VR-Map: A New Device for Patient Registration and Optimal Robot Positioning

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Abstract:

Optimal robot positions for a specific robot-assisted surgery can be preoperatively planned based on patient specific data. Immediately before the intervention in the operating room (OR), a registration needs to be done to reference the patient in the OR with the preoperative data. The optimal robot base positions then need to be localized in the OR. The goal of the work presented here is to speed up and facilitate these steps. This is achieved by use of the VR-Map, a newly developed integrated device for registration and localization that can be mounted onto a robot. Thus, no additional tracking hardware is required and the data is measured in the robot coordinate system. In this paper the hardware design of the device and the integration into the intra-operative planning of the DLR MiroSurge setup are described. Finally, first results are shown that demonstrate VR-Map's accuracy and ease of handling.

Keywords: Registration, Localization, Intraoperative Setup Assistance, OR projector

1 Introduction

Robot-assisted surgery requires a preoperative planning of the intervention, e.g. based on MRI or CT data. In order to transfer preoperatively planned data into the operating room (OR), registration is necessary as well as a method to localize the planned data in the OR. This data may comprise e.g. entry point positions into the human body in case of minimally invasive interventions or cutting trajectories for osteotomies. Additionally, the robots have to be optimally positioned relative to the patient and with respect to the planned intervention.

Various methods were proposed to handle patient registration, see e.g. [1]. In former studies we showed markerless patient registration with a handheld 3D-scanner device [3] to perform sufficiently accurate for referencing planning data in robotic surgery.

Augmented reality systems as presented in [2] serve to localize planning results in the OR. Our group developed the so called AutoPointer [4] for localization of the preoperatively planned data by using a handheld laser projector device.

In our former studies, an optical tracking system measured the pose of the scanner system and the laser projector. However, this setup had several disadvantages. Firstly, an additional tracking system has to be setup in the OR, requiring additional space. Secondly, since the intervention is performed by remotely controlled robots, the measured data has to be transferred to the robot coordinate system. Therefore, the tracking system has to be calibrated to the robot, either by measuring tactile reference points or by using known reference markers on the table. This decreases the overall accuracy of the setup, since the pose error of both, the tracking and the robot are concerned.

This work presents an integrated device for registration and localization that can be mounted onto a robot, the so called VR-Map device. Thus, no additional tracking hardware is required and the data is measured in the robot coordinate system. In this paper the hardware design of the device and the integration into the intra-operative planning of the DLR MiroSurge setup [5] are described and first results are shown. A discussion concerning accuracy and further improvements closes the paper.

2 Hardware Design

In the following, the design and implementation of an integrated device for the mapping between virtual planning data and the real surgery system (VR-Map) is discussed that can be used either mounted onto a robot or hand guided. It incorporates two functionalities: registration of patients for medical applications and laser projection to project symbols and trajectories onto the patient's body or the OR table.

2.1 Design Considerations

A basic requirement for the design of the VR-Map is a light-weight and compact design to stay below 3 kg, which is the maximum payload of the MIRO medical robots used in the MiroSurge scenario. A compact design is important to guide the robot-mounted device by hand.

The VR-Map device should provide a sensor for 3D surface digitization and subsequent registration. In former work [1], different sensor principles were tested. Here, an active scanner system, similar to the laser stripe profiler (LSP) [6], should be used, since it is more robust to changes in environment lighting than a passive system. It consists of a laser beam that illuminates a stripe on the surface and a camera that records its reflection. The 3D position of different points contained both in stripe and on the surface may readily estimated by means of image processing algorithms followed by triangulation – provided a calibrated system [7]. The design should also provide a stereo vision system for further research.

For localizing the virtual planned object in the real scene, a laser projector needs to be integrated, that allows for drawing symbols and trajectories onto patient and OR table, as already shown in [4].

2.2 VR-Map Implementation

The implementation of the VR-Map system integrates two AVT Guppy F-046C Firewire cameras with Pentax lenses (f=6mm), a Scanlab ScanCube 7 laser projector, and a laser-line module with 650 nm wavelength, 5 mW laser power, and 60° opening angle. The weight of the system is 1,3kg. Its dimension is 242.5 mm x 100 mm x 140 mm. The mechanical concept of the system is shown in Figure 1.

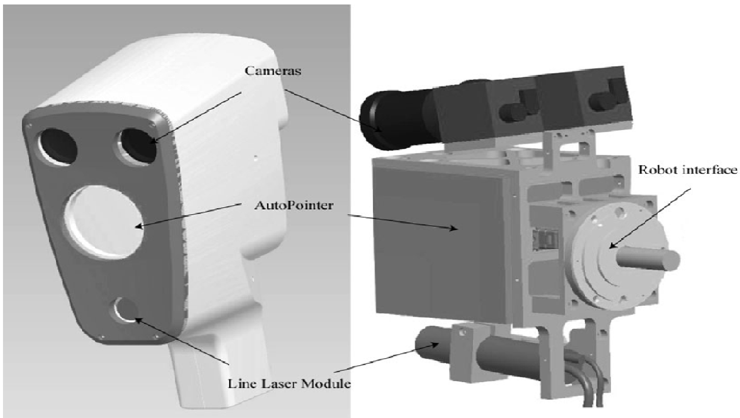

Figure 1: Mechanical concept and components of the VR-Map with and without casing.

The cameras are tilted by 10° and have a base distance of 55 mm, which is a trade-off between perspective difference and range precisions. The laser-line module is separately inclinable (0-10°) for different measurement ranges. At a laser-beam tilt angle of 5°, this results in a minimum scan distance of about 138 mm.

The main component of the AutoPointer is a ScanCube 7 laser projector. Its position-controlled high speed gyro-scanners deflect a laser beam in two axes. Hence, it can project complex cutting trajectories and multiple symbols at the same time.

The casing is designed to fulfill the main criteria of ideal handling: it protects the technical components, while keeping dimensions as slim as possible. The shape minimizes the risk of collisions with the robot as well as squeezing of the fingers between the scanner and the robot. An integrated handle guides the cable and directs it away from the hands to avoid disturbances. It is placed close to the TCP to allow precise manipulation of the device. A mechanical interface for the DLR MIRO magnetic mount is attached on the rear side.

3 Results

The VR-Map device is successfully integrated into the intra-operative planning setup of MiroSurge. After computer assisted planning of the surgery based on CT/MRI data, an algorithm calculates optimal positions of robot bases and entry points into the patient. The next steps of the workflow that involve the VR-Map device to transfer the planning results into the OR are explained more in detail in the following.

3.1 Registration of 3D surfaces

The cameras and laser-line projector are used to generate stripes of range data at a rate of 25 Hz, using the laser stripe profiler (LSP) [6] method of the DLR multisensory 3D-Modeler [7]. The intrinsic parameters of the scanner system (i.e. camera model and laser plane) are calibrated once, using a high precision pose sensor (e.g. a measurement arm) [6]. Thus, only a fast extrinsic eye-in-hand recalibration is performed with the respective MIRO robot, using the calde/callab toolkit [10]. This enables flexible change of robots and fast verification of the calibration.

The range data is merged with the poses of the MIRO robot and iteratively integrated into a 3D surface model during the data acquisition [11]. After scanning, the measured 3D-model is registered with the preoperative data using a feature based registration method and can be instantly displayed in the intra-operative planning display.

Registration determines the pose of the patient relative to the OR table and the MIRO robot holding the VR-Map. The MIRO robots are attached to the OR table and can be freely positioned only along its rails. These restrictions were unknown in the preoperative phase. Therefore an additional optimization needs to be done once the patient pose is clarified to comply with the positioning restrictions. Since this optimization only slightly alters the previous optimization results, it is computed in just a few seconds.

Figure 2: Scanning of the patient: The VR-Map is attached to the robot (left) and guided by hand to scan the patient surface (right). A meshed surface is generated online (display in left image).

3.2 Localizing robots and planned data

The MIRO robot holding the VR-Map is used to project the setup data onto patient and OR table. The device is guided by hand such that it coarsely points towards the area where data needs to be positioned. The integrated AutoPointer automatically controls its mirror positions so that the data is projected to the predetermined positions. Figure 3 (left) shows the MIRO robot in the back holding the VR-Map while it projects the optimal base position for the MIRO robot in the front. A close-up of the projected dagger sign is shown on the right of Figure 3. The robot is then manually positioned according to the projected information.

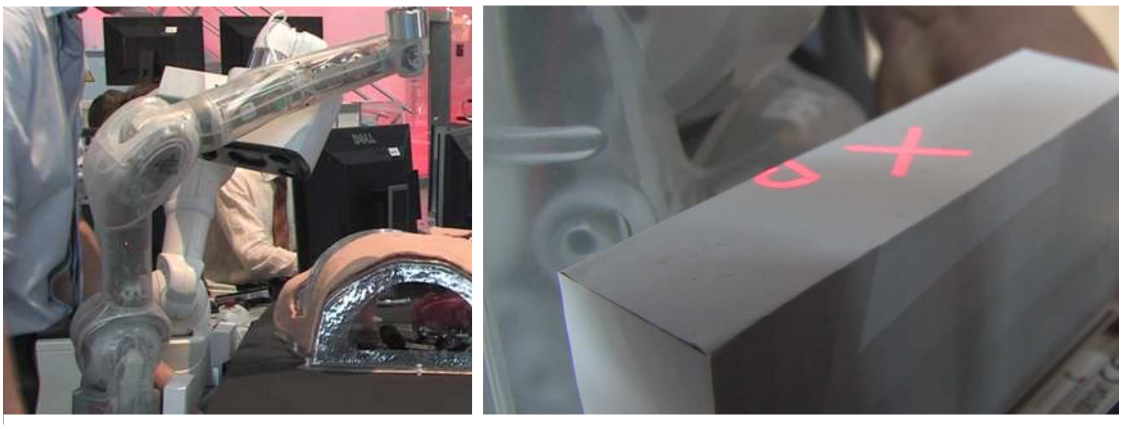

Figure 3: Projection of the optimal robot base position: a dagger sign (right) is projected towards the robot base of the transparent Miro robot (left) to show the optimal setup position.

4 Discussion and Outlook

The concepts of the VR-Map device have a very high potential to simplify the workflow of accurately transferring planning data of robot-assisted surgeries into the OR. The device can be attached to the MIRO robots using their standard magnetic coupling, and both scanning and localization can be accomplished within minutes.

As concerns the device's accuracy, the main source of inaccuracy is the position data coming from the robot controller and required to calculate the pose of the VR-Map. Due to their light weight design, the MIRO robots are less stiff compared to standard industrial robots. It is therefore essential to comprehensively calibrate the robot to include compensation of elastic deformations induced by the weight of the system and the forces applied when touching and moving the device. Currently, accuracy in scanning and localization is below 5 mm, and an accuracy increase towards 1.5 mm seems feasible by improving the robot calibration. To further support the pose determination, self localization methods as presented in [12] could be exploited by the stereo camera system of the VR-Map.

The size of the device may be further reduced in the future, as development of laser projectors unceasingly provides smaller devices. If the prospective electronic will be smaller, a survey will be conducted in order to further optimize ergonomics and intuitive handling. Moreover, further research on robust passive 3D digitization methods, e.g. binocular stereo reconstruction, would allow for removing the laser-line from the system.

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