DEVELOPMENT OF A VIRTUAL REALITY APPLICATION FOR PLANNING OF ROBOTIC PROSTATE TRANSPERINEAL BIOPSY

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Abstract: Performing prostate biopsy represents a complex procedure but it can be improved by using a specialised robot which brings the advantage of a higher precision in accessing the established target without intersecting vital organs. This paper presents the architecture of a system developed in order to integrate in a virtual environment the model of a patient to be subject to the procedure of robotised prostate biopsy. A virtual environment has been modelled containing the virtual model of the patient placed on the operating table and the BIO-PROS-1 robot that is going to perform the prostate biopsy, positioned relative to the patient.

Key words: Virtual Reality, Prostate robot, Trajectory planning

1. Introduction

The prostate cancer represents one of the main causes of death among the male patients diagnosed with. About 14% of the male patients diagnosed with cancer had cancer formations localized in the prostate [9]. In order to detect the type of cancer the biopsy procedure is performed that involves the removal of a sample of tissue from the targeted organ.

Most urologists use transrectal biopsy with ultrasound-guided needle (through ultrasonography) to obtain tissue from the prostate in order to diagnose cancer. Another method proposed to achieve prostate specimens in transperineal manner because it implies a lower risk of infection,

easier access to the prostate and a higher detection rate. The main disadvantage of the transperineal interventions is the higher cost because generally it requires anesthetizing the patient [3].

Using the robotic system allows, thanks to higher stiffness and precision of robotic arms compared to human hands, the avoidance of the obstacles as well as the significant adjustment of the position and orientation of the needle tip prior to penetration of tissues, which improves access to the established target[1].

Programming the trajectory for a robot that performs the biopsy operation is difficult due to the geometric and topological complexity of the 3D model of the patient and the multiple parameters to be

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taken into consideration during the biopsy procedure.

2. Objectives

In planning the biopsy procedure for the prostate, an important issue is to identify, from the geometric point of view, the methods for approaching the paths followed by the biopsy needle, in order to choose optimal trajectories, thus avoiding puncturing vital organs (bone, major blood vessels, and internal organs).

Virtual reality is not perceived only as a three-dimensional graphical environment, but may represent a new tool that provides solutions to real problems in medicine [2, 4, 8] and other fields.

In this paper is presented the virtual working environment necessary for performing the robotic biopsy procedure and software (prototype) implemented in order to allow physicians to define the robot trajectory to achieve the biopsy surgery. The steps for accomplishing the robotic biopsy procedure are:

ÉModelling the virtual environment.

ÉModelling the patient and his internal organs from the pelvis area.

ÉThe introduction of robotic structures in the virtual environment.

É Implementation of imaging data.

ÉImplementing the algorithms necessary for the interaction with the robotic system, including the data obtained through ultrasonic processes.
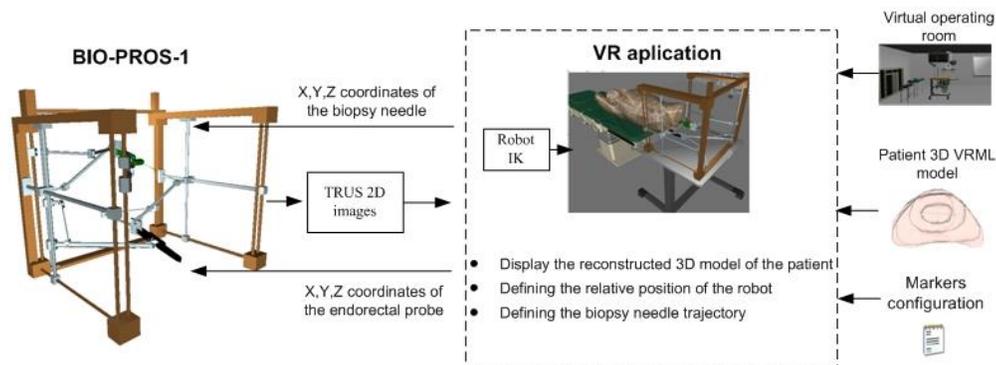

Fig. 1. *The software architecture of the developed VR system*

3. Material and Methods

The designed system architecture is presented in Fig. 1. The software consists of several software modules that allow the user to define the robot paths which are avoiding the risk areas. The essential component of this architecture is the central software module, which performs the following functions:

- Integration of patient data in the virtual environment.

- Defining the geometry and position of the prostate (this data will represent the target points within the 3D model).

- Defining the position of the patient in the operating room.

- Manual definition of the linear point approach trajectories for each established target point, taking into consideration the data obtained by ultrasound.

- Generate linear point approach trajectories for each established target point.

- The processing and extraction of optimal

linear point approach trajectories for the robot.

• **Integrating the robotic structure in the virtual environment**

The BIO-PROS-1 [6] parallel robotic system for prostate brachytherapy consists of two (almost) identical robots working together: one for guiding the trans-rectal ultrasound probe (TRUS) and the other for guiding the biopsy gun. Each robot consists further of two parallel modules: the first one having M=3 DOF with constant orientation of the platform and three active joints; the second one with M=3 DOF and two active joints (rotation is free). The two modules are connected via two cardan joints through a link that has attached to it the TRUS and the biopsy gun, respectively.

In the virtual environment was introduced the virtual model of the parallel biopsy robot BIO-PROS-1[7]. The CAD model of the robotic structure BIO-PROS-1 was developed using the Siemens NX8 CAD program. For integration into the virtual environment, it was necessary that the CAD model of constructive solution to be converted to a neutral format of representation in virtual environments because there is no standard for interoperability between CAD program NX8 and virtual reality applications. The CAD model of the robot developed in this project has been transformed into a neutral format of representation in virtual environments VRML 2.0 and then integrated in the virtual environment.

Because the CAD model of the robot is a complex assembly consisting of several parts, it was necessary to realise the conversion operation for each component separately because when conducting the conversion for the whole model the identification information of each component is lost.
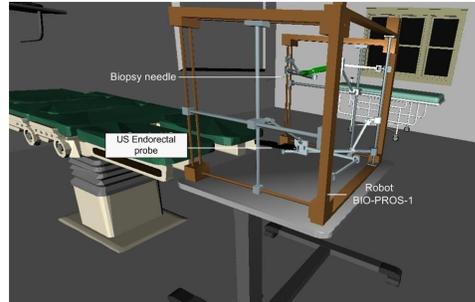

Fig. 2. *Introducing the BIO-PROS-1robot in the virtual environment*

The robot was positioned on a table which can be moved within the operating room (Fig. 2). Also the virtual robot contains assembled the virtual models of the biopsy needle and endorectal ultrasound probe. The locating of the robot in the virtual environment was accomplished by specifying translations and rotations from the VRML Transform node type used for grouping IndexedFaceSet node type.

In order to set the configuration of the BIO-PROS-1 robot in the virtual environment, the inverse kinematics model was developed [5]. For configuring the virtual robot it was used an External Authoring Interface (EAI) interface using COM objects and JavaScript language included in a Script VRML node. Through this EAI interface the user can control virtual robotic arm.

• **Integrating the patient data in the virtual environment**

In the preparation phase for the biopsy procedure using BIO-PROS-1 robotics structure it is necessary the development of a 3D virtual environment containing the equipment to be used, but also a 3D model specific to each patient. It was developed a methodology for modelling 3D anatomical organs of interest in the pelvic area using

the software 3D Slicer 4.4 (www.slicer.org) and the integration in the 3D virtual environment using a standardized neutral format representation. The proposed methodology consists of the following steps:

- MRI images processing for 3D Slicer integration using ImageJ;
- segmentation of anatomical organs of interest in the pelvic area using 3D Slicer;
- 3D modelling organs of interest in the pelvic area using 3D Slicer;
- converting from the format of representation for the 3D Slicer virtual model (* .vtk) in a neutral standardized format representation (VMRL).

The advantage of this methodology is the possibility to use multiple formats for MRI images from different MRI scanner manufacturers as well as the use of free open source programs. Further are presented the steps of the proposed methodology, with examples for 3D modelling of the prostate.

The result of the 3D reconstruction phase using MRI images of the human patient consists in more 3D geometric models in VRML neutral format. Because this model can be used to define the trajectories for the BIO-PROS-1 robot, it is necessary to pre-process the information of each geometric 3D VRML model.

The pre-processing operation for each 3D model of the human patient includes the following steps:
- joining the vertexes situated at a very small distance from each other;
- deleting the double vertexes and faces;
- removing the unused vertexes for generating flat polygonal elements that are composing the 3D model geometry;
- remove polygonal plane items with null area;
- remove polygonal items that are self-intersecting;
- generation plane polygonal elements in areas where there are spaces in the 3D

geometry model;
- applying a smoothing algorithm for planar polygon elements normals;
- reducing the number of planar polygonal elements using the iterative decimation algorithm Quadric Edge Collapse Decimation.
- grouping the IndexedFaceSet VRML type nodes that are composing the model and assigning an ID tag using VRML DEF instruction;
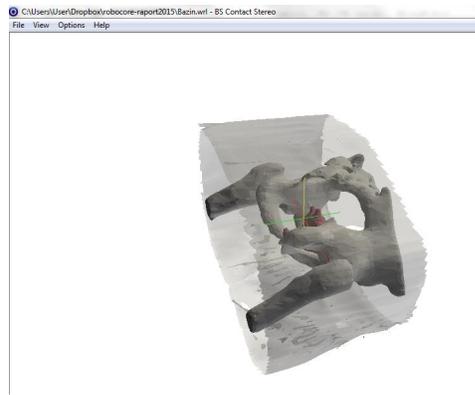

Fig. 3. *The 3D reconstructed pelvis area*

For pre-processing the plane polygonal elements for each 3D model component of the 3D virtual patient was used the open-source software MeshLab (meshlab.sourceforge.net) and for grouping the IndexedFaceSet VRML type nodes and for editing the information regarding the topological details of the VRML model was used a text editor.

After pre-processing all 3D VRML models components of the virtual patient, they were assembled into a single VRML model and integrated into the virtual environment (Fig. 3). Locating the human virtual model into the virtual environment was achieved by specifying the translation and rotation from the Transform VRML type node used for grouping the IndexedFaceSet type nodes (Fig. 4).
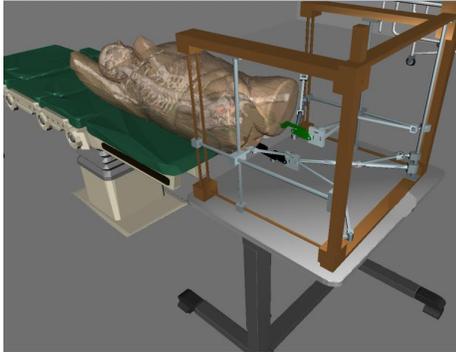
Fig. 4. *The* virtual *patient positioned in robot workspace*

4. Results

In the test, conducted to validate the software developed for the virtual reality, has been used the 3D model of a patient reconstructed from MRI images according to the methodology presented previously. In Fig. 5 is observed the 3D model of a patient with skin, bones, pelvis, bladder and prostate, obtained after the 3D reconstruction phase. For the validation the prostate was chosen as a focus area for the biopsy procedure. Prostate biopsy procedure is a complex process because the tip of the biopsy needle must avoid the intersection with high-risk areas and reach precisely the target position. Validating the virtual reality software consisted in the following steps:

- Pre-processing the 3D model of the patient reconstructed from MRI images and its integration into the virtual environment;
- Specifying a target point within the prostate to be achieved by the tip of the needle biopsy.
- Positioning the virtual human model into the workspace of the BIO-PROS-1 robot.
- Defining the relative position of robot-patient.
- Introducing the US endorectal probe.
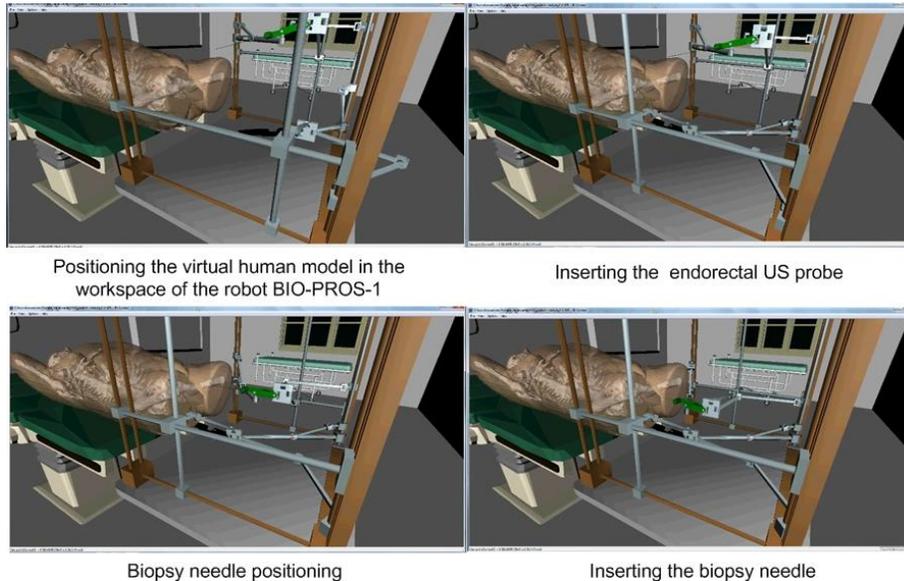- Positioning the biopsy needle.
- Inserting the biopsy needle.

Positioning the virtual human model in the workspace of the robot BIO-PROS-1

Inserting the endorectal US probe

Biopsy needle positioning

Inserting the biopsy needle

Fig. 5. *The simulation of robotic insertion of the biopsy needle and the endorectal probe using the developed virtual reality software.*

4. Conclusions

This paper presents the architecture of a system developed in order to integrate in a virtual environment the model of a patient to be subject to the procedure of robotised prostate biopsy. A virtual environment has been modelled containing the virtual model of the patient placed on the operating table and the BIO-PROS-1 robot that is going to perform the prostate biopsy, positioned relative to the patient. The virtual model of the patient is obtained by processing the data provided by the MRI images. The developed virtual reality software has been validated by conducting a test in which are simulated the steps that must be followed to perform the robotised biopsy. This entails the integration of the patient model in the virtual environment after processing the MRI images, specifying a target point within the prostate, introducing the US endorectal probe, positioning the biopsy needle and then inserting it in order to reach the target point.

Acknowledgements

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