CRITICAL REVIEW ON PAPERS PRESENTED IN SEMINAR

Group 11

600.646 – Computer Integrated Surgery - II

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PROJECT

NAME: Enabling Technologies for Robot Assisted Ultrasound Tomography

GOAL: Design a prototype that uses a robot controlled ultrasound probe to follow the motion of the free hand probe that can be used for Ultrasound Tomography.

PAPERS SELECTED:

PAPER 1

Hippocrate: a safe robot arm for medical applications with force feedback

- **Authors:**Francois Pierrot, Etienne Dombre, Eric D´egoulange, Loıc Urbain, Pierre Caron, Sylvie Boudet, J´erome Gari´epy and Jean-Louis Megnien
- **Published:**Medical Image Analysis (1999) volume 3, number 3, pp 285–300
- **Purpose:** To develop a robotic system to help doctors to reconstruct the three-dimensional profile of arteries using Ultrasound

PAPER 2

3D Femur reconstruction using a robotized Ultrasound Probe

- **Authors:** Pedro M.B. Torres, J. Miguel Sanches, Paulo J.S. Gonclaves, Jorge M.M. Martins
- **Published:** IEEE RAS/EMBS on Biomedical Robotics and Biomechatronics, Rome(June 2012)
- **Purpose:** To develop a robotized ultrasound probe to perform 3D Femur reconstruction

REASONS FOR SELECTING THESE PAPERS

- Gain understanding of how Robots are used for performing ultrasound, the safety precautions to be taken while the robot is placed and is working in vicinity of patient and doctor.
- How one can perform and obtain Ultrasound Tomography using 2D linear array probes.
- To understand the minute details of the previous work done in the field.
- Gain knowledge of the different control loops that can be used to obtain better accuracy and thus, ultrasound tomography images.

PAPER 1 :: Introduction and Background

The authors describe the importance or need of robots to perform the ultrasound procedures. They explain a method of how a robot assisted ultrasound system can be used to get an ultrasound tomography if the carotid artery using Hippocrate, a specially design robot to be used for this purpose.

The authors talk about using this method for skin grafting by mounting a dermatone installed on the end effector of the hippocrate but could not get a good control for perfect smooth motion.

PAPER 1 :: Method Overview

Authors mention the use of an industrial robot arm as a testbed, the robot chosen was a 7-DOF DOF, human-like industrial robot, the PA-10 from Mitsubishi Heavy Industry with tweaking by changing the gear on each motor in order to slow down the robots linear velocity to 0.5m/s for initial experiments. Later, in order to comply with safety constraints, a dedicated robotic system, Hippocrate was designed.
The procedure of using the robot for performing ultrasound has two phases, teaching phase and the automatic phase. In the teaching phase, the operator defines the two, initial and final positions of the trajectory to be followed or the part of the body to be analyzed. After these two positions are defined, the automatic phase initializes, thr robot goes back to the first position of the trajectory and then starts moving towards the goal by taking 0.1mm steps and taking ultrasound photos. At every position, the force is kept constant at 5N and the robot moves automatically along z-axis in order to get the exactly constant force and getting standard images throughout.
The things that the authors kept in mind while designing the system was to keep in mind the precautions to be taken while building the robot were as follows:

- They placed 3 emergency buttons to switch off power of the system.
- A Watchdog board, if anything goes wrong in the software part, the cyclic signal sent to the watchdog is stopped which causes the entire system to shut down.
- If any process stops at a time, entire process is stopped.
- If force exerted by US probe exceeds a limit, system is shut down.
- Joints have limits, to limit workspace.
- When difference between current and desired position is high, power is switched off.
- Action of Dead Man Switch (foot pedal) necessary to authorize any motion.
- If robot reaches singularity, any and all motion stopped until it is moved away from it.

PAPER 1 :: Critique

The authors did a good job of designing a robot assisted ultrasound system, keeping in mind that the paper was published in 1999, it is highly advanced. The system setup has been explained with minute details and gives a good example of showing how this system can be used although the explanation of results is not very explicit. The system has a good control loop, multiple in order to make it safe for the use next to humans. It has very good safety features and have been explained thoroughly throughout the paper. The authors also explain using a graph of force with respect to time, which shows that if we set the force to be applied has to be 5N, it remains 5N throughout the procedure. Along with these positive aspects, the authors did not provide a detailed explanation of the application, it also has lack of placement of information details where it is required to explain the entire system.

PAPER 1 :: Conclusion and Future Work

In the paper, authors have successfully demonstrated the application of using the hippocrate robot to perform ultrasound tomography to obtain the images of the carotid artery and also explain the use of the same robot for skin grafting technique, where it is not completely successful for now. It is an active arm in the sense that it is actuated but its power is limited. The main features are a maximum linear velocity at the probe tip of 10 cm s^{-1}, a resolution of 0.1 mm and a maximum payload of 2 kg.

Hippocrate offers clear advantages when force control is needed together with a pre-defined trajectory in six dimensional space and thus could help in other medical or biomechanical applications.

PAPER 2 :: Introduction and Background

The authors describe the importance or need of robots to perform the ultrasound procedures in order to get the images for the 3D reconstruction of femur surface. They explain a method of how a robot assisted ultrasound system can be used to get an ultrasound tomography of femur bone. It allows to build virtual models of anatomical units of the human body, which can be used in surgical navigation.

They talk about a specially built robotic arm, Hipprob project, which can co-manipulated by the surgeon for hip resurfacing surgery.

PAPER 2 :: Method Overview

The procedure includes three major processes, System Calibration, Ultrasound Image Processing, Image Segmentation.

In system calibration, the authors get a method of transforming the image coordinated of the ultrasound images to the world coordinates. This is done using a cube phantom with a small and large egg of known dimensions. We take the ultrasound of this system to obtain values of the scaling factors and then they use it further on for the patients.

In ultrasound image processing, after obtaining the images, the authors say that the images need to be processed. They only need the femur bone surface and as we know, the bones are solid and completely reflect off ultrasound wave from the surface of the bones. This causes a very blurred image, which needs to be processed to get a better look at the bone surface, this means, removing speckled noise. Next we have to align the images, which is done by normalize cross correlation, in order to develop the 3d model of the femur from 3D sliced images of the femur taken using ultrasound probe. These images need to be aligned so that we get the best 3D model of the femur surface.

Third, the authors mention the method for image segmentation which is done by selecting the outline of the femur bone surface and then applying marching cube's algorithm. Image segmentation is done after all the images have been aligned.

The robotic system used, consists of an Eurobtec IR52C robot manipulator, an ALOK A prosound 2 echograph with a 5MHz probe and a computer with a standard video card for image acquisition. The probe is placed in the end effector of the robot, responsible for positioning the probe in contact with the leg.

In the experiment preformed, a 18 cm girl leg was scanned, on the central part of the leg from the tip of the knee. 297 images were required, i.e. spacing between consecutive images was 0.6062 mm. After images were acquired, denoising of images was done. Then image alignment was obtained by maximizing correlation among images Then segmentation is done after the user identifies a curve around the bone in the first image providing us with the bone surface reconstruction.

PAPER 2 :: Critique

The authors did a good job of designing a robot assisted ultrasound system, it is highly advanced. The entire setup is explained with full detail with the example of femur surface reconstruction but does not give an explicit example. After the robot control loop to obtain certain accuracy, further accurate reconstruction is obtained by performing different image processing techniques. Along with these positive aspects, the authors did not provide a detailed explanation of its reconstruction algorithm which is the main part of the process. But overall, the paper gives very good explanation of the entire setup and method used for performing reconstruction.

PAPER 2 :: Conclusion and Future Work

The authors describe a system for 3D reconstruction of the femur using robot assisted ultrasound technique. This system is accurate as it uses the same pose of ultrasound probe throughout with a smooth slow motion so that ultrasound images can be taken clearly. But even if it is less accurate, further accuracy can be obtained by image processing techniques.

The future work entails, making the system available for being used in actual surgical procedures for bone surface reconstruction.