Interdisciplinary Description of Complex Systems 23(2), 110-117, 2025

AUTOMATION POTENTIAL IN THE WORKFLOW OF A SCRUB NURSE

Peter Schmid[1,*], Max B. Schäfer[2], Nina M. Stadel[1], Peter P. Pott[2] and Thomas Maier[1]

[1]University of Stuttgart, Institute for Engineering Design and Industrial Design, Research and Teaching Department, Industrial Design Engineering
Stuttgart, Germany

[2]University of Stuttgart, Institute of Medical Device Technology
Stuttgart, Germany

DOI: 10.7906/indecs.23.2.4
Regular article

Received: 30 September 2024.
Accepted: 5 November 2024.

ABSTRACT

One of the heavily burdened actors in the operating theatre is the scrub nurse who is responsible for the organized and orderly workflow in the operating theatre. One of the main tasks of the scrub nurse is to perform quick and appropriate instrumentation because fast and proactive instrumentation is crucial for the success of the operation. The actual deficiency of specialist staff in the healthcare sector is motivating the automation of repetitive tasks and simple work steps in order to relieve staff in the future and free up capacity for complex and important activities. A robotic assistance system appears to be a suitable solution for many of these challenges. The vision is to develop advanced assistance systems for the handling of instruments in future surgical procedures. In this work, surgery of the carpal tunnel was chosen as example task. The focus lied on the type and scope of the individual working steps. The analysis was carried out by video analyses and by observing corresponding surgical procedures. Based on the results of the analysis, potentials for improving the workflow were derived and requirements for a robotic assistance system were defined.

KEY WORDS

workflow, human-machine interaction, ergonomics, robotic assistance system, scrub nurse

CLASSIFICATION

JEL: I12, J81

*Corresponding author, η: peter.schmid@iktd.uni-stuttgart.de; -; -

MOTIVATION

Worldwide the healthcare sector is facing an increasing challenge concerning the growing shortage of specialized staff [1]. This shortage of specialists not only leads to a considerable overload of existing staff, but also jeopardizes the safety and well-being of patients. According to Blum [2], the operating theatre is a highly complex, functional field of work that is characterized by an increasing differentiation and specialization of tasks and in which the increase in mental and physical stress on employees is an essential problem (see [3, 4]). One of the most heavily burdened actors in the operating theatre is the scrub nurse. The high workload impairs the quality of care and increases the risk of errors in everyday clinical practice. In view of this problem, it is necessary to look for ways to reduce the stress on medical staff, particularly in the operating theatre. One promising approach lies in the automation of processes and the implementation of technologies that can take over repetitive tasks and thus relieve the stress on specialist staff [5].

This research analyses the activities of scrub nurses during surgery for carpal tunnel syndrome. This surgical treatment is the most frequently performed hand surgery procedure today [6]. By carefully analyzing these activities, it is possible to identify potential for increasing efficiency and reducing the workload of the scrub nurse, which can help to improve working conditions and increase patient safety by automating repetitive tasks (see Figure 1).

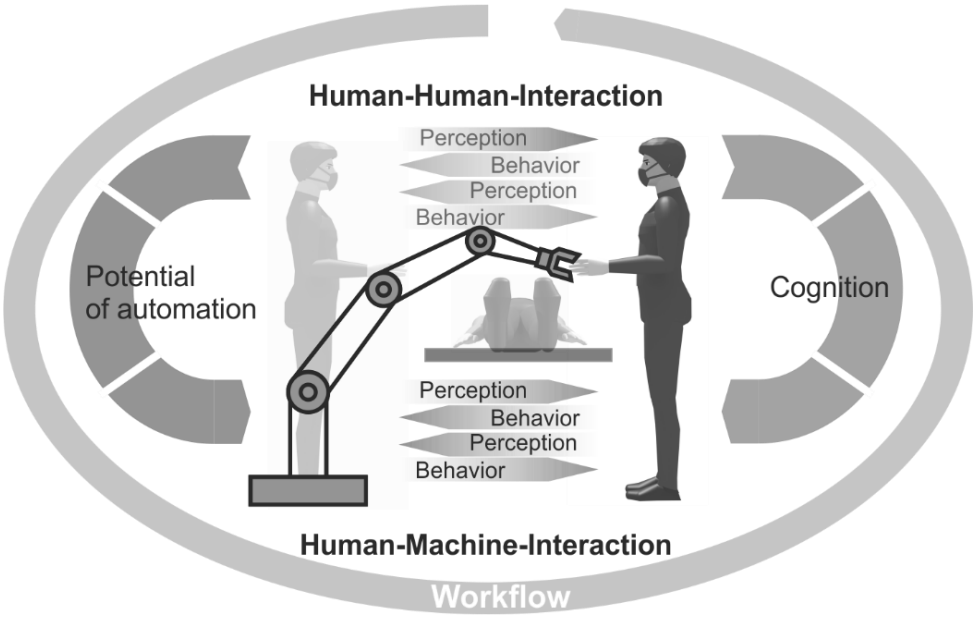

Figure 1. The figure shows the current bidirectional information exchange and information processing in the workflow between scrub nurse and surgeon. For automation the bidirectional perception, behavior and cognition process is to be transferred to a robotic scrub nurse.

METHOD

In order to identify potential for automation in the workflow of a scrub nurse (see Figure 1), the handling of a single instrument is of interest in this work. In order to analyze the work of the scrub nurse, the scrub nurse is observed in the operating theatre. A workflow analysis was carried out on the handling of instruments by the scrub nurse during an operation. It is characterized by an individual way of working or a specific procedure [7]. The workflow method is based on the observation of human-machine interaction using equipment e.g. camcorder, camera or audiography. The interaction is transferred to the workflow diagram in a data transcription step [8].

The workflow analysis aims to visualize the time sequences and the instruments used and to examine the interactions and information flow between the medical staff. A visual representation of the operating theatres was developed for each use case, which provides comparable data diagrams and makes it possible to visualize the processes running in parallel. The type and scope of the individual work steps and the interactions with the operating theatre team members during the operation are of particular interest for analyzing the instrument handling by the scrub nurse performing the instrumentation. The patient is not included in this analysis, as there is no direct interaction with the scrub nurse performing the procedure.

For evaluation, the handling of instruments by the scrub nurse is noticed in a table. Therefore the sequence of instruments is verified followed by the notice whether the instrument was requested and used by the surgeon or the scrub nurse. The way in which the instrument was requested is also documented. A distinction is made between verbal, non-verbal and no requests. In addition to the start and end points of the instrument us., the handling of the instruments by the scrub nurse is documented, also the hand used to pick up, hand over and receive the instruments. All tasks performed by the scrub nurse during the operation are recorded in the video, which involves preparing the suture material, preparing the dressing and tidying up the instruments.

RESULTS

Concerning the video analysis data, the operation was divided into operating scenarios based on individual micro-actions. Each individual operating scenario was subdivided into six individual micro-actions. In addition, the suturing and dressing were added, resulting in a total of eight micro-actions. These micro-actions are: ‘Request’, ‘Pick up’, ‘Pass, ‘Take’, ‘Return’, ‘Put away’.

The individual micro-actions can be divided into general actions and instrument-specific actions. The general actions describe actions that are independent of the instrument. The general micro-actions include ‘requesting’, ‘returning’ and ‘putting away’ the instruments and the instrument-specific micro-actions include ‘picking up’, ‘passing’ and ‘taking’ the instruments. With regard to instrument-specific micro-actions, it should be noted that this can vary depending on the instrument. This is due to the fact that safety precautions must be observed when handing over certain instruments or the instruments must be made available for direct further work. As part of the study, a total of 67 instrument handlings were analyzed in five different operating theatres. Instruments such as scalpels, forceps, scissors, hooks and needle-thread combinations were analyzed. Compresses and dressing materials were not included, as there are no specific requirements for their use.

The scrub nurse sits at the instrument table while the surgeon sits at the operating theatre table. A certain distance must be covered to the handover point for each instrument handover. These handover areas can be divided into three zones (see Figure 2): the zone above the instrument table (Figure 2a), the zone above the operating table (Figure 2b) and the zone between the two tables (Figure 2c).

If a medical instrument is passed over or returned in the zone above the instrument table, the scrub nurse has to cover the shortest distance to the handover location(Figure a). In contrast, handover in the zone above the operating table requires the longest distance for the scrub nurse (Figure 2b). If the handover location is between the two tables (Figure 2c), the distance is the same for both. The evaluation of the handover areas in clinics shows that overall, most instruments are handed over above the operating table, followed by handovers between the two tables. The zone above the instrument table is the area with the fewest handovers. When

Figure 2. Handover areas: a) above the instrument table, b) above the operating table, c) between the two tables.

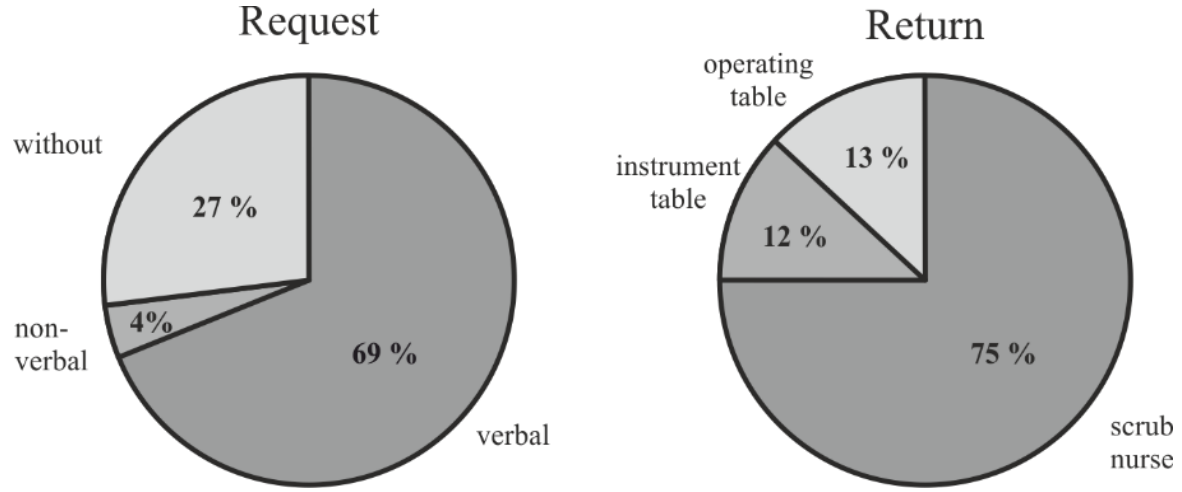

Figure 3. Type of request (verbal, non-verbal, without communication) in percent and location of return in percent across the analyzed instrument handlings during surgery.

handovers do take place in this zone, it is usually for the return of instruments. Regardless of the clinic, the scrub nurse always covers the greatest distances when handing over instruments.

Instruments can be requested verbally, non-verbally or without communication (unsolicited). The distribution of the various request options is shown in Figure 3. Figure 3 clearly shows that 69 % of the instruments are requested verbally. Non-verbal requests are the least common in the clinics analyzed. Only 4 % of the instruments were requested in this way during the study. In 27 % of cases, the instruments were presented without prior communication. Instruments can also be returned directly to the scrub nurse, to the operating theatre table or to the instrument table. The analysis shows in Figure 3 that the instruments are generally returned directly to the scrub nurse. One exception is the placement of instruments on the instrument table, which only takes place if the scrub nurse is not currently available to receive the instruments. Instruments can be placed on the operating table if the surgeon needs to get rid of the instrument promptly and removes it without further action. The scrub nurse takes them back to the instrument table independently. In the analysis, 75 % of the instruments were returned directly to the scrub nurse, 12 % were placed on the instrument table and 13 % were placed on the operating table. Contaminated instruments are cleaned by the scrub nurse before being placed on the instrument table or used again. In the operating theatres analyzed, 91 % of the instruments did not need to be cleaned during the operation.

Furthermore, the individual instruments were analyzed in more detail. In 61 % of cases, the scalpel is picked up and held at the front of the handle in front of the blade (see Figure 4). This gives the surgeon the largest free area on the handle to pick up the instrument. In a few cases

(23 %), the scrub nurse grips the scalpel at the center of the handle. In most cases (69 %), the scalpels were passed diagonally in accordance with the literature [9, 10] and the blade pointed towards the patient. None of the scalpels were passed vertically or placed on the operating table. Without exception, the scalpel was taken by the surgeons from below in order to be able to use it analogue to a pen. In 23 %, the scalpel was passed in the surgeon's hand with a little pressure.

According to [9, 10] the forceps are picked up and passed closed. In the clinics, the forceps are picked up by the scrub nurse either at the front or in the center so that they can then be passed closed (front: 50 %, center: 21 %, see Fig 4). 28 % of the forceps are picked up at the upper end so that they cannot be passed closed. The majority (64 %) of the forceps were passed diagonally, the other part vertically (36 %) from the scrub nurse to the surgeon. None of the forceps were passed horizontally or placed on the operating table. The forceps were either passed from below or from the side. In 64 % of cases, and thus most frequently, the forceps were passed from the side. In 21 % of cases, the forceps were passed directly in the hand with some pressure, so that the surgeon did not have to actively reach for the forceps, but only had to close the fingers.

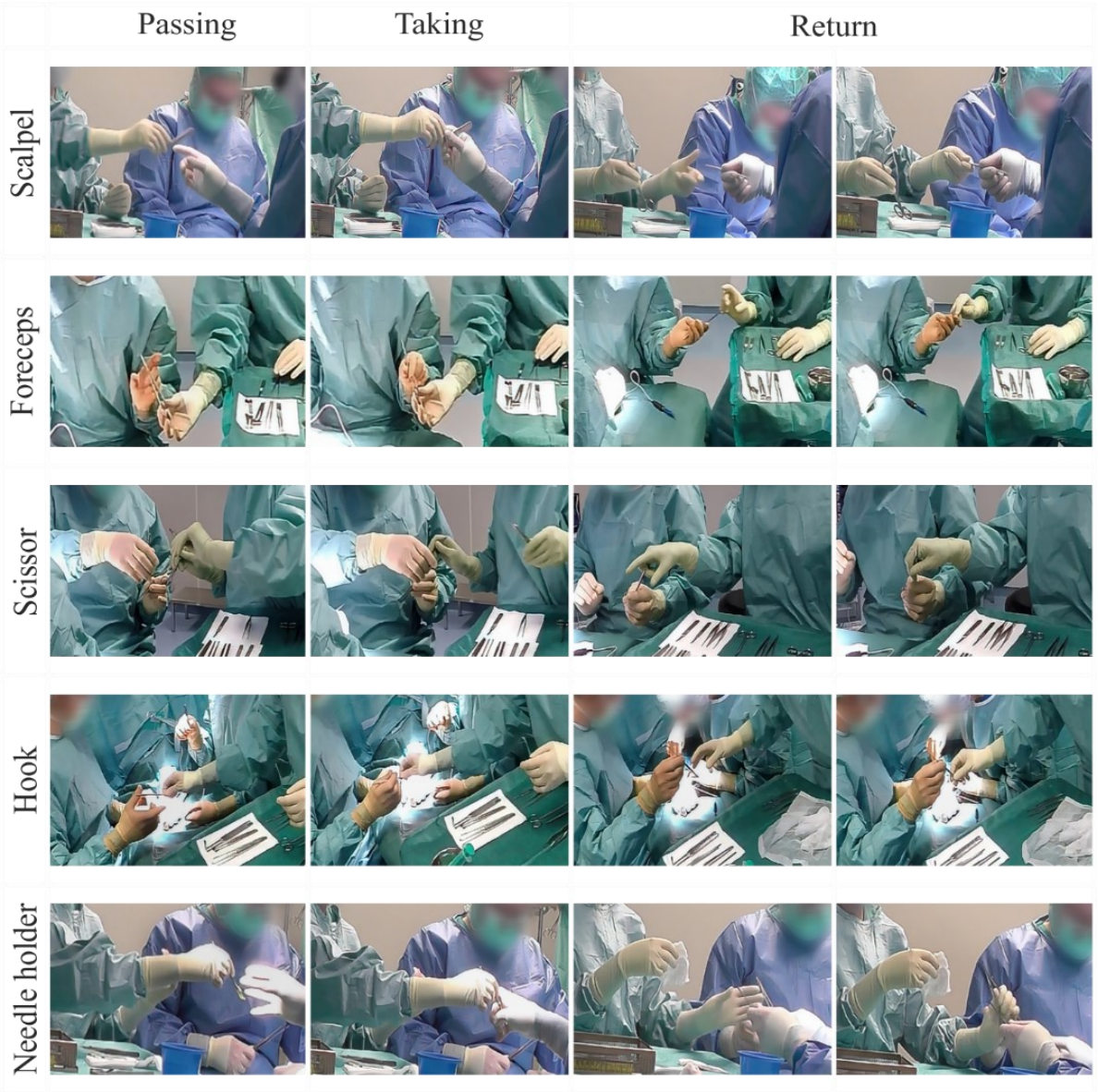

Figure 4. Instrument handling concerning the micro-actions passing, taking and returning between scrub nurse (instrument table) and surgeon (operating table).

67 % of the scissors were picked up at the front of the cutting blades and 13 % in the center at the branches. The scissors were passed diagonally to the surgeon. Only in two cases were the scissors handed vertically. Depending on how the scrub nurse picked up the scissors, the scissors were passed from the side or from above. The scissors are most frequently passed from the side (64 %), in the remaining cases (36 %) the scissors are passed from above. Only one pair of scissors was placed directly in the surgeon's hand. None of the scissors were passed from below or placed on the operating table.

The hooks were generally most frequently picked up in the center of the handle (50 %) (see Figure 4). In 45 % of cases, they were picked up at the front in the direction of the tines or the blade. Only once, a hook was picked up at the rear end. In the literature, hooks are usually passed horizontally [9, 10]. In practical implementation in the operating theatre, however, most of the hooks are passed diagonally (65 %). The remaining 35 % were passed horizontally. In most cases, the hooks are passed by the surgeons from below (55 %). In 25 % of cases, the hooks are passed from the side and in 20 % they are passed directly in the hand with a little pressure.

The needle holders are picked up in the center (80 %) and only 20 % is picked up at the front at the tip. The needle holders are passed like the scissors, either diagonally or vertically. 80 % of the needle holders are passed diagonally and only one is passed vertically. None are passed horizontally or passed on the operating table. In three cases, the surgeons take the needle holder from above, in one case from the side and in another case it is passed in the hand. The acceptance is again dependent on how the scrub nurse picks up the needle holder. None of the needle holders were picked up from below or from the operating table.

DISCUSSION

This study aimed to evaluate the potential for automation or partial automation within the surgical workflow by analyzing the role of the scrub nurse during a standardized surgical procedure. To achieve this, video recordings of the same surgical procedure were collected from multiple clinics and subsequently analyzed. The analysis focused on distinct phases of the operation and individual surgical steps, with particular attention to the timing, duration, and method of execution.

Observations made during surgeries, coupled with discussions with surgeons and scrub nurses, indicate that surgeons and scrub nurses often function as highly coordinated teams, particularly when they have already collaborated over an extended period. This prolonged cooperation enables them to anticipate each other's needs with minimal verbal communication. [11, 12]

An analysis of the chosen standardized surgical procedure revealed greater variability in instrument handling and workflow processes than expected. Each clinic adheres to internally defined standards, leading to distinct differences in the procedural execution and instrument usage. Some clinics employed a broader range of instruments, while others successfully completed the same procedures with fewer tools, without compromising outcomes. Additionally, some clinics differentiated between scalpels for different tissue layers, whereas others utilized a single scalpel throughout the procedure. While micro-actions, such as the passing, taking, or returning of instruments, mostly follow literature guidelines (e.g. [10]), some deviations from established protocols and guidelines were noted. Furthermore, the distribution of tasks between surgeons and their assistants varied, with some clinics demonstrating equal participation, whereas others maintained a more rigid division of responsibilities.

In summary, variations in instrument handling are influenced by individual surgeon preferences, the longstanding collaboration between team members, and patient-specific anatomical factors. These elements play a significant role in shaping the surgical workflow, contributing to observable differences across clinics, even within standardized procedures.

OUTLOOK

The findings of this study indicate that, due to the considerable variability in interaction despite a standardized intervention, the implementation of a rigid technical system is not feasible. Instead, the system must exhibit a high degree of context sensitivity and intelligence, allowing for seamless user configuration and adaptation to dynamic conditions and individual preferences.

The analysis of the scrub nurse's role highlights several opportunities for automation and robotic assistance. Instrument handling and handovers could be optimized by robotic systems capable of predicting surgical needs based on real-time procedure tracking. These systems could enhance efficiency by providing instruments in a timely and standardized manner. Additionally, automated monitoring of surgical phases could improve workflow coordination by precisely managing timing and transitions between steps. Robotic systems offer potential benefits in maintaining sterility and adherence to safety protocols, minimizing human error while handling instruments [13, 14]. Moreover, automation could streamline inventory management by tracking instrument usage and availability, reducing the manual workload. Customizable robotic systems could also adapt to individual surgeon preferences, further optimizing the workflow. These findings suggest that incorporating robotic assistance into the surgical workflow has the potential to improve operational efficiency, safety, and precision, while relieving the burden on human staff.

Future research will prioritize a deeper investigation into human-system interaction, with a particular focus on the bidirectional handover process, as well as verbal and non-verbal communication. These aspects will be analyzed both analytically, in the context of human-to-human interaction, and experimentally, in human-system interaction scenarios.

A critical question arises regarding the target user demographic for systems designed to relieve operating room staff workloads. One approach is to develop a system that replicates the behavior of a human scrub nurse, thus optimizing interaction and communication to ensure seamless integration into the existing workflow. Alternatively, there is potential to create a more advanced system that surpasses the current standard, although achieving full implementation and user acceptance may require a longer timeframe. Both approaches offer distinct advantages and should be carefully evaluated in the development of future technical assistance systems.

REFERENCES

[1] –: *Fachkraefte mangel-ist-Herausforderung-Nummer-eins*.
https://www.aerzteblatt.de/news/fachkraeftemangel-ist-herausforderung-nummer-eins-ace35cfe-5f5a-459f-b5a3-1bd500ec67f9, accessed 27th July 2024,

[2] Blum, K.: *Krankenhausversorgung*.
In: Hurrelmann, K. and Razum, O., eds.: *Handbuch Gesundheitswissenschaften*. Beltz Juventa, Weinheim & Basel, pp.813-836, 2016,

[3] Busse, T.: *OP-Barometer 2017*.
https://www.hartmann.info/de-de/wissen-und-news/3/7/op-barometer-2017, accessed 7th February 2024,

[4] Welk, I.: *Teamwork im OP*.
Im OP **9**(5), 211-215, 2019,
http://dx.doi.org/10.1055/a-0942-0155,

[5] Diabots: *Fachkräftemangel im Gesundheitswesen nachvollziehen*.
https://diabots.de/2024/05/29/fachkraftemangel-im-gesundheitswesen, accessed 27th July 2024,

[6] Frank, U. and Frank, K.: *Diagnostik und Therapie des Karpaltunnelsyndroms.*
Handchirurgie Scan **08**(04), 283-296, 2019,
http://dx.doi.org/10.1055/a-0977-4886,

[7] Macleod, M.: *Performance measurement and ecological validity*.
In: Jordan, P.W.; Thomas, B.; Weerdmeester, B.A. and McClelland, I.L.: *Usability Evaluation in Industry*. Taylor and Francis, London, 1996,

[8] Schmid, M. and Himmelein, M.: *Workflowbasiertes Mensch-Maschine-Bewertungssystem am Beispiel von Digitalkameras*.
In: *Useware 2008 Verfahrens- und Produktionstech-nik, Engineering, Informationspräsentation und Interaktionskonzepte*. VDI-Bericht 2041, 2008,

[9] Liehn, M. and Schlautmann, H.: 1×1 *der chirurgischen Instrumente: Benennen-Erkennen--Instrumentieren*. 4th edition.
Springer, 2022,
http://dx.doi.org/10.1007/978-3-662-65028-8,

[10] Wagenhäuser, K. and Wagenhäuser, K.-H.: *Instrumente anreichen*.
Im OP **08**(04), 142-145, 2018,
http://dx.doi.org/10.1055/a-0597-0425,

[11] Nestel, D. and Kidd, J.: *Nurses' perceptions and experiences of communication in the operating theatre: a focus group interview*.
BMC Nursing **5**, No. 1, 2006,
http://dx.doi.org/10.1186/1472-6955-5-1,

[12] Lingard, L.; Reznick, R.; Espin, S.; Regehr, G. and DeVito, I.: *Team Communications in the Operating Room: Talk Patterns, Sites of tension and Impacts for Novices*.
Academic Medicine **77**(3), 232-237, 2002,
http://dx.doi.org/10.1097/00001888-200203000-00013,

[13] Schäfer, M.B., et al.: *Robotic Scrub Nurse: Surgical Instrument Handling with a Granular Jamming Gripper*.
Current Directions in Biomedical Engineering **9**(1), 174-177, 2023,
http://dx.doi.org/10.1515/cdbme-2023-1044,

[14] Bajraktari, F.; Fleissner, K. and Pott, P.P.: *A comparison of two CNN-based instrument detection approaches for automated surgical assistance systems*.
Current Directions in Biomedical Engineering **9**(1), 599-602, 2023,
http://dx.doi.org/10.1515/cdbme-2023-1150.