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Robotic Scrub Nurse: Surgical Instrument Handling with a Granular Jamming Gripper

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Abstract: The global shortage of healthcare staff has led to high workloads and subsequent risks to patient well-being. One of the professions affected is that of the scrub nurse. Robotic scrub nurse systems have the potential to reduce workload and to assist in handling surgical instruments. Existing approaches mostly use two-finger grippers or electromagnetic grippers. However, it is assumed that a granular jamming gripper is more suitable for handling various surgical instruments, regardless of material and shape. A gripping unit based on a granular jamming gripper and attached to a robotic arm is presented. For evaluation, six surgical instruments were repeatedly gripped and transported. The granular jamming gripper was found to be suitable for picking up and transferring most instruments, however, handling very flat instruments turned out to be challenging.

Keywords: robotic scrub nurse, granular jamming gripper, instrument handling, robot-assisted surgery

1 Introduction

The increasing shortage of healthcare staff is a global challenge [1]. Understaffing and the increasing quantity and complexity of work tasks are leading to staff overload, which can compromise patient well-being [2–4]. One of the professions affected is that of the scrub nurse.

Scrub nurses are responsible for the organized workflow in the operating room (OR). Therefore, scrub nurses perform a wide range of tasks, such as preparing the OR, transferring and positioning the patient, handing surgical instruments, and documenting the surgical procedure. In this context, the fast and anticipatory handling of surgical instruments is crucial for the success of the operation.

Errors that occur due to overload of the surgical team can jeopardize patient safety. It is therefore desirable to relieve staff of simple and repetitive duties in order to free up their resources for more demanding tasks. Intelligent assistance systems have the potential to reduce workload in the OR. A robotic assistance system can support scrub nurses in some tasks, such as the instrument handling and the accompanying documentation of materials used. Challenges arise from the limited space around the OR table and differences in material, shape, and size of instruments.

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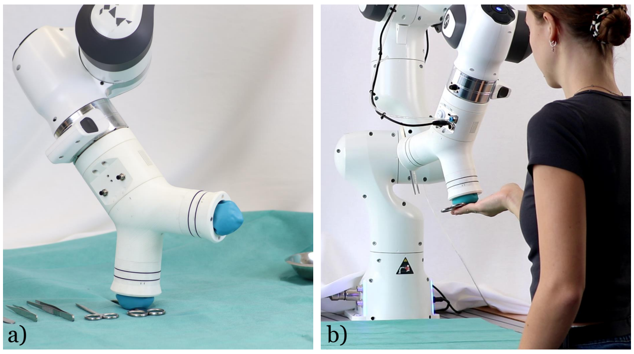

Figure 1: Pickup of instrument (a); handover from user to RSN (b).

1.1 State of the Art

Existing approaches to realize a Robotic Scrub Nurse (RSN) system can be classified according to the type of gripping principle: The Penelope [5], the Quirobot [6], the Gestonurse [7], and the system developed by Ezzat et al. [8] make use of an electromagnetic gripping principle. The system developed by Yoshimitsu et al. [9] and the approach of Kuluru et al. [10] use two-finger grippers. The same research group as in the latter approach is also investigating a double-layered, brushy conveyer belt system for handling of instruments in the OR [11].

Besides these RSN systems, Heibeyn et al. [12] developed a dedicated gripper for handling surgical instruments. Their SteriRob gripper consists of two fingers and, together with a plunger, establishes a form closure around the surgical instrument. Furthermore, Bernhard et al. investigated mobile service robots for the OR, such as circulating nurses [13].

The systems mentioned above use different approaches for the interaction between OR staff and the RSN, such as voice commands, hand gestures or eye tracking (see Table 1). Furthermore, different approaches for the handover process are presented, such as the exchange of instruments via an interchange tray [14]. Some systems allow the instruments to be handed over, but not received, for which a storage surface is then used [5, 15].

It is assumed that two-finger grippers and electromagnetic grippers are of limited suitability for the safe, sterile and precise handling of a wide range of instrument shapes and materials. It is hypothesized, that a Granular Jamming Gripper (GJG) [16] is suitable to handle a wide variety of surgical instruments, regardless of material and shape. In addition, it is assumed that a GJG is inexpensive and thus, designed as a sterile disposable product, also particularly safe.

1.2 Robotic Scrub Nurse Concept

An RSN concept is created to derive requirements for a gripping unit to be used in the OR environment. A collaborative robot with redundant degrees of freedom (DOF) for increased maneuverability in the confined space around the OR table is equipped with a gripping unit. The GJG-based gripping unit shall be able to pick up instruments from the table, place them on it, transfer them to the user's hand, and also pick them up again from the user. In addition, a camera will be attached to the robot's endeffector so that instruments can be identified and located by an image-based object detection. Interaction is to be based on voice or gesture commands while the contact between gripping unit and instrument, which is either on the table or in a user's hand, shall be detected by contact force measurement. The GJG should be inexpensive and quickly interchangeable to realize a sterile interface. In this paper, the suggested gripping unit for the outlined RSN concept is presented and assessed. Aim of the project is to setup an RSN as a research platform for instrument handling with a GJG-based gripping unit and a collaborative robot (Figure 1).

2 System Design

The first prototype of the gripping unit is designed to pick up and transfer basic surgical instruments. The transfer of the instruments should be provided for both directions, from the RSN to the surgeon's hand and vice versa. To ensure a time-efficient transfer, the gripping unit consists of two GJGs enabling the delivery and receiving of instruments within the same transfer cycle. They are arranged at an angle of 90°. With overall dimensions of 200 mm in height, 208 mm in width, and 88 mm in depth, the prototype has a mass of 730 g. Detachability of the GJGs from the gripping unit allows a sterile interface and is therefore considered in the concept phase. However, this feature will not be implemented in the first prototype for the sake of simplicity. As the gripping unit will be combined with an image-based object detection in the next phase, attachment points for a camera are implemented. To achieve an open system architecture, the Robot Operating System (ROS) is being utilized, with connectivity via USB or UART. Nevertheless, a manual mode with control of the valves for debugging and simple testing is available. Therefore, two hardware buttons for manual control mode are implemented on the front of the gripping unit. The on/off switch, the vacuum port, the USB-connector for flashing the micro-controller, the port for the power supply (24 V) and the UART connector are located on the rear of the gripping unit. All vacuum-related and electronic components are housed in the gripping unit (Figure 2).

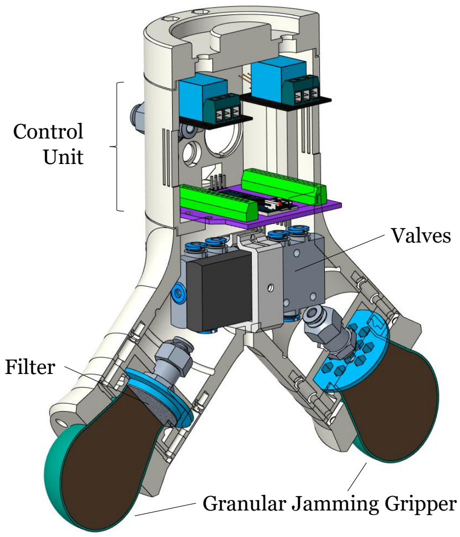

Figure 2: Cross section of the gripping unit with main components.

3 Materials and Methods

3.1 Prototyping and Components

Mechanical parts are manufactured using a Prusa i3 MK3S 3D-printer (Prusa Research s.r.o., CZ) and polylactic acid filament (PLA). Latex foil is used for the outer shell of the GJG. A mixture of ground coffee and sand (3:1) is used as the filling to achieve a tradeoff between a proper flow of the granules around the object and sufficient jamming under vacuum [20]. Two solenoid valves (Festo SE & Co. KG, Esslingen, DE) are used to open and close the connection between vacuum port and the respective GJG. GJGs, solenoid valves and the vacuum pump are connected with silicon tubes (⌀ 2 mm). Paper filters prevent the granules from entering the vacuum lines. The components of the gripping unit are controlled by an Arduino Nano V3 (Arduino S.r.l., Monza, IT). A Franka Emika

Table 1: Overview of found research projects on robotic scrub nurse systems.

Name	Gripper	Interaction	Handover	Robot	Ref.
Penelope	Electromagnetic gripper	Voice commands	To hand; Return via transfer table	Custom-made	[5, 17]
n/a	Two-finger gripper	Voice commands	To hand; Return via tool changer	Custom-made	[9, 18]
Quirobot	Electromagnetic gripper	Voice commands	Interchange tray	Fanuc LR Mate 200iB	[6, 14]
Gestonurse	Latex-encased electro-magnetic gripper	Hand gestures, voice commands	To hand; Return via pickup from table	Fanuc LR Mate 200iC	[7, 19]
n/a	Electromagnetic gripper	Eye tracking	To hand; Return via tray	Universal Robot UR5	[8, 15]
n/a	Two-finger gripper	Voice commands	To hand	Franka Emika Panda	[10]

Panda 7-DOF articulated robotic arm (Franka Emika GmbH, Munich, DE) is used as the collaborative robot carrying the gripping unit. The robot has torque sensors in all axes and can thus estimate forces on the endeffector.

3.2 System Evaluation

A vacuum pump (Thermo Fisher Scientific Inc., MA, USA) was used to evaluate the system, however, any vacuum port can be used, such as those present in most ORs. For the evaluation, six standard surgical instruments (see Table 2) were picked and placed repeatedly. Each instrument was grasped by one GJG, transported over a distance of 450 mm and deposited again. It was then transported in the opposite direction. Both fixed positions were known to the robot for the sake of simplicity. In addition, the aeration and deaeration was controlled manually, while the robot applied a force of about 15 N to the instruments with the GJG. This test was performed 10 times for each instrument and the number of successful/failed attempts was recorded.

4 Results

In order to pick up an instrument, one GJG of the gripping unit needs to be slightly pressed onto the instrument. The granules inside the latex capsule flow around the instrument and embrace it. Deaeration of the GJG leads to jamming of the granules in the shape which is enforced by the object itself. The resulting form-closure in combination with the adhering properties of the latex foil leads to a holding force. Aeration of the capsule immediately reduces the jamming of the granules and thus leads to the release of the instrument. Both, the pick-up of instruments from a table surface and from a hand is possible (see Figure 1). The current manual control of the gripper aeration results in a slower transfer compared to an automated process triggered by reaching a defined contact force.

Table 2 shows the results of the evaluation of a GJG with six basic instruments. A distinction was made according to the degree of success in transferring an instrument, where success is classified into three categories: complete transfer of the instrument, partial transfer, where the instrument was picked but not successfully transported, and unsuccessful transfer, where no pick-up and thus also no transport was achieved.

Table 2: Successful/failed pickups/transfers of surgical instruments.

	Pickup successful	Pickup successful	Pickup failed
	Transfer successful	**Transfer failed**	No transfer possible
Anatomical forceps	10	0	0
Surgical forceps	10	0	0
Scissor pointed/blunt	9	1	0
Scissor double-pointed	1	9	0
Scalpel fixed blade	0	10	0
Scalpel replace. blade	0	7	3

5 Discussion

The preliminary tests of the first prototype allow to derive a basic suitability of the chosen concept for the targeted application. However, there are still open challenges, which need to be addressed. Among these are issues around a contact-free user interface, a safe collaboration despite the fact that sharp instruments have to be handled, and the time a robotic assistance system needs compared to a human scrub nurse. Nevertheless, there is potential for solving further challenges such as the anticipation of a required tool or the simultaneous documentation of the tools and materials used in an intervention.

The chosen gripping technology has been suggested before in literature for different applications (see [21]), but was not investigated for usage in the OR environment. The GJG has advantages over existing approaches such as two-finger grippers or electromagnetic grippers. However, it also requires precise adjustment of multiple parameters to allow a safe and reliable grasp. Among these parameters are the thickness of the latex foil, the mixture of the granules, or the level of vacuum. Furthermore, it is also of interest to investigate the ideal force, which with the GJG has to be pressed onto an object during deaeration and to use active aeration instead of only opening the valve.

6 Outlook

In this work first results of using a GJG for the handling of surgical instruments in an RSN system were presented. However, the suggested gripping unit can also be helpful to handle instrument when aiming on the automation of reprocessing processes. Future work will focus on the combination of the gripping unit and an image-based object detection. Furthermore, the above-mentioned parameters of the GJG will be extensively investigated to find a configuration, which allows for safe gripping of a wide variety of surgical instruments. In addition, the realization of a sterile interface by implementing a quick connection mechanism between the relatively cheap and simple GJG arms and the main part of the gripping unit is planned. As well, a material should be chosen that is more suitable for use in the OR environment than latex. Last but not least, the implementation of force and pressure sensing will be investigated to be able to monitor and control the gripping process more accurately.

Author Statement

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