembles a human vessel, was acquired and the result is shown on the computer screen.

3. Conclusions

A prototype medical robot was developed and presented. This system provides accurate and standardize but at the same time flexible scanning of several organs and tissues. In particular, the authors believe that the system could be a good alternative for 3D-US imaging systems in particular in quantifying the progression of cardiovascular diseases.

Figure 3. The 3D US robotic experimental setup. The robotic arm carries the probe and the position sensing receptor from the US scanner and the spatial locator, respectively. The workstation personal computer controls the movements of the robotic arm with the aid of a joystick. Images are tagged with their spatial location and showed on the screen.

The preferred robotic systems are those where medical doctors can use their regular imaging equipment and easily integrate their scanning operations. Our system is flexible as it can operate with a common ultrasound scanner and may assist the operator in defining personalized scanning paths for each patient according to the ROI to be scanned. We believe that the accuracy of the results generated by the robotic system are higher than 3D freehand systems since the volume is regularly sampled.

In future work, the robotic system must be validated by performing calibration and acquisition/reconstruction tests with a vascular phantom.

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