Robotic System for Image Guided Therapie – B-RobII

Gernot Kronreif [1], Martin Fürst [1], Wolfgang Ptacek [1], Martin Kornfeld [1], Joachim Kettenbach [2]

[1)] Mechatronic Automation Systems, ARC Seibersdorf research GmbH
A-2444 Seibersdorf, Austria
E-mail: {gernot.kronreif; martin.fuerst;
wolfgang.ptacek; martin.kornfeld}@arcs.ac.at

[2)] Department of Radiology, Medical University Vienna, General Hospital
Währinger Gürtel 18-20, A-1090 Vienna, Austria
E-mail: joachim.kettenbach@meduniwien.ac.at

Abstract: *Robotic systems for interventional radiology aim to serve as the physician's 'third hand' providing with a stable and accurate guidance of the medical tool towards the lesion. Clinical applications for such a system include image-guided biopsy of suspicious lesions, interstitial tumor treatment, or needle placement for spinal blocks and neurolysis. This paper describes a new design for a robotic targeting device 'B-RobII' developed by ARC Seibersdorf research GmbH. The paper outlines the system modules and reports about first in-vitro studies with different setups.*

Keywords: *Interventional Radiology; Medical Robotics; Image Guided Therapy; Image Guided Needle Placement*

I INTRODUCTION

As needle guided procedures continue to increase in numbers and importance, as they have the past several years, there will be more demand for technological assistance. In this role, needle positioning robots may have a place and this needs to be demonstrated in randomized clinical trials. Ten years ago image-guided procedures largely consisted of biopsies. Over the past decade (image guided) interventional techniques have blossomed and include procedures to ablate tissue with energies such as radiofrequency, heat, cold, and laser. Reconstructive procedures have also developed – e.g. vertebroplasty in which methymethacrylate is injected into fractured vertebra to repair them.

The high efficacy of these techniques largely depends on the accuracy of the needle placement. At times, access to a target can be technically challenging due to various factors, including a limited space at the skin entry site or a difficult angulated access.

To improve the accessibility of lesions, surgical robots and manipulators have potential advantages that are well known in the clinical and technical community (cf. [1], [2], [3]). Based on the experiences drawn from a first robot prototype for needle placement and from the results of various in vitro studies (cf. [4], [5]) a new setup for a

programmable targeting device for percutaneous interventions under US (= ultrasound) and CT (= computed tomography) guidance has being realized by ARC Seibersdorf Research GmbH in cooperation with the Department of Radiology of the Medical University Vienna as well as Medical Intelligence GmbH, Schwab-münchen/ Germany.

Main goal for this new design is to transfer the proofed concepts from previous prototype 'B-RobI' (cf. [6]) into a practical clinical setup. Thus, major aims for the new development are:

(1) modular setup for a broad variety of clinical applications,
(2) significant reduction of technical complexity (compared to the previous prototype) in order to reach an acceptable cost/benefit ratio for the entire system,
(3) easy integration into available devices / systems for interventional radiology,
(4) seamless integration into clinical workflow, as well as
(5) 'plug&play' philosophy.

II ROBOT SYSTEM B-ROBII

The developed targeting device 'B-RobII' consists of a combination of one or two 2DOF (degree of freedom) positioning modules in different configurations. In order to use the system also inside of the CT gantry without major restrictions, mechanical design of the device has to be of low-profile (WxLxH = 100mm x 150mm x 30mm for one 2DOF module). The achieved integrated design allows high dexterity regardless of the small dimensions of the module. Depending on the chosen configuration the targeting device allows 2DOF needle angulation (+/-30°) and 2DOF positioning (+/-20 mm) with high accuracy. For gross positioning of the needle entry point, the module(s) are mounted on one or two passive 7DOF multi-functional holding arm(s) (ATLAS arm, Medical Intelligence GmbH). Figure 1, for example, shows a setup with 2x 2DOF modules attached to a localizer frame.

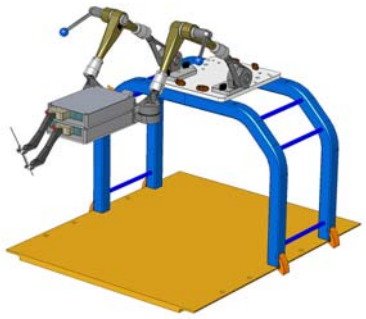

Figure 1
2x 2DOF robot setup

The chosen kinematic concept for the device is based on the parallelogram mechanism already realized for the previous prototype 'B-RobI', where orientation of the needle is defined via relative motion of two parallel carbon 'fingers' connected to each other by means of spherical joints (cf. [6]). For easy sterilisation, the two fingers - together with the polymer bearings and the needle guideway - can be disconnected from the positioning module (i.e. the robot) by means of a rapid-change bayonet connection.

For each DOF the driving system consists of a motor/planetary gear combination, an anti-backlash gear stage as well as an anti-backlash ball screw system. Linear movement is further supported by a pair of high-precision monorail guides with two carriages for each rail. Actuation of

Figure 2
Example for a planning/navigation software (left); B-RobII in clinical setup (right)

each axis is performed by a miniature DC-motor connected to a 64-pulse rotational encoder system for position measurement. Optionally, a redundant optical linear encoder with 10µm resolution can be used for position estimation.

The robot control system consists of a pair of in-house developed axis controllers for each positioning module, a central 'Safety Card' which maintains the communication bus as well as disconnects all motors from power supply in case of an emergency stop, and a power supply module – all of which is integrated into a HF-dense 19" housing. All modules are interconnected via a standard RS485 bus system. For remote control of the robot a special designed handheld operating unit is part of the control system.

The standard use of the robot system is for image guided procedures where the planning of the intervention is based on CT- or US-image data acquired pre- and/or intra-operatively. Depending on the particular setup spatial relation between the imaging space and the robot system ('registration') either is being established by means of an optical tracker, a mechanical tracker arm (e.g. for US-guided interventions) or via (semi)automatic registration based on a CT data set. Different types of planning systems – e.g. a slice based planning system for US-guided biopsies or a multi-planar navigation system for CT-based interventions – have been developed (Fig. 2).

The entire control system is structured in a client/server configuration in order to offer maximal degree of modularity. According to this configuration the application software (i.e. the planning / navigation system) is designed as client; data exchange with the in-house robot control system takes place via a dedicated 'Hardware Server'; for data exchange with an optical/mechanical tracker system a 'Tracker Server' could be integrated into the control system.

Communication between the 'Hardware Server' and the robot control system is via RS232 interface using a proprietary data protocol – for communication between application software and Hardware/Tracker Server TCP/IP socket connection is being used.

III IN-VITRO EVALUATION

For evaluation of different clinical setups appropriate in-vitro test scenarios and protocols have been developed and performed. In the following a short description of two representative test setups as well as first results of this ongoing in-vitro evaluation are given.

3.1 Simulation of US-guided Biopsy

For this first series of in-vitro tests a phantom model was prepared, which consists of a dense plastic bag (E-Z-EM enema bag, E-Z-EM), filled with gelatine and equal-sized peas (mean diameter 0.93 ± 0.1 cm).

Imaging was accomplished with a 2.0-4.0 MHz curved array transducer and an Ultramark 9 HDI scanner; (ATL - Advanced Technology Laboratories) equipped with a standard video output interface. After selection of a target by US, different scans of the target were acquired and stored for planning procedure by grabbing from the video output of the US scanner and conversion into a digital file using a commercial video capture card (WinTV, Hauppauge Computer Works). Spatial relation between the US scan and the robot coordinate frame was established via a commercial mechanical tracker system (Microscribe G2LX, Immersion Corp.). The evaluation setup is shown in Figure 3.

For planning, the most appropriate scan was selected from the stored 'image book' and the target region was selected graphically. Given the current position of the needle guide, the system calculated the needle trajectory.

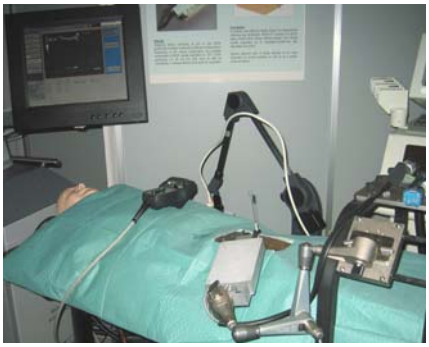

Figure 3
Test setup for US-guided biopsies

After evaluation of the trajectory by the physician, the planning was confirmed and sent to the robot controller. After confirmation by the physician, the robot automatically moves into the calculated position in order to maintain the planned trajectory.

At this position, a 17-gauge puncture needle (length 130 mm; Bard, Angiomed) was inserted into the robotic needle holder. According to the insertion depth calculated by the planning workstation, the small rubber marker of the puncture needle was moved to the position displayed in order to indicate the appropriate insertion depth. Once the puncture needle was inserted into the phantom, the stylet of the puncture needle was removed and the 18-gauge biopsy needle (Bard, Angiomed, length 160 mm) was inserted. Using an automated biopsy device (Magnum Core high Speed, 22-mm excursion), one biopsy sample was obtained coaxially.

After biopsy the puncture needle was removed and the length of the harvested pea specimen was measured. Once the robot has been removed, the trajectory within the gel phantom was documented in both planes (transverse

and orthogonal) in order to measure the deviation from the center of the target.

Result: Each of the targets (n=40) could be reached straightaway with sufficient accuracy. Length of the harvested specimen also shows the efficiency of the robot-guided procedure.

3.2 Simulation of Neurosurgical Setups

For this series of in-vitro tests a special designed phantom model made from acrylic glass was pre-operatively scanned by CT (Somatom Sensation 16, Siemens Erlangen, Germany; 1mm slice thickness) and afterwards attached to the OP-table by using two different setups: by a Mayfield clamp or by means of a CRW frame (Fig. 4) respectively. Planning/ navigation was using single slice based software for the first test series and multi-planar navigation software for the second series. Transfer of CT-data for both software setups was using DICOM format. Registration between pre-operative CT data and intra-operative robot configuration was performed by means of a mechanical tracker (Micro-scribe G2LX, Immersion Corp.).

After selection of the target point and planning of the trajectory the robot is being moved to its final position/angulation and the biopsy needle (15-gauge puncture needle; length 160 mm; Bard, Angiomed) is being advanced according to the calculated depth. After needle insertation the robot is moved manually in x/y-direction until the needle tip is being exactly located at the selected target position. The required robot movement in x- and y-direction for this 'correcting movement' is representing the positioning error for the automatic positioning and thus is being used for calculation of RMS error.

Figure 4
Test setup for NS interventions; phantom attached to CRW frame

Result: 50 biopsy procedures were successfully performed for both software setups. The calculated average targeting error shows 1.05 ± 0.35 mm (RMS).

Conclusion

This paper describes a new design for a robotic targeting device for needle based percutaneous interventions. Main development goal was to come up with a modular, reliable system which meets the requirements derived from practical use.

First in-vitro trials of the system using different setups (simulating different clinical applications) show that the designed and realized prototype of a modular automated needle guide allows image guided positioning of a biopsy needle with high accuracy. The system is easy-to-use and does not considerably interfere to the clinical work-flow. A first risk analysis of the complete system [7] did not come up with particular risks. A further series of quantitative evaluation studies – for

both US and CT guided biopsies and for different system setups (no/ mechanical/ optical tracker; remote controlled operation, etc.) – is currently in process. Different clinical applications are under evaluation at different research centers in Austria, Germany and USA. Long-term goal is to create a multi-purpose system for a broad range of percutaneous treatments, in any part of the body, using any kind of intra-operative image guidance.

References

[1] Yanof J, Haaga J, Klahr P, et al.: CT-integrated Robot for Interventional Procedures: Preliminary Experiment and Computer-human Interfaces. Comput Aided Surg. 2001; 6, pp. 352-359

[2] Masamune K, Fichtinger G, Patriciu A, et al.: System for Robotically Assisted Percutaneous Procedures with Computed Tomography Guidance. Comput Aided Surg. 2001; 6, pp. 370-383

[3] Cleary K, Onda S, Banovac F: CT-directed Robotic Biopsy Testbed: User Interface and Coordinate Transformations. Proceedings of the 15th International Conference on 'Computer Assisted Radiology and Surgery CARS2001' (Ed. Lemke et al.), ICS 1230, 2001, ISBN 044450866, Elsevier Science B.V. pp. 171-177

[4] Kronreif G, Kettenbach J, Figl M, et al.: Evaluation of a Robotic Targeting Device for Interventional Radiology. Proceedings of the 18th International Conference on 'Computer Assisted Radiology and Surgery CARS2004' (Ed. Lemke et al.), ICS 1268, 2004, ISBN 0444517316, Elsevier Science B.V. pp. 486-491

[5] Kettenbach J, Kronreif G, Figl M, et al.: Robot-assisted Biopsy Using CT-guidance: Initial Results from in Vitro Tests. International Journal 'Investigative Radiology', Volume 40, Issue 4, April 2005, Lippincott Williams & Wilkins. pp. 219-228

[6] Kronreif G, Fürst M, Kettenbach J, et al.: Robotic Guidance for Percutaneous Interventions. Journal 'Advanced Robotics'. Vol. 17, Number 6, 2003, ISSN 0169-1864, VSP and Robotics Society of Japan. pp. 541-560

[7] Korb W, Kornfeld M, Birkfellner W, et al.: Risk Analysis and Safety Assessment in Surgical Robotics: A Case Study on A Biopsy Robot. International Journal 'Minimally Invasive Therapy and Allied Technologies – MITAT'. Vol. 14, No. 1, 2005, Taylor&Francis. pp. 23-31