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Integrating 3D cameras into sterile surgical environments: A comparison of different protective materials regarding scan accuracy

Development of a sterile camera enclosure for the detection of laparoscopic instruments

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Abstract: This work presents a sterile concept for 3D cameras within sterile surgical environments. In the digital operating room (OR), such cameras can serve as a valuable data source for cognitive workflow assistance systems, e.g decision or mechatronic support systems. One recent example are robotic assistants for instrument handling, such as the robotic scrub nurse currently developed in the framework of the *SASHA-OR* research project[1]. In this context, we detect laparoscopic instruments and the surgical environment with a 3D camera, whereby hygienic requirements need to be met.

Using a *Zivid Two* sensor, we generated point clouds of the laparoscopic instruments located in an instrument holder and a drop zone. We compared the effect of using different pane types and thicknesses for the sterile camera enclosure and compared the performance with and without protective pane in terms of the point cloud accuracy.

When analyzing multiple pane types, polymethyl methacrylate with 0.5 mm thickness (PMMA 0.5) provided the best results. At a scan distance of 560 mm to the surface center, which is required for the complete acquisition of a laparoscopic instrument, PMMA 0.5 achieved the smallest Chamfer distance (CD) values for both the scans with the laparoscopic instruments in the instrument holder (0.23 ± 1.52 mm) and in the drop zone (0.12 ± 0.25 mm).

Keywords: Laparoscopic Instrument Detection, Point Clouds, Sterility, Optical Plastic

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1 Introduction

Nurse staffing shortages are an enduring problem, that is expected to grow in the upcoming years. Especially scrub and circulating nurse understaffing limits the use of available operating capacities in hospitals [1]. Due to the shortage of personnel, there is increasing recourse to unqualified staff, whose inexperience has a significant influence on the workflow of a surgery. While the vision of the cognitive operating room [2] aims at mitigating these effects by means of smart assistance and decision support systems, extensive sensor input is needed as a foundation for understanding the current needs of the surgical team. In this context, 3D cameras are an especially feature-rich modality and therefore highly desirable for various applications, such as assistive robotics. However, integrating such sensors can be challenging, especially if they need to be mounted in proximity of the operative field thus affect hygienic requirements.

To address the problem of nurse understaffing, several robotic scrub nurse concepts have been introduced within the scientific community [3-8]. Previous work has focused primarily on open surgical procedures. However, due to its

[1] Technical University Munich: SASHA-OR. URL: web.med.tum.de/en/miti/research/projects/sasha-or/ [12.05.2022]

significant advantages over open surgery, laparoscopic surgery has become the gold standard for a range of surgical procedures, including cholecystectomies, appendectomies, inguinal hernia repair and some types of colon surgery [9] and provides great potential for the use of robotic scrub nurse systems. As a part of the StMWi-funded *SASHA-OR* project we are developing a context-aware robotic assistance system for flexible instrument and object management within the sterile area of an OR. For the handover of instruments and sterile goods to the surgeon, we have designed a platform where a robotic handling arm (*Panda*, Franka-Emika Gmbh, Germany) is intended to take over the tasks of a human scrub nurse. The platform consists of an instrument holder, in which the laparoscopic instruments are stored, and a drop zone, which allows the surgeon to return the instruments. A 3D camera (*Zivid Two*, Zivid, Norway) was installed on the robotic arm for object recognition of the laparoscopic instruments.

Since the robotic platform will be used in the sterile area of the OR, specific hygienic regulations have to be met. Reusable medical devices used during a surgical procedure are considered potentially contaminated, and as such must be reprocessed after use to prevent surgical site infections. The reprocessing method used is based on the criticality of the device, and ranges from simple disinfection to a combination of cleaning, thermal disinfection, and moist heat sterilization in an autoclave [10]. As some medical devices, particularly larger equipment with electronic parts such as robotic handling arms, are not suitable for reprocessing due to their size and components, other methods of ensuring sterility have to be developed. Especially, maintaining the sterility of the 3D camera is problematic, as a clear field of view must be ensured for the instruments to be recognized. In this paper, we propose a concept for a sterile enclosure of the 3D camera and demonstrate the effectiveness of our approach in the context of laparoscopic instrument detection.

2 Material and Methods

The method section is split into four parts. In the first part, we explain the 3D model acquisition of the surgical tools. These models are to be employed for vision-based detection and localization of the objects in the OR. This is followed by the description of the camera enclosure and the presentation of the scan setup to generate point clouds. Finally, we describe our evaluation metric used.

2.1 Models of surgical instruments

Most laparoscopic instruments are built upon three parts: a handle, an elongated sheath and an effector [11]. Some of the instruments differ only in the instrument tip. A thumbwheel allows the effector to be rotated 360° for optimal maneuverability at the surgical site. However, the available features make it difficult to identify an instrument using a 3D camera. For robust recognition, the instruments were scanned using a 3D scanner (*EinScan-Sp*, Shining 3D, China) and saved as a Standard Transformation Language file. Using the 3D model, visual features can be learned to enable the instruments to be recognized on the robot platform.

2.2 Camera enclosure

For compliance with hygiene regulations in the sterile area of the OR, we have developed a device for the *Zivid Two* sensor. In daily clinical practice, sensitive equipment with electronic components must be quickly covered with sterile surgical drapes, covers or foils for single use. To ensure that scanning of the instruments and the surgical environment is still possible, a transparent pane must be installed in the device in front of the sensor. Foils that are very vulnerable to visual obstructions can be excluded. Plastics such as polymethyl methacrylate (PMMA), polycarbonate (PC), and polyvinyl chloride (PVC) are more suitable for use in the OR than optical glass because of their properties of being less fragile and brittle. Acrylic has the lowest refractive index and the highest Abbe number of these plastics. The material is very scratch resistant and not very water absorbent, which is why it is used in many plastic optical applications. PC stands out with its high impact resistance. [12] The plastic pane was integrated into the sterile drape and fixed by magnetic locking. In order to obtain the best possible scan result, we want to examine the effect of using different plastic pane types and thicknesses regarding their performance and compare their performance with and without the protective pane in terms of point cloud accuracy. The plastic types used together with their thickness and labeling are shown in Table 1.

2.3 Scan Setup

The *Zivid Two* sensor uses structured light as 3D technology, whereby the optimal working distance of this sensor is between 500 mm and 1100 mm. To investigate the effect of using different pane types with respect to the scan results, we chose different scan distances from the instrumentation table what we refer to as scan depth. Since the maximum range of motion of the *Panda* robot arm is 855 mm, we decided to use scan depths of 560 mm and 810 mm. We scanned selected laparoscopic instruments (clip applicator, grasping forceps, scissors and *DaVinci* scissors) both in the instrument holder and lying in the drop zone with automatic calibration (auto) and with the calibration setting of a scan without glass (no pane). For a scan depth of 560 mm, a laparoscopic instrument is fully located within the field of view of the sensor. A scan depth of 810 mm represents the maximum possible distance of the sensor from the platform. To verify the optimal working distance of the sensor, we additionally performed scans at a height of 950 mm.

Table 1: Overview of the different plastic pane types and their thickness used during testing

Label	Plastic type	Thickness
PMMA 0.5	Polymethyl methacrylate	0,5 mm
PMMA 1	Polymethyl methacrylate	1,0 mm
PMMA 1.5	Polymethyl methacrylate	1,5 mm
PMMA 2.0	Polymethyl methacrylate	2,0 mm
PC 1	Polycarbonate	1,0 mm
PVC 1	Polyvinyl chloride	1,0 mm

2.4 Measurements

Point clouds consist of a set of 3D points sampled on surfaces in the scene and are a common 3D data representation. The point cloud obtained from a scan of the laparoscopic instruments in the drop zone with a depth of 560 mm is shown in Figure 1. However, comparison of point clouds is challenging because they cannot be compared using a common metric such as Euclidian metric since they are not a function on a grid. A common method for comparing point clouds directly is the Chamfer distance, where the individual sample points from two point clouds are compared. [13]

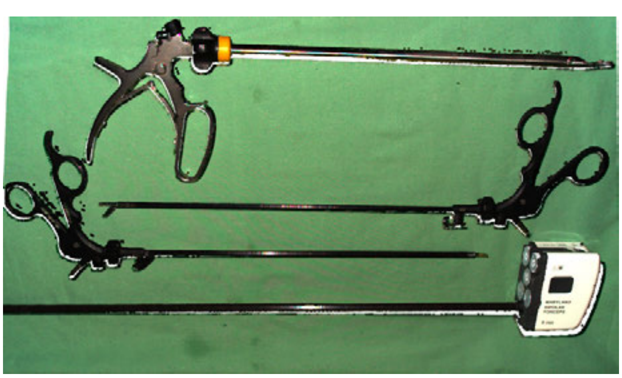

Figure 1: Point cloud of laparoscopic instruments with a scan depth of 560 mm. Instruments from top to bottom: clip applicator, grasping forceps, scissors and *DaVinci* scissors.

We consider the point cloud of the scan without the pane as the ground truth or reference for calculating the Chamfer distance. For each point in the respective point cloud, the Chamfer Distance (CD) finds the closest point in the other point cloud and sums up the square of the distance. The metric between two point clouds S_1 and S_2 is defined as

$$\boldsymbol{CD}(\boldsymbol{S_1}, \boldsymbol{S_2}) = \frac{1}{|S_1|} \sum_{x \in S_1} \min_{y \in S_2} \|x - y\|_2^2 + \frac{1}{|S_2|} \sum_{y \in S_2} \min_{x \in S_1} \|x - y\|_2^2 \,. \tag{1}$$

For evaluation we use the mean CD between the respective point clouds with the different pane types and the reference point cloud averaged over the number of 3D points.

3 Results

Figure 2 shows the CD values with the laparoscopic instruments in the instrument holder, while Figure 3 shows the results with the instruments in the drop zone. The x-axis displays the different plastic pane types and the y-axis the mean Chamfer distance. The different scan depths are highlighted in different colours, while the dashed line indicates the metric values based on the auto-calibration setting and the solid line the results based on the calibration setting without the pane.

Achieving lower mean CD values indicates smaller deviation of the 3D points compared to the 3D points of the scene without a pane. Thus, the smaller the CD value, the smaller the negative influence of the pane on the accuracy of the scene representation.

By comparing the scan results of the surgical instruments in the instrument holder (Figure 2) we notice that PMMA 1 shows very constant CD values, while the values for PMMA 0.5 are more dispersed. However, PMMA 0.5 has the lowest CD value with 0.23 ± 1.52 mm at a scan depth of 560 mm with autocalibration. For a scan depth of 810 mm, PMMA 1.5 achieves the lowest CD value of 0.63 ± 0.32 mm with auto-calibration. The CD values of PC 1 are comparable to those of PMMA 1.5. PVC 1 delivers slightly lower CD values than PC 1. When examining the scan results with the laparoscopic instruments in the drop zone (Figure 3), we see that PMMA 0.5 shows clearly better values this time compared to the other pane types. The lowest CD value is again obtained for a scan depth of 560 mm with auto-calibration with 0.12 ± 0.25 mm. PMMA 2 once again shows clearly higher CD values compared to the other pane types and is therefore not suitable for sterile housing of the *Zivid Two* sensor. PC 1 delivers better results than PVC 1 at scan depths of 810 mm and 950 mm, however, both show poorer results in comparison to PMMA 0.5.

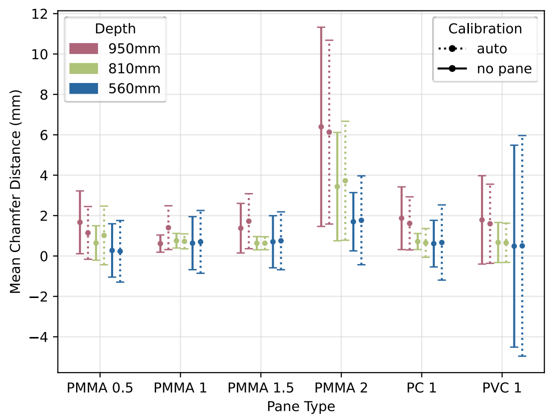

Figure 2: Mean chamfer distance and standard deviation between the respective point clouds of the scans with different plastic panes and the reference point cloud. Instruments are placed in the instrument holder.

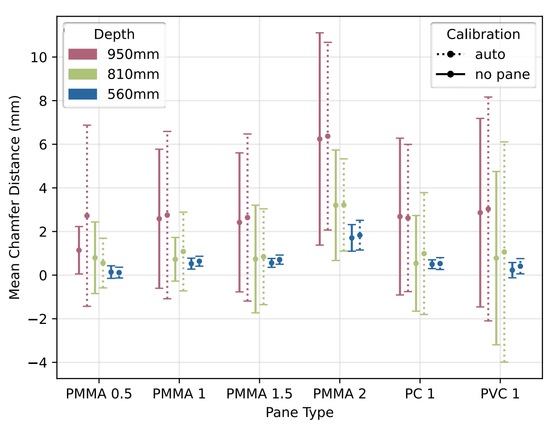

Figure 3: Mean chamfer distance and standard deviation between the respective point clouds of the scans with different plastic panes and the reference point cloud. Instruments are located in the drop zone.

4 Discussion

The results regarding the scan accuracy indicate that material properties have a notable influence on the quality of the scans. As expected, the PMMA panes yields the best results, since this type has the highest Abbe number and the lowest refractive index. As PMMA has the lowest absorption rate, primarily PMMA panes were investigated in this test setup. Nevertheless, not only material properties have an influence on the performance but also the pane thickness. Figure 2 and Figure 3 reveal that PMMA 2 gives the worst results, which can be attributed to this parameter. The PMMA 0.5 pane type achieves the best results for a scan depth of 560 mm, both for the instruments in the instrument holder and in the drop zone. Since the laparoscopic instruments are fully located in the field of view at this scan depth, we decide to use the PMMA 0.5 type within our concept.

As a limitation of our experimental method, it must be noted that the evaluation of the scans using the CD does not involve a comparison with the underlying surface of the considered point cloud, but with the point cloud generated by the scan without a pane, which we have assumed to be the ground truth. Thus, we compare generated sample points, which may have a sensitive effect on the CD.

In the future, we plan to incorporate further materials and thicknesses to allow for an even more comprehensive comparison.

5 Conclusion

Due to the requirements in the sterile zone of the OR, cameras have to be enclosed adequately. Therefore, we developed a sterile concept for a 3D camera maintaining vision-based recognition of laparoscopic instruments and the surgical environment. For the vision-based tasks in the sterile zone, a clear-transparent pane has to be installed in front of the 3D camera, which do not influence the emitting structured light of a 3D camera. For this purpose, we tested different types of plastic panes and evaluated them using the mean CD values regarding the generated point clouds of laparoscopic instruments. Based on our results, we recommend the use of PMMA with a thickness of 0.5 mm. As a next step, we want to extract the visual features of the 3D models of the instruments described in section 2.1 in order to be able to classify them using computer vision algorithms. We will then perform rescans and evaluate the computer vision recognition rate of the instruments with and without camera enclosure.

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