# A Preoperative Planning Procedure for Robotically Assisted Minimally Invasive Interventions


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**Abstract.** A successful robotically assisted minimally invasive intervention necessitates preoperative planning which is done by the surgeon to prepare the intervention and to decide about the best access to the surgical site. In the context of robotically assisted minimally invasive surgery, this requires to optimally place ports and robots such that important conditions and requirements like sufficient dexterity, optimal view and a collision free workspace are satisfied. This paper describes the preoperative planning procedure currently under development for the DLR minimally invasive robotic surgery system which utilizes an optimization procedure.


## 1 Introduction

The use of teleoperated robots in the operating room (OR) for minimally invasive interventions has been investigated closely in the past years both in abdominal and heart surgery [4, 5, 10, 12, 13]. One key aspect necessary for a successful intervention is preoperative planning. Preoperative planning is done by the surgeon in order to prepare the intervention and to decide about the best access to the surgical site. In case of robotically assisted interventions the results of these decisions must be transferred also to the robotic equipment. Ports and robots must be placed such that no collisions between the robotic arms occur, the robotic system always provides sufficient dexterity, the view at the surgical site is optimal and the patient's trauma becomes minimal. The different criteria which must be met for an optimal port and robot placement can hardly be satisfied using an trial and error approach or just by experience. For that reason the use of optimization algorithms for preoperative planning seems to be necessary to ensure a high quality of interventions in the context of robotically assisted minimally invasive surgery.

Preoperative planning procedures which utilize optimization algorithms are usually carried out in the following way (see Fig. 1): First of all patient specific tomographic data is recorded and segmented in order to obtain 3D models of the anatomical structures of interest. After this the surgeon can plan the intervention on basis of the virtual patient specific model. He determines the parts of the organs which must be reachable by the instruments and visible by the laparoscope. This is followed by the optimal placement of ports and robots which is conducted in the background automatically by the optimization algorithm. The results of the optimization algorithm are displayed to the surgeon and can be validated by him. In a virtual environment he can simulate the intervention. He decides if the proposed port and robot positions are feasible. In case he encounters any problems, the planning is possibly modified and the optimization is redone. Then, during the preparation of the actual intervention, the preoperatively determined data must be transferred into the OR. The first step in doing this is to register the virtual preoperative environment to the real anatomy of the patient. Eventually, the ports and robots must be positioned according to the preoperative plan.

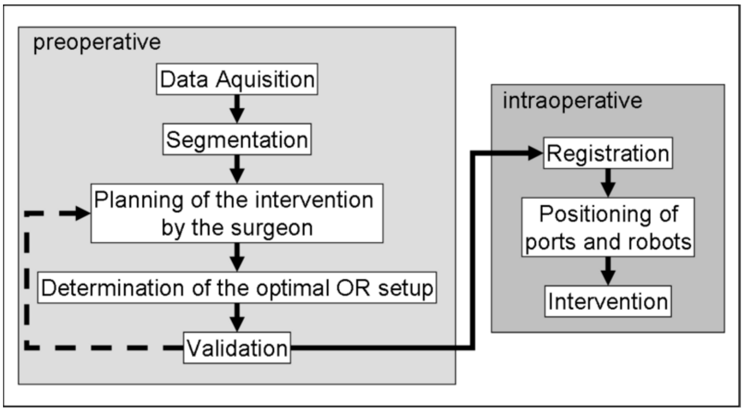



**Fig. 1.** Steps of a robotically assisted intervention with preoperative planning.

This paper will discuss the preoperative planning strategy which is developed for the DLR minimally invasive robotic surgery (MIRS) system (see [11]) shown in Fig. 2. It consists of three light-weight, kinematically redundant, impedance controlled surgical robots (two of them equipped with sensorized and actuated instruments, the third one holding the laparoscope) and a master console. The master consists of a stereo video screen and two PHANToMs as kinesthetic feedback devices. The surgical robots are currently designed, manufactured and assembled. The discussion of the proposed planning strategy takes place with respect to the preoperative planning environment by the Chir team of INRIA [1] which belongs to the most important preoperative planning tools developed so far. Other approaches can be found in [2, 3, 9, 15, 16].
The planning environment of the Chir team is highly tailored to the daVINCI robotic system by Intuitive which consists of three robotic arms mounted on the same base. Each arm has a remote center which has to be positioned at the entry point (port) into the human body. Because all daVinci arms are mounted at a common base, the registration and port positioning can be conveniently done using the robotic arms as position sensor. In case of the DLR setup this is not possible and an external positioning system

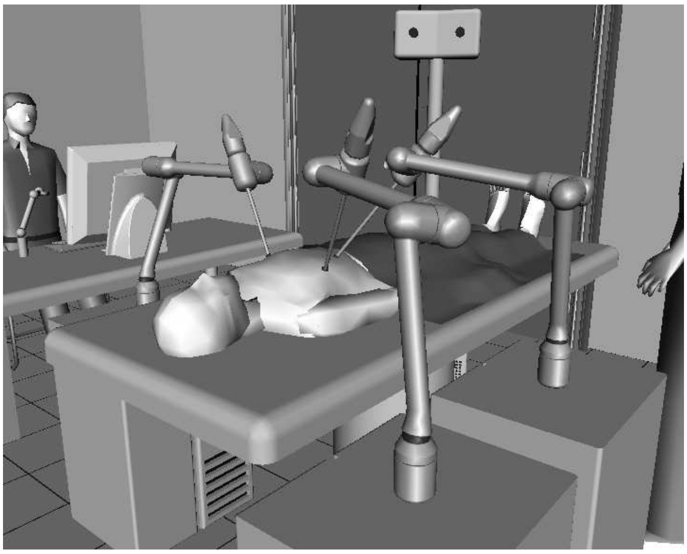


**Fig. 2.** The DLR MIRS system in development.

must be used. Registration will be done using a handheld laser scanner (developed by DLR) by matching the preoperative with the scanned data (see [8]). An advantage of using a laser scanner is that the application of fiducial markers can be avoided. Furthermore, the laser scanner relies on an infrared tracking system which can also be used to position ports and robots. Another difference between the Chir and the DLR approach is that in case of Chir the calculation of the optimal port and robot positions is done subsequently neglecting the dependence of the manipulator dexterity on the robot kinematics. Because this dependence seems to be in most cases rather weak this two step approach delivers good results as reported in [1]. In contrast to this the DLR planning tool utilizes an integrated approach where the problem of optimal port and robot placement is solved in one step exploiting more general measures of manipulability and accuracy [7].
The planning of the intervention by the surgeon is described in section 2. Section 3 presents the optimization procedure and section 4 the process of validation and simulation. The transfer of the planning into the OR is described in section 5, and section 6 summarizes the results and gives an outlook to further research.

## 2 Intervention Planning

After segmenting the tomographic, patient specific data, the 3D model of the patient is shown to the surgeon. During the planning process, he can preposition the necessary OR equipment and determine the area of interest on the resp. organ as well as potential port locations on the skin of the patient. This is done by simply drawing on the resp. organs as depicted in Fig. 3.

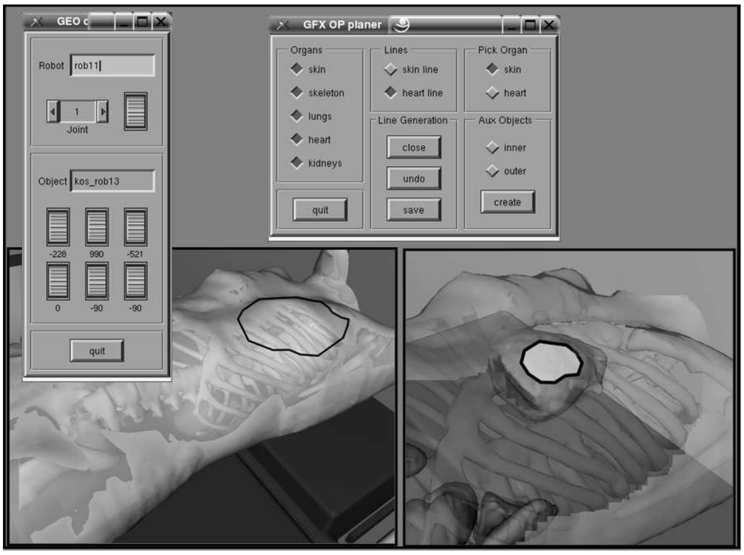
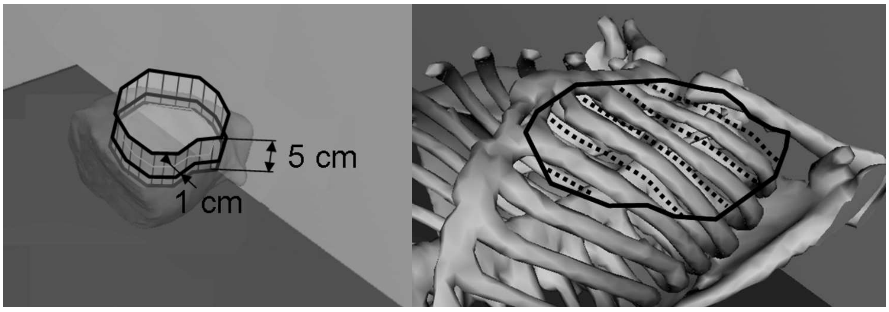



**Fig. 3.** Planning of the intervention: Determination of potential port locations and the area of interest on the organ to be operated.

An important issue to be taken into consideration is the intraoperative shift of the organs due to e.g. insufflation. To the authors' knowledge, there are no algorithms available to foresee the intraoperative position of the organs preoperatively. However, the shift can be roughly estimated as e.g. in [14]. To take into account this shift, the workspace which has to be accessible to the robots is generated from the surgeon's specifications as follows: First the borderline of the area of interest is shifted by 1 cm with respect to the reverse direction to the center of curvature. The workspace is then defined by translating the enlarged area of interest 4 cm in direction of the averaged surface normal and 1 cm in the opposite direction as depicted in Fig. 4(a). From the area accessible for port locations, possible ones are calculated using the 3D model of the rib cage where the intercostal space is determined (Fig. 4(b)). In the next section, the optimization procedure is described that leads to an optimal OR setup.

## 3 Determination of an Optimal OR Setup

In order to achieve an optimal OR setup, the positions of the ports and the robot bases must be determined such that important conditions and requirements like sufficient dexterity, optimal view and a collision free workspace are satisfied. This will be assured using an optimization procedure described in this section. This optimization procedure is right now in development at DLR and will be evaluated in collaboration with surgeons. In order to set up the optimization procedure, optimization parameters have to be identified, significant optimization criteria must be formulated and a suitable optimization




(a) (b)

**Fig. 4.** Workspace (a) and possible locations for the entry points in the intercostal space (b).

procedure for the problem has to be developed.

**Optimization parameters.** With respect to the DLR MIRS system, the bases of three robots have to be positioned as well as their resp. ports. Furthermore, the lengths of the instruments can vary and eventually the position of the patient and that of other OR equipment can be taken into account.

**Optimization criteria.** Reasonable criteria for an optimal OR setup are given in [1]. The DLR approach additionally formulates constraints on the dexterity of the robots itself. Thus it will be guaranteed that the robots provide sufficient manipulability and accuracy throughout the workspace and that no singular robot configurations (configurations that do not allow the movement of the instrument tip in a certain direction, resulting in severe control problems) appear. The developed measures for manipulability $w_{\mathrm{man}}$ and accuracy $w_{\mathrm{pos}}$ are depicted in Figure 5 in the vicinity of a singular configuration to show that singularities can be omitted by choice of reasonable constraints for $w_{\mathrm{man}}$ and $w_{\mathrm{pos}}$ (see [7] for details). To formulate significant criteria concerning e.g. patient trauma, further criteria are currently developed and validated.

**Optimization procedure.** The rasterized workspace must be completely accessible by any robot holding an instrument. To obtain a robust setup, this must also be true if small variations are applied to e.g. the port locations. Thus unavoidable errors in registration can be compensated. As mentioned above, the DLR approach determines all optimal parameters at a time. Since the resulting search space is of high dimension (up to 17 optimal parameters are sought simultaneously), and the optimization problem itself is

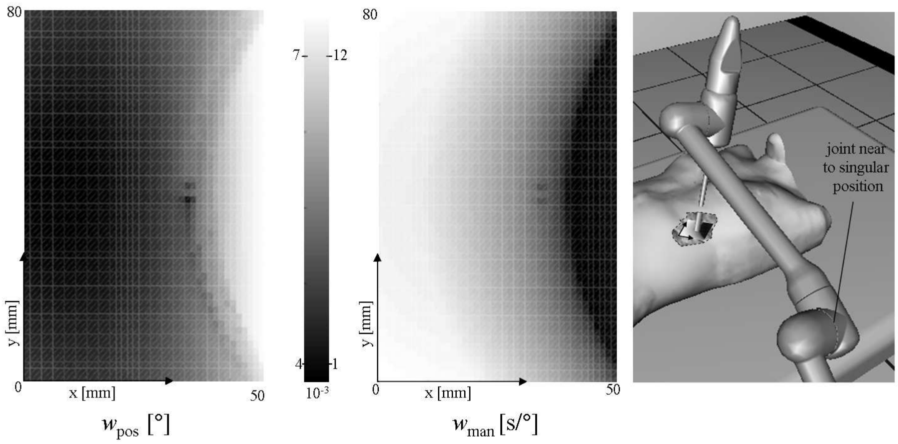



**Fig. 5.** The developed dexterity measures for manipulability $w_{man}$ and accuracy $w_{pos}$ in the vicinity of a singular configuration.

discontiguous, genetic algorithms are suitable for optimization [6]. A subsequent gradient based method speeds up the process. As result of the optimization process, different feasible parameter sets are obtained, related to local maxima of the optimization problem. In the next step, the surgeon validates the parameter set of the best solution. He has the possibility to compare this solution to others found by the optimization process.

## 4 Validation and Simulation

The determined optimal OR setup is presented to the surgeon in a virtual environment as depicted in Fig. 6. He can verify that the whole workspace is accessible by moving the robots interactively or by automatically positioning the robots at the rasterized positions inside the workspace. He can also compare the found optimal OR setup to alternative setups referring to local maxima as mentioned above.

## 5 Intraoperative Registration and Positioning

Markerless registration using a handheld laser scanner promises to give good results in neurologic surgery [8]. It is currently analyzed if this method can also be applied to the registration of the thorax. First trials with a plastic phantom using rigid registration prove the ease and speed of this method. However, the important soft tissue displacements concerning the thorax might demand a more complex, non rigid approach which is work in progress. Once registration is accomplished, the positioning of the ports and the robot bases can be done using pointing targets localized by the tracking system and markers attached to the robots.

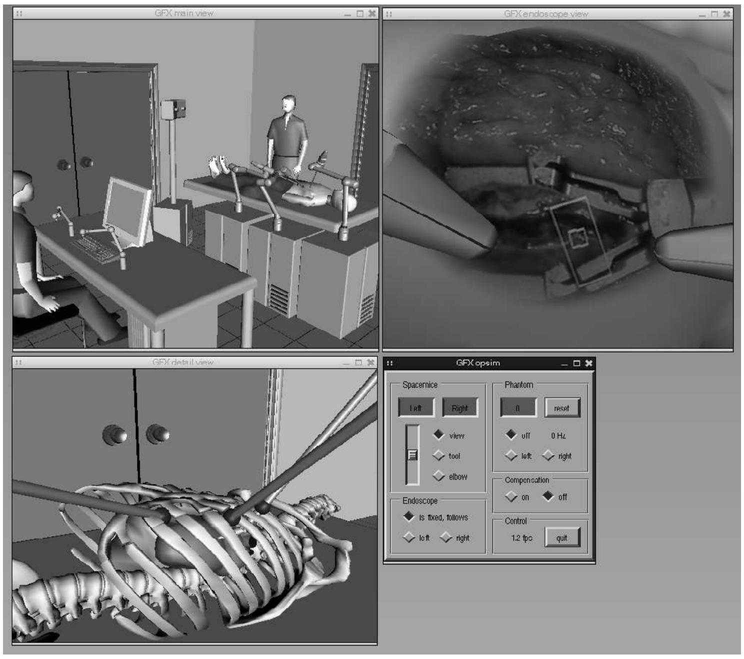



**Fig. 6.** Validation of the optimized OR setup.

## 6 Summary and Outlook

Preoperative planning of robotically assisted minimally invasive interventions with the inclusion of optimization algorithms is necessary for high quality interventions. The planning process has to be transparent to the surgeon and the optimization criteria must be significant for and adaptable to the resp. intervention. Especially the intraoperative steps of the planning procedure are highly time critical.
The DLR approach in doing preoperative planning in combination with the DLR MIRS system is presented in this paper and compared to the work presented in [1]. The proposed planning procedure utilizes an optimization approach. The optimization procedure includes criteria to guarantee the dexterity of the robotic system, further criteria are currently developed and evaluated. The validation of the optimized OR setting by the surgeon is done through simulation in a virtual environment. The results are transferred into the OR by markerless registration with a handheld laserscanner and by positioning the robots and ports using an optical tracking device.

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