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Conveyor-based robot allows fast and safe instrument handling in the operating room

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Abstract: According to [1]–[3], the healthcare systems are suffering from severe personnel shortages with a lack of medical care workers, operating room nurses, and surgical technicians. This deficiency will become worse in the upcoming decades. Automatization of highly standardized procedures could be a promising approach to address this issue. We designed a new concept for the automated handover and return of surgical instruments to the surgeon in an operating theater scenario to relieve operating room personnel from their workload. In this setup, the surgical instruments are delivered pre-sorted in an upright position by the sterilization unit in an instrument basket or drum. A single-use, double-layered, brushy conveyor belt system mounted on a robot arm acts as the connector between pick-position (instrument basket) and individually pre-definable hand-over-position. The system is placed next to the table inside the operation room (OR). Based on voice commands, the conveyor intake moves over to the selected instrument and delivers it to the surgeon in a fast and short motion. After use, the surgeon can feed the instrument into the intake at the handover position and place it back in the instrument basket. The robot arm allows precise maneuvering of the intake and output position.
The concept was realized as a minimal-viable product and will be evaluated for further improvement.
Keywords: COBOT, Collaborative robots, Automatization, Surgical technicians, Surgery assistant, Scrub nurse, Instrument handover, voice command

1 Introduction

Similar to other industries in the Western world, the healthcare systems are suffering from severe personnel shortages [2], [3]. In Germany, 30.188 nurses work in surgery support, and 20.300 lack specialist training. Additionally, the number of surgeries will increase. In 2019, 7.1 million of the 18.8 million in-patients treated underwent surgery [4]. These data show a need to automate work in medical support procedures to relieve the medical staff and save time for essential tasks. The introduction of robotic systems for standardized procedures in operating theatres shows a potential to address this need/issue.
Most robotic surgery systems that are on the market are manipulators performing human controlled motion e.g. [5], [6]. Those robotic assistance systems are used to support the surgeon by holding devices like endoscopes or instruments or performing the surgery. Only some robotic scrub nurse approaches have been reported from other research groups, e.g., [7]–[10]. In these setups the robots are providing tools and equipment to the surgeon at the right time. Unfortunately, a full automatization of surgical assistance to relieve surgical technicians is not available on the market until now.
Conventional and planned low-risk surgeries (e.g., adiposities, hernia, gall bladder) show potential for robotic support instead of the human assistance staff due to their highly repetitive and simple tasks.

In a standardized surgery, the instrumentation operator hands the instruments from a pre-sorted instrument table (Figure 1) to the attending physicians on command and takes them back again. This handover is a highly repetitive procedure, which makes it ideal for automatization by a surgical assistant robot. The robot can take the required instruments from pre-sorted sieves or instrument tables by command from the surgeon and hand them over. By introducing a surgical assistant robot, the instrument operator

Figure 1: Pre-sorted instruments on an instrument table

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can be relieved for the procedure's duration, or his/her resources can be made available elsewhere. In [11], we have proposed a collaborative robotic arm as a scrub nurse that can be controlled via voice commands. Based on surgery observations and clinical users' feedback, we now designed a concept for a fast and safe instrument delivery by the robot.

2 Methods

An essential task in developing a concept for clinical use is understanding the surgical workflow and interaction of the OR team [12]. Therefore, several surgical procedures were observed and documented. These documents and additional discussions with clinical users led to requirements and boundary conditions, e.g., instrument shapes, sizes and weight, working space, setup time, determination of handover location, transfer speed, control options and sterility issues. Considering these requirements, a concept for a surgical assistant robot was developed. The main sub-functionalities of a surgical assistance robot are

- Pick up of instruments of various sizes and shapes in defined positions on command and in a changing environment of an OR
- Fast and safe transport of these instruments to a predefined placing position with an included "hand over" procedure
- Takeback and replacement of used instruments in the instrument storage
- Fast and easy setup of the System close to surgery table

These functionalities must be integrated into an automated, reliable and easy-to-integrate concept.

Integration into the clinical workflow is one of the essential requirements for the surgical assistance robot. The OR is a highly individual workspace and depends on the local setup, the planned procedure, the equipment used, the involved staff and the patient. The robot has to act as a cobot in direct interaction with humans and adapt to this changing environment. For our concept, we chose a Panda robot (Franka Emika, Germany) mounted on a moveable cart as a basis. This robot can be easily placed near the OR table and registered for the pick-up position through a defined docking point. The surgeon can manually and individually define the handover position in a quick demo move without any programming. A possible system placement in the OR environment is shown in Figure 2. If the surgeon requests an instrument, this information has to be fed into the robotic system. Therefore, we improved the voice control of our first approach [11]. The OR environment is usually quiet and voice commands can be transferred easily.

After the command, the surgeon expects a fast and immediate delivery of the requested device. Due to safety reasons, a standard pick-and-place approach as shown in [11], only

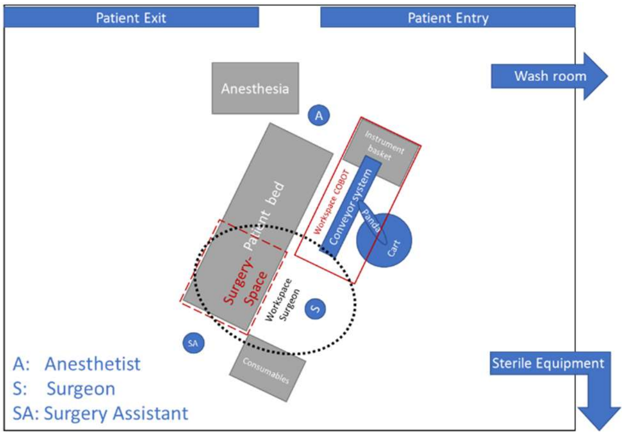

Figure 2: Placement of a surgery assistant robot in the OR.

allows slow motions. A fast action of the robot, holding a surgical instrument, could be dangerous for the patient and the surrounding staff. For this reason, we now created a closed transportation system. Our covered conveyor system ensures fast and safe delivery of partially sharp instruments. A brushy conveyor belt allows the adaption of the transportation system to various shapes and sizes of the instruments and a safe pick and feed. It can be used in both directions and transports instruments back into the storage as well. The conveyor system can be mounted on various robot arms with simple adapters for fine positioning in interaction. With the use of simple plastic parts, it can be designed as a cost-efficient single use consumable. Figure 3 shows a conceptual design of a conveyor belt system mounted on the Panda robot arm.

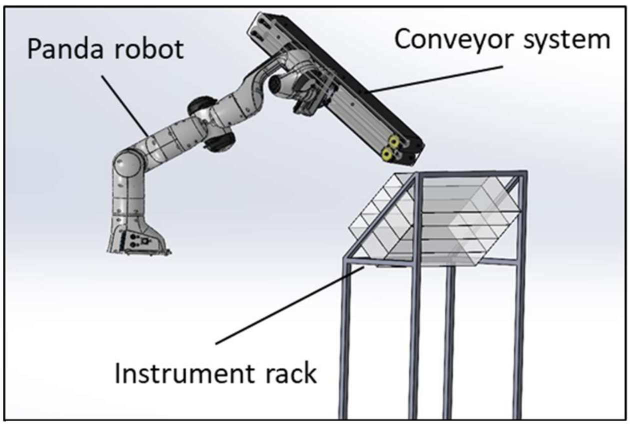

Figure 3: CAD Design of the surgery assistant robot

The handover position will most likely be outside of the surgeon's field of view. Therefore, the handover of the instruments has to be realized with a signal or haptic feedback so that the surgeon does not have to avert his / her eyes from the surgery. The conveyor feeds the instrument until it hits the surgeon's palm of the hand, as known in conventional surgeries. Then, it stops automatically at the designated handover position or when a resistance of the hand is detected. Then, the surgeon can take out the instrument.

To utilize the conveyor system, a safe instrument pick-up is essential. Today, the instruments come from the sterilization unit in prepared instrument boxes and the instruments are placed in predefined positions on the instrument table by the surgical technicians. For automatization of the instrument handover, these boxes should be substituted by pre-sorted and pre-arranged baskets in a way that every instrument has a defined position. We copied the idea of the cutlery basket of a dishwasher for the instrument provision. All instruments are placed upright with a 3 cm overstand to allow easy pick-up. This basket can be designed as a matrix system, as a rotational drum or as a rack system. Instrument positions for the different surgeries can be predefined and programmed in the robot.

To realize the control of the panda robot, the ROS (Robot Operating System), version ROS Melodic Plus, and the MoveIt Motion planner for robot control are used. For the voice command, a user interface was implemented in the Pocket Sphinx library for speech recognition. The robot control and user interaction are published in detail under [11].

The voice control was implemented into the robot control and tested by different users in a pick-and-place setup [11]. The

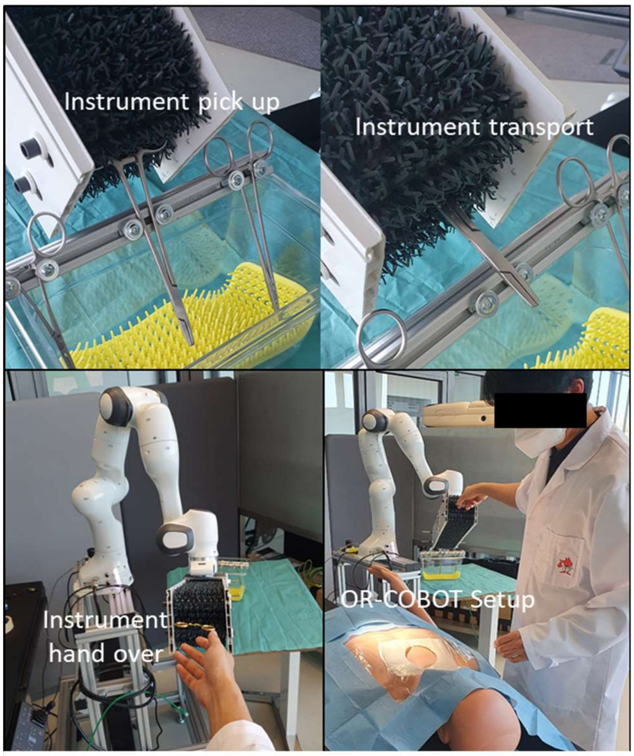

Figure 5: Placement of a surgery assistant robot in the OR.

concept for a surgical cobot was built up in our test OR and the general feasibility was evaluated (Figure 5).

3 Results

Parts of the described concept were realized in a minimally viable setup. Therefore, the Panda robot was placed on a cart made out of ITEM aluminum profiles with a defined docking point for the instrument rack. The conveyor belt system was designed in CAD and partwise 3D printed. A plastic doormat was used to create the brushy conveyor belts for handling multiple instrument shapes. To attach the conveyor to the Panda robot, a connector was built out of aluminum brackets (Figure 4).

For the pre-sorted instrument basket, a miniature plastic rack was selected that has a defined docking point to the robot cart. The instrument positions in the rack are programmed. By changing the direction of motion of the conveyor, instruments can be placed back into the rack or sorted out.

4 Discussion

The conveyor-based surgical assistant robot concept combines various technologies and solutions that show promising feasibility. The usability of the Panda robot allows a fast adaption and integration into a changing OR setup through predefined docking points and individually setable handover positions. The single-use conveyor system combines the need for a sterile environment with safe and fast instrument transportation. The electrical motors produce a only silent buzzing. The brushy conveyor belts can adapt to various instrument shapes and sizes. A pre-sorted instrument rack enables the defined instrument to pick up and could additionally improve instrument handling and cleaning in the whole hospital instrument reprocessing procedure. Finally, voice control allows human-machine interaction without losing attention to the surgical procedure.

5 Conclusion

The perspectives of healthcare systems regarding human resources show a need for automating support processes in medical applications. Highly standardized procedures are predestined for this purpose. Instrument handover is a mixture of the challenging, changing environment of the OR and the standardization of instrument sets, OR preparation, workflows and interaction. Our concept of a conveyor-based surgery assistant robot demonstrates promising features to address these challenges. However, the described surgical assistant robot only shows a first concept. All features have to be improved and tested in the next step.

Author Statement

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