# Virtual Planning of Needle Guidance for a Parallel Robot used in Brachytherapy


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## Scope

The paper aims to develop an accurate virtual planning of the needles trajectory for an innovative parallel robot used for general brachytherapy. Brachytherapy is an innovative cancer treatment method that allows the delivery of high doses of radiation to specific areas of the body, using specific needles. The brachytherapy needles must be introduced inside the tumour and through their catheters, radioactive seeds will be placed. The method's effectiveness has been already demonstrated with good results, but it is conditioned by the following restriction: the needles must be precisely placed since the radiation dose decreases abruptly from the base and an incorrect position leads to the damage of healthy tissue [1]. Using brachytherapy to treat the tumours situated in the thoracic or abdominal areas prove to be a difficult task, as inserting the needles might cause damage to the internal organs and/or fail to reach the target.

The use of robotic systems allows, based on the higher stiffness and precision of the robot arm, as compared to the human hand, the avoidance of obstacles and significant adjustment of the position and orientation of the needle before the penetration of cancerous tissues, improving the access to cancerous tumours. Therefore, the new developed parallel robot offers a viable solution for the treatment of cancer patients considered inoperable or when their general status does not allow an aggressive treatment. A careful trajectory planning of the needles becomes very important, mainly due to safety reasons.

## Material and methods

The critical analysis of the latest achievements in robotic assisted brachytherapy has shown that the already developed structures are built for specific organs and moreover almost all are targeting the prostate [2]. In order to make possible a universal technique for cancer treatment on several organs of human body within brachytherapy, a new parallel robot has been developed.

The PARA-BRACHYROB parallel robot for needle guidance in BT is the result of a patent application filled in 2013 [3] having 5-DOF plus one prismatic redundant DOF used for the insertion of the needle up to the target point in the patients tumour. The corresponding control algorithm and user interface are also presented. The structural synthesis of the robot mechanism has been presented in [4] and its CAD model is presented in figure 1. The robotic structure sits on an aluminum plate frame supported by a baseplate which can be fixed to the CT table, with the main five active joints (motors) fixed to the top of the frame from where these are referenced. The needle insertion modules motion will be obtained by rotating the ball screws or grooved shaft held by bearings connected to the fixed frame, necessary for a smooth motion at the active joints. For additional precision both columns will be connected by a structural bridge which will both stabilize the robotic structure and provide a viable electrical connection path.

Compared to other pre-planning applications for robotic needle insertion presented in [1, 2], the novelty of the present approach is the possibility to generate automatically, using VR techniques, linear trajectories for the proposed robotic system that allows the avoidance of the proximity with high risk areas. Considering this purpose, a 3D virtual scene was created containing, on one hand, the complete necessary equipment for real case intervention and medical equipment for specialized brachytherapy procedure: brachytherapy needle, proposed brachytherapy robotic system, guiding template and computer tomography device (CT) and, on the other hand, a 3D reconstructed model of the patient's target area (figure 2). For the 3D reconstruction of the patient's target area, the DICOM files, obtained after achieving a computer tomography (CT) were the input data. For the test case, a complete 3D data set containing the liver and all the nearby organs were reconstructed (figure 3).

The virtual pre-planning of the robotic brachytherapy intervention can be achieved using the developed algorithms, allowing automatic or manual definition of the needles trajectories, punctually for every target or using the guiding template. The main steps of the algorithm designed for automatic generation of linear robot trajectories are: (i) load the 3D model of the patient into the application; (ii) mark the target area for treatment (tumour position); (iii) import configuration of target points defined by the physician; (iv) define parameters: starting point, direction (D), the vertical (Pv) and horizontal (Po) displacement step; (v) successively translate on vertical and horizontal with the step Pv/Po the guiding template/mark point and check whether there is an intersection with organs at risk or the tumor; (vi) automatic process all the generated trajectories and automatically select the optimal linear robot trajectories.
In order to determine the intersection between the linear trajectories and the high risk areas a rayhit collision detection algorithm was used. This algorithm allows the detection of the contact between a linear segment and the triangles of the

virtual object mesh. Control points are defined on the linear segment, used for collision detection. The algorithm returns the intersection point between these points and a line corresponding to the brachytherapy needle mounted on the robot TCP (figure 3).

The developed Virtual Reality (VR) software application for PARA-BRACHYROB has a Single Document Interface structure and contains a display area of the virtual environment and a Graphical User Interface (GUI) area that contains a menu allowing sending events to the virtual environment. In order to validate the chosen trajectory of the needles, a kinematic simulation has been implemented, in which the robot moves from the current arbitrary position, with respect to a fixed coordinates system, up to the insertion point in the patient’s body, achieving in the same time its final orientation of the needle, after which it will drive the needle to the target point, in the tumour along a linear path.

**Results**

A kinematic simulation in VR has been achieved, in order to validate the chosen trajectory of the BT needles. The following simplifying hypotheses have been considered: (i) the gravity forces, the external and inertia forces have been neglected; (ii) the bodies are considered to be perfectly rigid. The considered test-case follows closely a real situation: the robot moves from the current arbitrary position, with respect to a fixed coordinates system, up to the insertion point in the patient’s body, achieving in the same time its final orientation of the needle, after which it will drive the needle to the target point, in the tumour along a linear path, avoiding the collisions.

**Conclusions**

The paper presents a novel algorithm for accurate virtual planning of robotic needle insertion, based on the restrictions concerning the possibility of tissue penetration. This is capable of either generating automatically the needle linear trajectories or allowing the manual definition of the robot trajectories for needle insertion. A virtual environment has been modelled using the CT-scan device and accessories, as well as the PARA-BRACHYROB parallel robot designed for BT, also presented in the paper. The needle insertion algorithm has been tested using both the modeled VR environment and simulations were achieved.

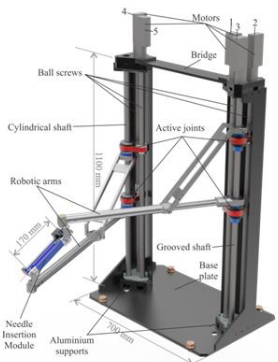

Fig. 1 The CAD model of PARA-BRACHYROB

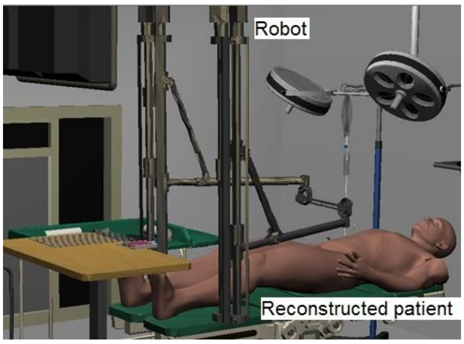

Fig. 2 Virtual environment and reconstructed model of the patient


Fig. 3 Needle implanting at a target

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