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Design and Evaluation of a Novel Instrument Gripper for Handling of Surgical Instruments

Abstract: *Introduction:* Contaminated surgical instruments are manually prepared for cleaning and disinfection in the reprocessing unit for medical devices (RUMED). Manual labour exposes staff to the risk of infection and is particularly stressful at peak times due to the large volume of instruments. Partial automation of processes by a robot could provide a solution but requires a gripper that can handle the variety of surgical instruments. This paper describes the development and first evaluation of an instrument gripper.
Methods: First, an analysis of gripping geometries on basic surgical instruments is carried out. Based on the identified common features and a review of the state of the art of gripper technology, the SteriRob gripper concept is developed. The concept is compared with a force closure gripper in a series of tests using seven criteria.
Results: Both gripping approaches investigated can be used for handling surgical instruments in a pick-and-place process. However, the SteriRob gripper can transmit significantly higher acting forces and torques. In addition, the gripping process is more robust against deviations from the expected instrument position.
Conclusion: Overall, it has been shown that the developed instrument gripper is suitable for about 60% of reusable surgical instruments due to the focus on horizontal cylindrical geometries. Because of the large possible force transmission, this gripping approach is particularly suitable for tasks in which the robot assists with cleaning processes.

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1 Introduction

Surgical instrument reprocessing is crucial for the supply of hospitals. Faulty reprocessing can cause nosocomial infections [1]. The reprocessing processes must be robust against disruptions, as failure may result in shutdown of clinical operations within a day. However, reprocessing performance is challenged by exceptional situations, such as the COVID-19 pandemic, imposing stress on the staff [2]. In addition, staff members are burdened in day-to-day operations by complex reprocessing tasks, risk of infection due to handling of contaminated instruments, staff shortages, and the burden of protective equipment [3,4].

Partial automation offers an opportunity to improve the reprocessing processes. For clean instrument sets automation solutions are available, for instance addressing inventory management [5]. However, there are currently no partially automated solutions for the more hazardous handling of individual contaminated instruments. For this application partial automation could potentially improve the reprocessing processes by reducing the infection risk and workload for employees. As instruments vary in shape and required processing steps, robotic assistance could provide the necessary flexibility for automation. A limiting factor for robotic handling is the challenge of grasping due to the large variety of instruments [6]. Against this background, this paper presents an analysis of instrument geometries as well as existing gripper solutions, followed by the development and evaluation of a novel instrument gripper suitable for a wide variety of surgical instruments.

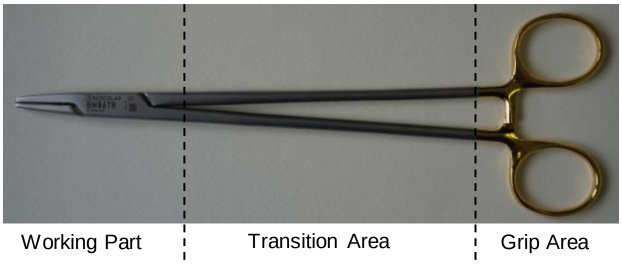

Figure 1: Characteristic Instrument Areas

2 Instrument Analysis

The properties of the instruments are one decisive factor for the choice of gripping concept [7]. Due to the very high number of different surgical instruments an all-encompassing solution is almost impossible. Therefore, an overview of basic instruments used in most surgical disciplines is used as a basis for the property analysis [8]. Basic instruments account for more than 60% of reprocessed instruments according to estimates of Aesculap AG, Tuttlingen, Germany.

Basic instruments can be divided into three characteristic areas [8] (Figure 1**Figure**), including the grip area, working area and transition area. The grip area is designed such that it can be grasped by the human hand. For instance, there may be a ring handle, as in scissors, a two-finger handle, as in forceps, or a fist handle, as in retractors. Therefore, the grip area could serve as a target for a gripper which is modelled to resemble the human hand. The working part is distinctive for each instrument, depending on the purpose. Hence, the working part is the most specific and least standardised area of each instrument and does not appear suitable as a target for a gripper. The transition between the working part and the grip area serves as an extension. Usually, the transition area is designed in form of one or more cylindrical structures. The cylindrical structures are a common feature of many instruments, which extends beyond the basic instruments [8]. Therefore, the transition area appears suitable as a target for a gripper. In addition, some individual sub-bodies of the instruments can also be approximated by cylinders as shown in Figure 2. In conclusion, a gripper capable of gripping the cylindrical areas can handle a majority of the basic surgical instruments.

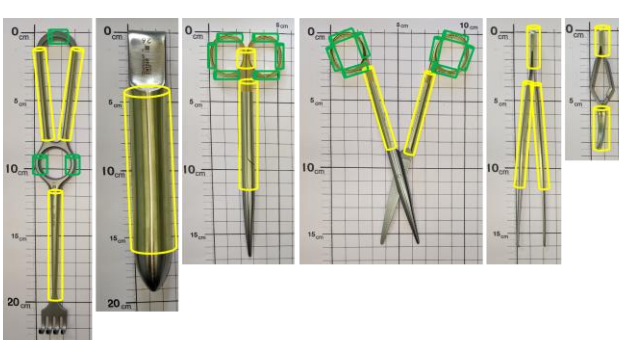

Figure 2: Cylindrical Sub-bodies

3 Conceptual Gripper Design

The gripping task is defined as the gripping of a cylinder in horizontal position on a flat surface. To enable gripping of an individual instrument in between other instruments, the width of the gripper opening must be adjustable. The gripper must be able to securely fix instruments with diameters between 3 and 25 mm and a length between 10 and 100 mm. Secure fixation of the contaminated instruments in the gripper is crucial to reduce the risk of hazard for the staff. In addition, the gripper should enable force transmission, for instance supporting robot-assisted pre-cleaning of instruments. The gripper should be able to transmit a force of 20 N and a torque of 1 Nm to utilise the payload of the 'Panda' robot (FRANKA EMIKA GmbH, Munich, Germany). The force limit of 20 N takes into account the weight of the gripper and the instrument with 5 N each.

3.1 State of the Art

Common approaches for gripping hazardous objects include magnetic principles, force or form closure, more rarely vacuum technology is utilized [6]. Electromagnetic gripping of instruments [9] has the disadvantage that instruments made of plastics, non-magnetic alloys or ceramics cannot be gripped. Vacuum grippers are mainly used for level surfaces [6], although more complex designs are possible that adapt to the shape of the gripping object [7]. However, a vacuum gripper could become clogged with soiling, which is to be expected on contaminated instruments. Force closure grippers usually achieve the fixation of the gripped object by one or more movable fingers [7]. The applied force fixes the object so that it is secured even during fast movements [10]. The use of more than three fingers is advantageous for upright cylindrical objects due to their centering properties [7]. Two fingers seem more suitable for instruments in flat position on a supporting surface. Whereas the transmission of forces and torques (e.g. for cleaning instruments) based on force closure requires (high) friction forces between the instrument and the gripper, form closure grippers have to be adapted to the object or flexibly designed [7]. A possible solution is the use of the

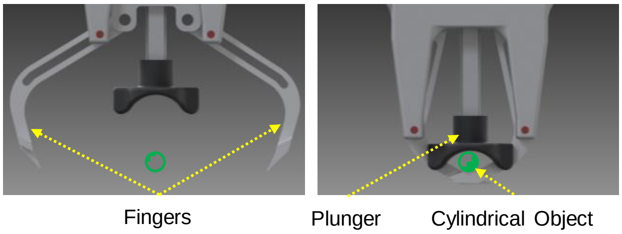

Figure 3: SteriRob Instrument Gripper

'palm' of the gripper-'hand' as a fixation point during enclosure for securely grasping horizontal cylindrical objects with variable shape [7]. In conclusion, the force closure approach with a two-finger gripper and the closure gripper with palm are considered as possible solutions.

3.2 The SteriRob Instrument Gripper

The proposed instrument gripper combines the advantages of both identified approaches. The hybrid gripping concept consists of two fingers that enclose the gripped object and a plunger that subsequently applies a force to fix the object in place, see Figure 3. The geometry of the fingers enables gripping of cylindrical bodies with diameters of 3-25 mm. The fingertips of the instrument gripper are wedge-shaped so that they can approach the object from the side at a flat angle. Therefore, the fingertips can slide under the instrument even when it is in a horizontal position on a supporting surface and achieve partial form closure. Subsequently, the form closure is completed by the plunger. In addition, a force is applied by the plunger, which fixes the object to be gripped securely against the closed self-locking mechanism of the fingers.

4 Evaluation

An experimental set-up was used to compare the identified suitable gripping approaches. The experiments were carried out with a two-point force closure gripper (FRANKA EMIKA GmbH, Munich, Germany) and the SteriRob instrument gripper. Opening and closing of the initial functional labtype of the SteriRob instrument gripper were manually operated. All experiments were carried out with 16 instruments provided by Aescualp AG, Tuttlingen, Germany, including a total of 11 instruments with ring handles, two retractors, one forceps as well as a bulldog clamp and a hegar dilatator. During the experiments both grippers were attached to a 'Panda' robot (FRANKA EMIKA GmbH, Munich, Germany). For sake of simplicity the position of the instrument was known to the robot. Each single instrument was picked up from a flat surface.

Seven evaluation criteria were defined based on preliminary considerations and requirements. The **manageable instrument variety** was determined by placing and grasping all test instruments successively in front of the robot. The number of successfully gripped instruments per gripper was documented. The gripping was considered successful if the instrument could be lifted and deposited elsewhere without falling out of the gripper. The criterion **precision** was tested by placing a pair of scissors in a defined position. The robot picked up the instrument, moved and then set the instrument down in a new position. The deviation of the deposit position from the target position was recorded. **Force absorption** was tested by gripping a pair of scissors and moving it vertically upwards. The scissors were connected directly at the gripping point to a force transducer. The force at which the gripper could no longer hold the instrument was recorded. **Torque absorption** was tested similarly, except that the force transducer was attached to the instrument with a defined leverage apart from the grip point. **Robustness to object displacement** was evaluated by introducing unexpected translational and rotational displacements of the gripping object. A pair of surgical scissors was used as gripping object due to the large difference in shape between the working part and the gripping area. The gripper always attempted to grip at the origin of the coordinate system, independent of the real position of the scissors. It was documented how far the real position could deviate from the grip position so that a successful grip was still achieved. **Robustness to rotation** was investigated by gripping all available instruments in sequence and applying torque by hand. It was determined whether the instruments in the handle could rotate. The **flexibility of the grip position** evaluated at which positions a pair of scissors could be reliably gripped.

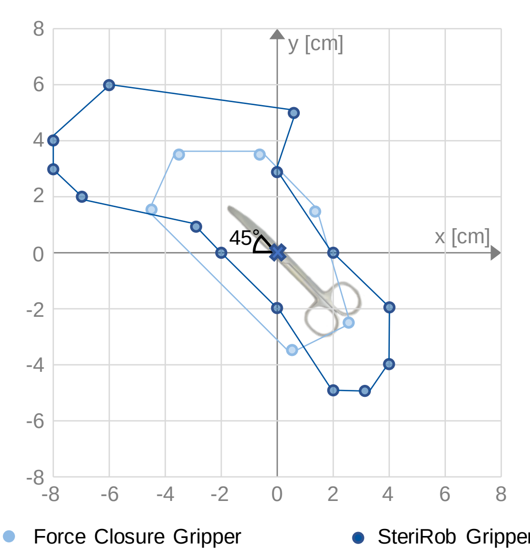

Figure 4: Robustness against displacement

For this purpose, the scissors were divided along the longitudinal axis into 15 equally sized sections, which were gripped one after the other by the grippers. The number of areas in which a successful grab could be performed was documented.

The results of the tests are shown in Table 1 and Figure 4. When measuring the absorbable force and torque, the SteriRob gripper reached the measuring limit of the force gauge without losing the instrument. The robustness to displacement is compared in Figure 4. The robot expected the rotary joint (blue cross in Figure 4) in the coordinate origin and the alignment of the scissors parallel to the x-axis. The gripping always took place at the coordinate origin. In contrast to the position expected by the robot, the scissors are rotated by 45° and the rotary joint is translationally displaced. If the rotary joint was within the colour-coded boundary, a successful gripping process was still possible.

Table 1: Results

	Force Closure Gripper	**SteriRob Gripper**
Instrument Variety	16 / 16	16 / 16
Precision	0 mm / 0°	0 mm / 0°
Force Absorption	5 N	>20 N
Torque Absorption	0.055 Nm	>1.1 Nm
Robustness to Rotation	14 / 16	16 / 16
Flexibility of Grip Position	13 / 15	15 / 15

5 Discussion and Conclusion

This work aimed at investigating the possibility of handling a variety of instruments, despite the multiple geometries, through a single instrument gripper. The results of the evaluation show that the SteriRob gripper is more suitable than the force closure gripper for handling of the instruments. The force-closure gripper used is suitable for simple pick-and-place tasks but transmits significantly lower forces and torques. In addition, the robustness against displacement and the flexibility of the SteriRob gripper is more suitable regarding future bin-picking tasks with different instruments. There are instruments, such as kidney dishes, that cannot be handled by the SteriRob gripper due to their shape. However, also the tested force closure gripper cannot grip kidney dishes. In this study, isolated instruments were gripped from a flat surface. This situation can occur during the preparation of the instruments for cleaning, during care and maintenance and during the packing process. However, in an instrument sieve instruments lie chaotically on top of and next to each other, resulting in more difficult gripping tasks.

Robust sensor-based localization and gripping of instruments in these scenarios is one objective of our ongoing work. The robustness of the gripper against localizing inaccuracies can be used as a reference point for the required precision of the sensor system. Another objective is to design a first prototype of the SteriRob gripper that can be reprocessed by standard procedures. In conclusion, the suitability of the SteriRob gripper for handling of surgical instruments could be confirmed for the simulated tasks, but further development is required to extend the presented results to bin picking from jumbled instrument sieves.

Author Statement

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