

# Augmented Reality for Port Placement and Navigation in Robotically Assisted Minimally Invasive Cardiovascular Surgery

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**Abstract.** Optimal port placement and intra-operative navigation in robotically assisted minimally invasive cardiovascular surgery are essential for the improvement and success of a teleoperator based heart operation. A new system incorporating both port placement planning and intra-operative navigation was established. Offline the optimal port placement is planned on a three-dimensional virtual reconstruction of the patient's computed tomography scan. Using this planned data an accurate in-vivo port placement can be performed, which is achieved by augmented reality techniques superimposing virtual models of the thorax and the teleoperator arms on their real world counterparts. A significant reduction of operation time may be obtained by a precise and collision-free planning and placement of teleoperator arms. Collision detection techniques are expected to allow for avoidance of consecutive new port placement by detecting intersections of instruments among each other and with the patient's anatomy. Endoscopic failure or switching to open surgery may be evaded.

*Keywords:* Augmented Reality; Port Placement; Teleoperation; Computer Aided Surgery; In-Situ Visualization

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## 1. Introduction

In teleoperator based minimally invasive cardiovascular surgery, only small incisions (also referred to as ports) are used to perform an operation. Open heart surgery can be avoided, resulting in less surgical complications than in conventional invasive surgery [1].

However, current teleoperator systems still have some limitations. First of all, it is difficult for the surgeon to place the teleoperator arms in a way that the whole operation region can be reached during the intervention. Frequently it is necessary to replace the ports during the operation to continue. Due to the limited field of view of the endoscopic camera, the surgeon lacks a larger overview over the operating region inside the patient. This makes the navigation hard, especially when the teleoperator tips are outside the view of the endoscope.

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## **2. Purpose**

We propose an approach for optimal port placement and intra-operative navigation in robotically assisted cardiac surgery in order to improve the efficiency of a teleoperator system. Our system was designed in close interdisciplinary collaboration of surgeons and computer scientists to aid the entire clinical workflow for robotically assisted cardiac surgery from the planning phase up to the actual intervention.

The system allows the planning and simulation of different port placements in a way that no collisions between the teleoperator arms and bones or vitals occur during the operation. Augmented reality technology, the visual registration of virtual data with real objects, is used for the intra-operative integration of the planned placement.

Thereby, the system provides an intra-operative navigation tool. The limited keyhole view of the endoscopic camera is augmented by embedding it into the patient's three-dimensional reconstructed model of the computed tomography scan. This gives the surgeon improved orientation inside a larger environment around the region of interest.

## **3. Our Approach**

Our intention is to provide the surgeon with an intuitive and comprehensive interface for the entire workflow of a teleoperator-assisted cardiac intervention. This is achieved by the development of modules, which support the surgeon to segment cross-sectional axial slices acquired by imaging modalities; reconstruct a three-dimensional virtual model of the patient from these slices; simulate the cardiovascular intervention in a virtual environment; and guide the placement and intervention.

### *3.1 Virtual simulation*

For the virtual simulation of an intervention, the teleoperator arms as well as assistance arms can be interactively placed and moved within the patient's model in such a way that they neither intersect with each other nor with vitals and bones. The planning tool's graphical user interface (cf. figure 1) provides various visualization, planning, and validation options. Computed tomography slices can be displayed in sagittal, coronal, and frontal directions and are automatically aligned with the reconstructed model in a common coordinate system. For a more intuitive planning procedure, the patient's model as well as the teleoperator arms can be made semitransparent or entirely hidden to see the patient's interior.

Collision detection techniques (cf. figure 2) and a virtual endoscope view support the verification of all poses of the teleoperator arms and their corresponding ports. Whereas collisions between teleoperator arms are avoided by real-time computations, collisions between arms and anatomy are detected by a fast triangle-triangle intersection detection algorithm applied on the patient's polygonal model [2]. Certain anatomical structures such as the left lung, which is usually deflated during the intervention, or the patient's skin can be hidden and excluded from these collision detection checks. Similar to its application in neurosurgery [3], a virtual endoscope simulates exactly the view as obtained by the endoscope arm's camera by setting the estimated parameters. It can be used to simulate critical steps of the intervention in advance, to test the reachability of

the whole working field. The planned position of the camera and the instruments are exported to the intra-operative port placement and navigation tool.

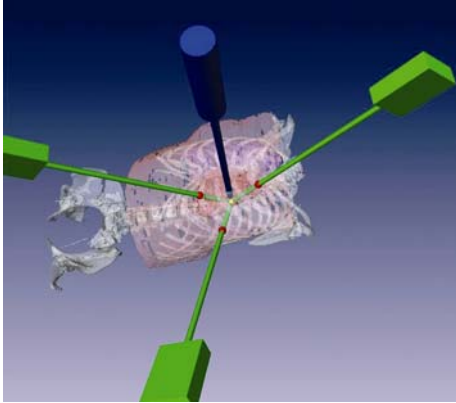


Fig. 1: Example for an optimally planned port placement using the proposed system

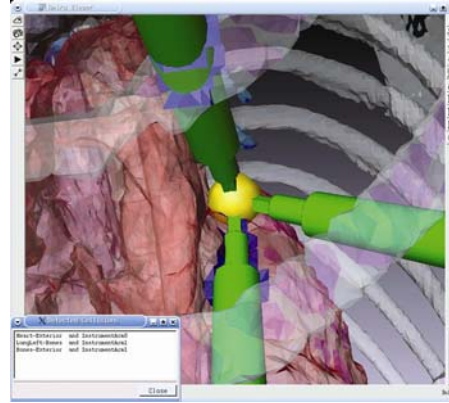


Fig. 2: Collision detection techniques identify intersections between vitals or bones and teleoperator arms

### 3.2 Augmented reality

Augmented reality techniques [4] enable the projection of the previously planned optimal poses for the port placement on top of the real world view of the patient (cf. figure 3). The physicians are provided with an expedient visualization interface to see inside the patient. The image data is registered in three dimensions with the patient's thorax in order to perfectly align the modalities reality and virtuality. Fiducials (i.e. artificial landmarks) are placed onto the patient's skin before the computed tomography scan is performed. By using ink tattoos, the exact location of these fiducials can be reconstructed in the surgery room [5]. An infrared tracking system<sup>1</sup> detects the position of the fiducials in the operating room at exactly the same location as detected in the computed tomography scan. A point based algorithm uses the corresponding position of the fiducials in both modalities reality and virtuality to compute the affiliated rigid transformation from one modality into another. Matching the three-dimensional model data with the patient during the surgery is done fully automatic based on a RANSAC approach [6]. It selects a random minimal subset of correspondences to compute the rigid transformation. The pre-operatively planned port position is then superimposed on top of a video image of the real patient after a rigid spatial registration.

The endoscopic camera and instrument arms are tracked using the same infrared tracking system the patient is registered in. The tracking does not rely on the actual teleoperator parameters as in related approaches [7] and therefore additional assistance arms that are placed independently of the teleoperator can be tracked. Furthermore, the proposed system can be used for verifying the mechanical tracking data provided via the teleoperator API (application programming interface).

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<sup>1</sup> smARTtrack1 by A.R.T GmbH, [www.ar-tracking.de](http://www.ar-tracking.de)

The position data can be used as a supplementary source of feedback during the placement process in order to compensate the missing third dimension on the image plane by color augmentation. In addition, the pose of the tracked instruments can be used for intra-operative navigation, where the position of the tracked arms is augmented on the three-dimensional reconstructed model of the patient's thorax in real time. This can be applied in a totally virtual environment or by using augmented reality techniques.

Throughout the entire intervention the instrument arms can be tracked using the infrared tracking system. Thus, the position and orientation of the instrument arms can be visualized in real time in the reconstructed three-dimensional model of the computed tomography scan of the patient's thorax (cf. figure 4).

In a visionary scenario, the limited field of view provided by the endoscopic camera may also be augmented. While other approaches [8] try to integrate the augmentation into the video frame, for instance to identify coronary vessels, we propose to extend the surgeon's view such that around the video image the reconstructed structures from the pre-operative data are displayed together with the tracked teleoperator arms. This may improve the surgeons' orientation and allow the surgeon to see the position of the instrument tips even when they are not visible inside the actual endoscopic image, which can be used to guide the instruments to the region of interest.

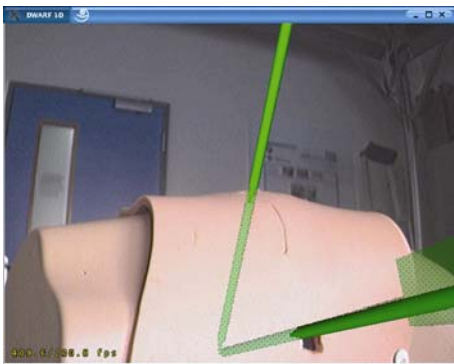


Fig. 3: The placement of the instrument arms is intra-operatively guided by augmented reality techniques, an overlay of reality and virtuality

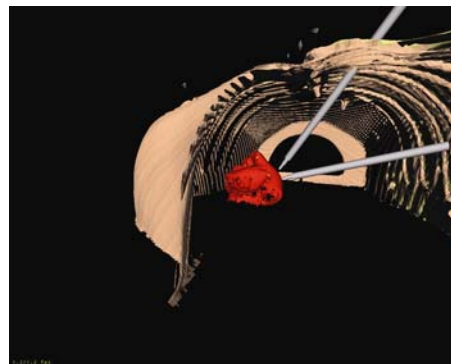


Fig. 4: For improved orientation, the tracked instrument arms are visualized in the reconstructed three-dimensional model of the patient's thorax

#### 4. Results

A prototype system using standard graphic workstations was built, that ensures a collision-free teleoperator assisted cardiac intervention. An accurate rigid spatial registration of the pre-operative acquired imaging data of the patient's anatomy is realized. Thus, the endoscopic camera and instruments are placed as intended.

The collision detection method ensures an intersection-free planning and proper placement of the teleoperator arms to access the volume of interest.

Whereas the overall system was evaluated on phantom data, the non-invasive part of the system, including planning, simulation, and patient registration was also tested on real patient data.

## 5. Conclusion

In applying the designed system, we anticipate a significant reduction of operation time by improved planning and intra-operative support. The pre-operative planning and integrated collision detection is expected to avoid the collision of instruments or camera among each other or with the patient's anatomy during the operation. Thus, we assume to avoid consecutive new port placement and to evade endoscopic failure and switching to open heart surgery.

In addition, the enhanced intra-operative orientation possibilities may lead to further decrease in operation time and improved quality.

We expect the overall system to provide the surgeon with a powerful tool to overcome the current disadvantages of robotically assisted minimally invasive surgery.

While the software already exists in a prototypical stage, several further improvements are needed for the system integration and hardware components for the clinical application. Additional advancements need to be considered for a more accurate intra-operative registration, for instance by 2D/3D registration to position the patient [9] or three-dimensional reconstruction of stereo-endoscope images to register the organs [10].

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