Section: **Mechatronik**

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Abstract-Title:
NAVIGATION AND SOFT-ROBOTICS FOR ACCURATE PLACEMENT OF BIOPSY NEEDLES

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Abstract-Text:
Purpose
Navigation systems are used often in surgery if small targets have to be reached with high accuracy, as this is e.g. the case in biopsy or brachytherapy applications. After successful registration of the patient the preoperative planning data can be trans-ferred into the operation room (OR). Optical markers attached to the surgical instrument and the patient are used to calculate the deviation between the current intraoperative pose of the instrument and the preoperatively planned pose. This deviation is then graphically displayed on a computer screen. The task of the surgeon is to compensate manually for the displayed deviation. Although navigation systems are al-ready a great help for the surgeon, some important difficulties remain: (a) frequent changes of the field of view include new eye accommodations, leading to high demands on the surgeon\'s concentration. (b) A spatial 3D error is displayed on a 2D screen which imposes high demands on the surgeon\'s spatial imagination. (c) Depending on the OR set-up the hand-eye coordination may be cumbersome. In order to support the surgeon, a novel generic robot "KineMedic" for medical applications has been developed at the German Aerospace Center, Institute of Robotics and Mechatronics together with the company BrainLAB. The goal of this development is to combine the advantages of both navigation and robotics while avoiding their respective disadvantages. The main characteristic of this light-weight robot is the possibility of haptic interaction between surgeon and robot: the robot can be touched at the structure and moved towards the desired goal while the exact pose of the tool-tip is controlled by the navigation system. See Fig.1 for the set-up of the system for biopsy applications. Similar to the pedicle screw placement application presented last year the tissue probe is not taken automatically. The robot only helps to position a guiding tube very accurately. Through this tube the needle is inserted manually by the surgeon (see Fig. 2), thus he keeps full control of the intervention and receives haptic feedback. Method
The system consists of the KineMedic robot, a light-weight, kinematically redundant and torque controlled robot and an optical intraoperative navigation system. The tool tip pose of the robot (i.e. the guiding tube) as well as the pose of the registered patient are tracked by the navigation system. Thus, it is possible to measure and to compensate for pose errors. The KineMedic robot itself is a highly integrated mechatronic system. Its main characteristics are the integrated torque sensors which allow for the measurement of contact forces between robot and environment/surgeon and the kinematically redundant structure being comprised of seven joints. In addition with the impedance control law a very intuitive man-machine-interface can be implemented: The surgeon simply moves the robot by haptic interac-tion (i.e. the robot is moved by pulling/pushing its structure) along

trajectories defined by the navigation system, leading to the desired pose. Additionally, the robot configuration can be changed by haptic interaction, too, without changing the pose of the tool center point. Therefore, it is possible to avoid collisions between robot and OR staff or equipment very intuitively. In the following, the intraoperative workflow is described:

Mode 1 (pre-positioning): From its starting position the robot arm is freely maneu-verable in all directions of the Cartesian space. The user switches to mode 2 if the arm is prepositioned.

Mode 2 (towards biopsy axis): The robot only allows movements along trajectory 1 (see Fig. 1) which guides the current biopsy needle axis to the pre-planned axis (trajectory 2) so that both axes coincide at interception point P. This is carried out by Cartesian impedance control, whereby the direction along trajectory 1 shows zero stiffness and all other degrees of freedom (DoF) possess a high stiffness. On reach-ing this axis it is automatically switched to mode 3.

Mode 3 (along biopsy axis): After the axis of the guiding tube is lying on the desired biopsy axis the user is guided along trajectory 2 to the insertion point. The control is analogue to mode 2. Shortly before reaching the insertion point it is automatically switched to mode 4.

Mode 4 (fine tuning): The user now releases the robot arm. The robot can thus align the pose of the guiding tube actively, without external disturbances and with highest possible accuracy, based on the current pose measured by the navigation system and the planning data. At this point there is still no contact between robot and patient. As the robot carries out movements independently and actively in this mode, speed and motion limits are very strict. The flow control allows a switch to mode 5 only if the pose error lies within certain tolerances.

Mode 5 (insertion of needle): The impedance-controlled robot runs with maximum stiffness (this basically corresponds to position control). The user now manually in-serts the biopsy needle into the guiding tube and takes the tissue probe (see Fig. 2). In this mode the robot mainly acts as a stand. Thanks to the correctly positioned guiding tube the surgeon has to control only one degree of freedom: the insertion depth. This depth is displayed on the computer screen (see Fig. 3) as the biopsy needle has attached optical markers which allow for the measurement of the penetra-tion depth by the navigation system. After the tissue probe was taken the user switches to mode 6.

Mode 6 (safe removal): The robot arm only allows movements along the needle axis - for safety reasons only away from the patient. As from 100 mm above the insertion point it is automatically switched to mode 7.

Mode 7 (free motion): The robot arm is now freely maneuverable again (as in mode 1). The vertical position, however, is restricted to 100 mm above the insertion point, whereby it is made sure that the robot can not come into contact with the patient occasionally.

Results and Conclusion

The robot shown in Fig. 1 implements the above mentioned concepts. The use of the robot is very intuitive. Thanks to the graphical interface of the navigation software the user is guided intuitively through the medical workflow. The desired pose can be reached very quickly and with high accuracy (after the fine tuning step an error of approx. 0,6 mm and 0,5° remains) as the robot acts as a haptic display guiding the surgeon towards the desired pose. Thanks to the low weight (approx. 10 kg) and the redundant structure which enables null space motion (i.e. the robot structure can be reconfigured without changing the tool tip pose this is important for collision avoidance and can be achieved by simply pulling/pushing the robot structure) the KineMedic robot can be easily integrated into existing ORs.

Bild 1/JPG

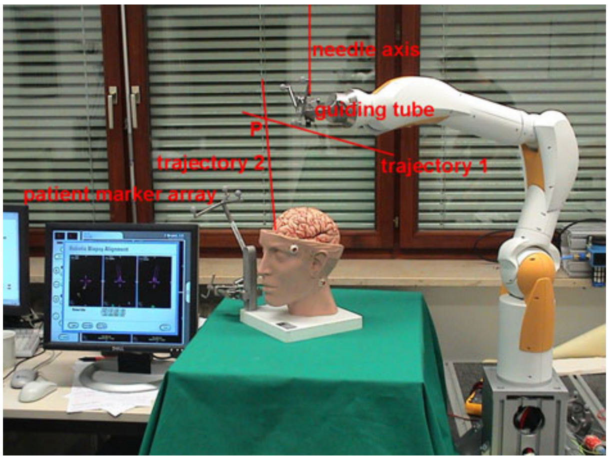


Bild 2/JPG

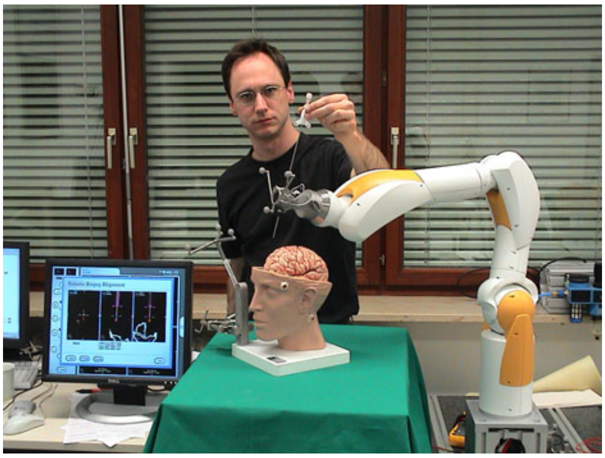
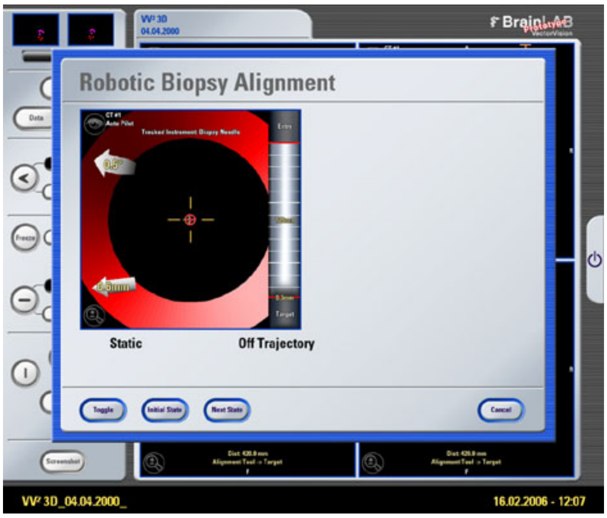


Bild 3/JPG



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Robotic Biopsy Alignment
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