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Real-Time Control Of A Robotic Surgery System

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Abstract
The planning and control software for a teleoperating robot system used in minimally invasive surgery is the main topic of this study. It incorporates capabilities like force feedback control, null-space handling for three robot arms, and robot setup planning to address the challenge of controlling a system with 41 degrees of freedom. Sequential planning and registration procedures make up the planning software. To account for operating room variances, a virtual reality version of the optimum setup is scaled up. The hierarchical levels of the real-time control system guarantee accurate and effective robotic system control. Because of its modular design, the system can be expanded and modified without sacrificing functionality. During teleoperation, it improves the surgeon's accuracy and control with both hands by giving them intuitive force feedback and hand-eye coordination.
Keywords: *Robotic Surgery, implementation, performance, layers*

1. INTRODUCTION

In minimally invasive surgery (MIS), the surgeon makes few incisions and uses small devices. Compared to open surgery, this has some benefits, including reduced trauma and pain, less blood loss, shorter hospital stays and recuperation times, and improved cosmetic results [1]. On the other hand, the treatment involving tiny incisions has certain drawbacks for the surgeon: (a) It is necessary to move the instruments around the insertion point. It loses its intuitive hand-eye coordination. Additionally, the entry site couples two DoF, limiting the surgeon's manipulability to four DoF per tool within the patient. This makes challenging procedures like suturing incredibly time-consuming. (b) The trocar, a tiny tube at the entrance, is where the instruments need to be supported. As a result, the surgeon can hardly feel the contact forces. Telesurgery systems offer a potential remedy to overcome the aforementioned drawbacks [9]. Using a teleoperator station equipped with haptic input devices (master), the surgeon operates the remote tele manipulator (slave). To improve accuracy and control, the device precisely projections the surgeon's directions onto the patient's body and offers visual feedback of interaction forces. The German Aerospace Center (DLR) has developed a very sophisticated minimally invasive robotic surgery (MIRS) prototyping system. With the use of an auto-stereoscopic display and force feedback support, the technology allows the surgeon to fully immerse themselves in the remote site, essentially regaining direct access to the operating area. It is a challenging task to design software for this dispersed system of diverse, changing, and evolving mechatronic components [2].
Three robotic arms, two actuated instruments, and two multi-degree-of-freedom haptic devices make up the system. Surgeons will find it easy to use, and researchers will find it flexible and expanding. Planning and real-time control features are covered in detail, along with the system's requirements and state-of-the-art overview. Preoperative planning outside of the operating room (OR) and intraoperative refinement are described in this section. The program's general architecture is provided by the separation of the offline planning element from the real-time control software. It is the surgeon's responsibility to finish the planning process both inside and outside the operating room before beginning the actual surgical operation. To guarantee accurate movements, prevent collisions, and preserve trocar point stability, the control program depends on planning data for robotic setup in the operating room. Although robotic aid in minimally invasive procedures has advantages, it also adds complexity, which could result in more error sources and longer setup times. Preoperative planning and in-OR computer-assisted setup methods can help reduce disadvantages like setup time and complexity. Clear optimization criteria and

consideration of the surgeon's specific training and experience are necessary for effective planning [3]. The application should have an intuitive user interface so that even people who are not familiar with robotics may use it effectively. This accessibility guarantees that a wider group of people can benefit from robotic help in surgery.

2. REVIEW OF LITERATURE

Preoperative planning is normally performed from MRI/CT scans of the patient. During surgery, there may thus be discrepancies caused by e.g. soft tissue displacement. These discrepancies must be accounted for. Finally, the automatically optimized robotic arm configuration must be checked by the surgeon and exported to the OR. A supporting tool for trocar position and robot base alignment is unavoidable in order to minimize setup time. There are several preoperative planning techniques for MIRS procedures, most of which are tailored to the commercial system device [4] . To find the best setup, the majority of them, however, use a trial-and-error approach. Other planning algorithms exclude collision avoidance or unique configurations, or they are dependent on performance measures that are opaque to the surgeon. only considers the complete process, which includes the OR setup. However, none of these techniques can be used to the robotic system described in this study [10].

Multiple control loops and operating modes, such as force feedback, collision avoidance, and joint control, must be managed by the control system. The system is spread across multiple computers to meet computational demands and provide resilience, allowing for dependable and effective operation. In addition to being adaptable and scalable, the control architecture must allow for the efficient implementation of control loops. The system needs to be adaptable to different prototype hardware and simple to modify. It is clear that strict interface requirements restrict research opportunities. Conversely, unstructured rapid prototyping creates systems that are challenging to manage. Prototyping, quick innovation cycles, and giving researchers a common knowledge of the system, all depend on a conceptual design. In the process of creating and improving the robotic system, this framework facilitates effective cooperation, adaptation, and flexibility. Common software frameworks and structures place a strong emphasis on implementation specifics and modularity. By defining standard objects and interfaces, modularity is achieved. The authors of this paper support a function-driven view of the control paradigm. The system is made to be flexible enough to accommodate future hardware changes and control ideas. Notably, it differs from current robotic systems by integrating cutting-edge capabilities like bimanual force feedback and null space collision avoidance in Minimally Invasive Robotic Surgery (MIRS) [5].

The process's goal is to position the robots in the operating room in the best possible way in respect to the patient. Taking into account robot kinematics, cutting down on OR setup time, and identifying potential sources of error during the process are the foundations of the created technique. To prevent collisions, singularities, and workspace restrictions, robot placements are optimized prior to surgery. Virtual reality and patient data, including CT/MRI pictures, are used in this planning. To provide accurate and secure robotic assistance, the surgeon offers input on the operative field and possible entrance points. Numerous configurations that sufficiently satisfy the optimization requirements across the operating field are then produced by an optimization technique based on a hybrid Genetic technique and gradient-based approach. This preoperative stage of the planning process is less time sensitive because it takes place outside of the operating room and before the intervention.

3. MATERIALS AND METHODS

The DLR system is introduced. When developing control software, a signal-oriented approach is taken. Signals connect functional blocks (elements) with in and out ports. When periodic execution is needed, closed loop control greatly benefits from signal-oriented approaches. Matlab/Simulink is a common example of such implementation. The system's non-real-time GUI interactions are based on a request/reply communication mechanism. The system model serves as a fundamental framework for the control and operation of the robotic system by depicting a static configuration of components and connections. Signal routing varies as a result of context shifts, or transitioning between process steps. This is not an issue because a fairly straightforward approach can be used to implement the MIRS-Scenario. The system's architecture incorporates local controllers, force feedback, and collision avoidance with a focus on closed-loop control during teleoperation. This guarantees safe, accurate, and responsive operation, allowing the surgeon to efficiently operate the robotic system. Several hierarchical layers make up the signal-based control software[6]. Different function-based components make up a layer. Every layer only communicates with its neighbouring layers, the hardware beneath the bottom layer, or the surgeon above the top layer. Two important goals are intended to be achieved by the architecture: (a) The system's components are arranged according to the execution time requirement. Lower layers nearer the mechatronic hardware, which need accurate timing and fast sampling rates, are given priority in the system's architecture. Higher layers can function with lower sample rates because they are less susceptible to delays, guaranteeing an effective use of computational resources. (b) The layer structure gives researchers and developers several levels of abstraction. The amount of mechatronic hardware increases with layer height. Higher levels of detail are seen on lower layers. The hardware is less abstracted [11].

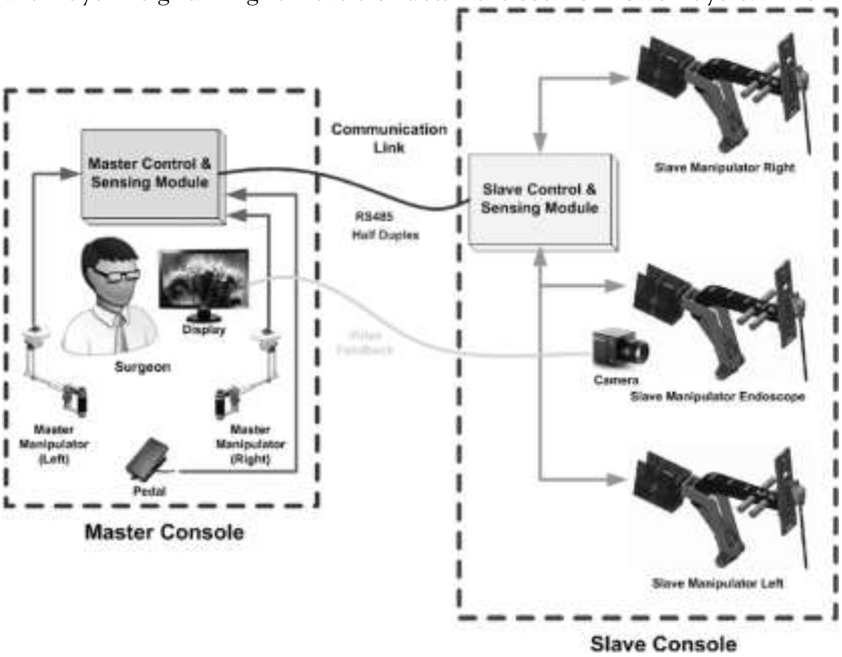

Figure 1: Proposed block diagram

In order to enable effective and responsive operation, the four-layered structure gives priority to crucial control elements like force and closed-loop control. Rapid prototyping and researcher cooperation are made easier by this architecture, and abstraction levels offer flexibility without imposing strict interface requirements or performance overhead. The design, which permits local or global control changes while preserving layer structure, is described with examples from the actual world. The following parts provide a thorough explanation of the system's operation by going into detail about bilateral teleoperation, operating modes, and inverse kinematics computation. The alignment of haptic and visual pathways results in hand-eye coordination. Only when the endoscope moves does the hand-eye coordination matrix update, which is computed efficiently. For both left and right master-slave systems, this computation takes place in the same layer as the forward kinematics of the endoscope, guaranteeing steady manipulator arm operation [7].

In every mode, the master is forcibly controlled. The master devices are gravity corrected while the surgeon is not using teleoperation. When the master and slave are paired during teleoperation, the instrument's sensor activates force feedback. In order to precisely move and position the endoscope, the surgeon can also use Layer 4 to control the endoscope robot using one of the masters. Since there is no force feedback, this is consistent with the Four Layer Architecture [8]. The task is therefore not time-critical. Two switches are used to represent switching between operational modes. For example, in manual motion mode, the components' trajectory Set up Impedance control, torque control, and move hands on are all activated; that is, the robot is connected to its out port. They are only connected to the ports of the components in the other pathways. Incoming sensor data determines the hardware's current state, which is used to continuously update and reset the system's internal states. This guarantees precise control and synchronization of the robotic system. This is accomplished so that switching is feasible in a single discrete time step and they consistently provide accurate outputs. The initial condition of the inactive components is always maintained. It is not permitted to engage in unstable activity that could compromise stability. A single Master-Slave arm can translate both frames and vectors into the appropriate values that are then transmitted to the mechatronic hardware.

4. RESULT AND DISCUSSION

The DLR MIRS system may be planned and controlled in real time. C++ on Linux is used to implement the planning process, and OpenGL is used to visualize virtual reality. The Matlab/Simulink-developed control system operates on QNX, a real-time operating system, and executes precise control by reading the output file from the planning process [13].

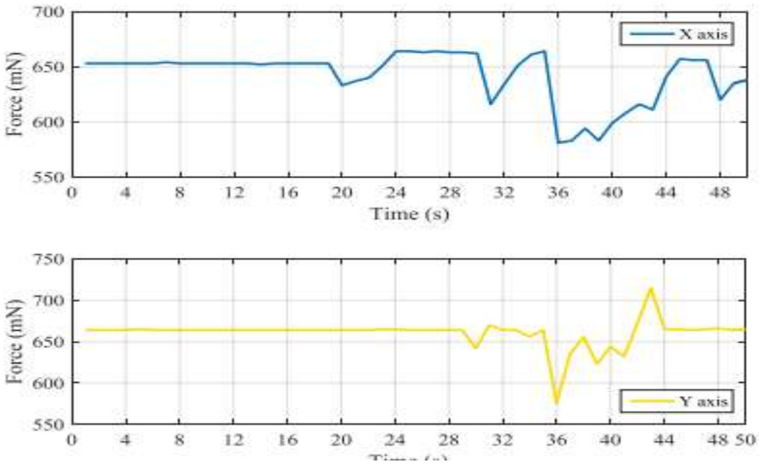

Figure 2: Force reflection from the force sensor

The entire workflow is covered by the planning approach, which guarantees a smooth and precise surgical procedure from patient-specific preoperative planning utilizing MRI/CT data to the precise positioning of robots in relation to the patient in the operating theater. The part of the process that takes the longest is preoperative planning [12]. It lasts for around fifteen minutes. This is not time critical because it is done outside of the operating room. Using the software is simple and convenient. After marking the operation field and a zone for the patient's entry points in the virtual reality, the user is presented with a number of configuration options. It just takes a few minutes to register and reschedule patients in the operating room.

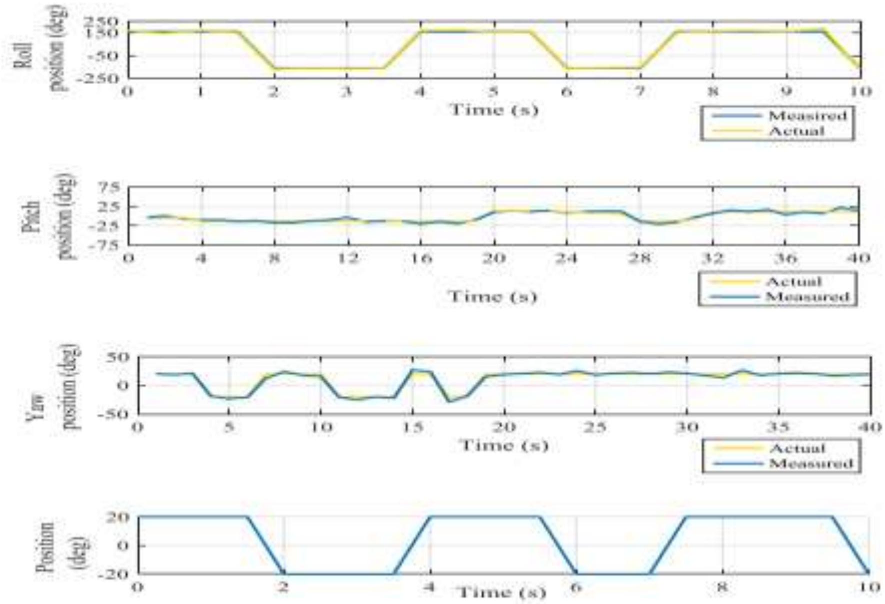

Figure 3: Position control observation

The Auto Pointer allows the OR personnel to easily set up the robots and projects the outcomes of the planning process immediately onto the patient. Initial experiments using an experimental setting validate the viability of the selected strategy [14]. Strong registration is also capable of handling patient scans that are not complete. The efficiency of the preoperative design and setup was demonstrated by the robots' successful operation in the particular operational field under optimal conditions [15].

5. CONCLUSION

The planning module and control software of the DLR robotic system for minimally invasive surgery are described in the article. While the control system is organized based on abstraction levels and real-time requirements for accurate control, the planning module optimizes OR settings before surgery and adjusts to intraoperative changes. The Four Layer Architecture, which serves as a functional representation of the system, is the conceptual result. This architecture provides flexibility and adaptability for upcoming developments in control or hardware design, and it forms the basis for simulation and control system realization. Advanced collision avoidance methods will be developed in the future to stop unwanted robot combinations. To improve accuracy and control, bilateral teleoperation may also include impedance control or broaden to include additional channels like locations and pressures. Other kinds of instruments will also be included in the system. Motion compensation in beating heart surgery will be one of the challenging and exciting parts. In this work, a unique robot-assisted fracture manipulation system was designed and implemented. By giving the surgeon a precise, safe, ergonomic, and minimally invasive robotic tool for managing fractures, the paper aimed to enhance actual surgery. This device removes the issues associated with current standard surgical approaches, including a longer recovery period following surgery, a higher risk of infection, and more soft tissue damage, by enabling precise fragment displacement without open surgery. Trials of positioning were employed to assess the system's precision and consistency.

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