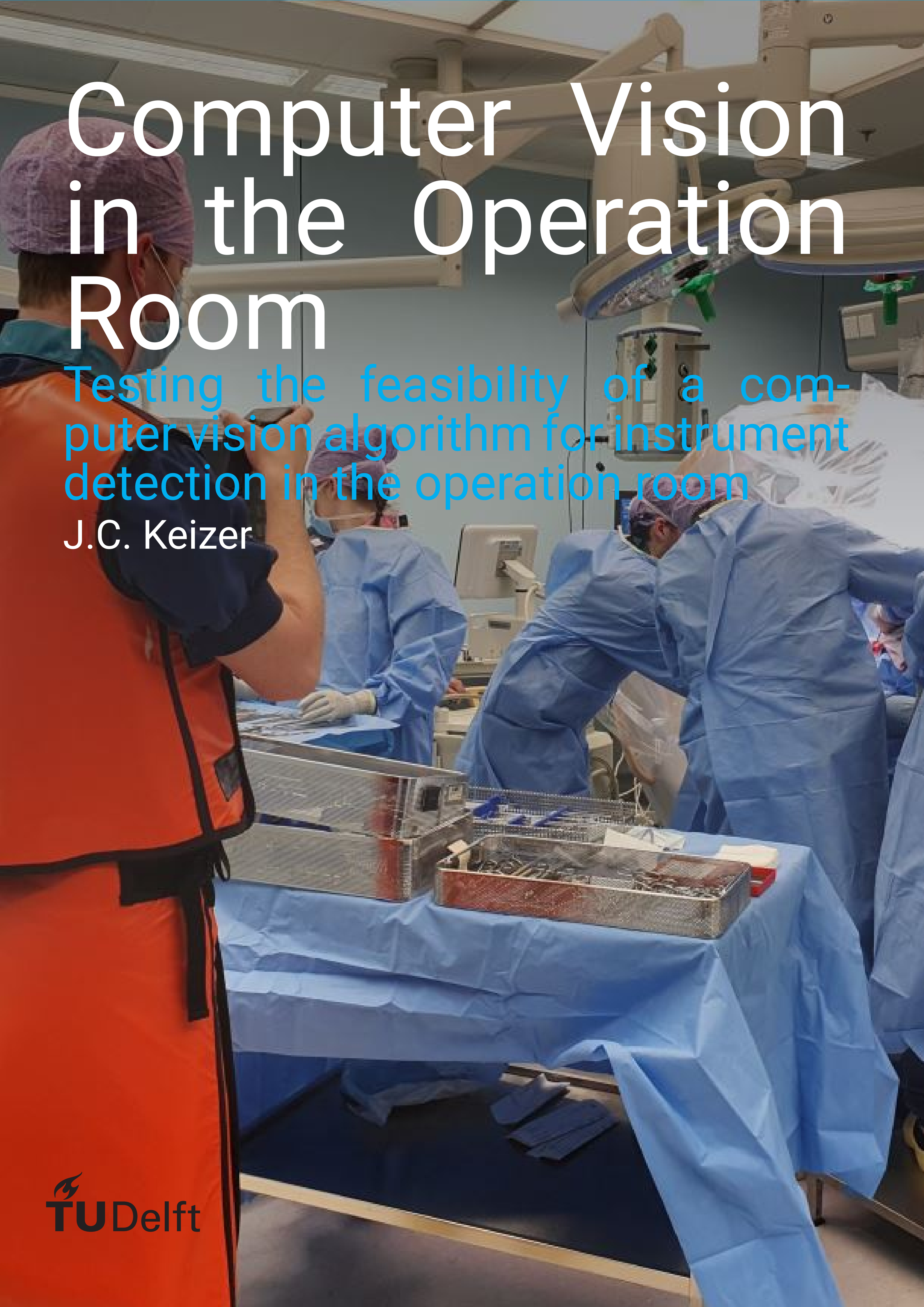

Computer Vision in the Operation Room

Testing the feasibility of a computer vision algorithm for instrument detection in the operation room

J.C. Keizer

TU Delft

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by

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An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

TU Delft

Preface

You are reading the final product of my graduation project at the Delft University of Technology. I started the project in November 2020 by contacting John van den Dobbelsteen. During my internship in autumn 2020 I looked into the possibilities of surgical instrument detection techniques in the OR. I asked John if I could do my graduation project around this subject as it interested me a lot. He brought me into contact with trauma surgeon Maarten van der Elst from the Reinier de Graaf Gasthuis (RdGG). Immediately I was given the opportunity to attend one of his surgeries and I was introduced to the clinical problem of instrument counting. I accepted the project and started setting up a research plan.

After a year of hard work in which I performed a literature study and a project at the RdGG, I got the opportunity to defend my work on the 14th of December 2021. I am very proud of this thesis and the work that I did during my graduation project!

First of all, I want to thank my supervisors John van den Dobbelsteen and Teddy Vijfvinkel.

John was my supervisor at the TU Delft. It was always a pleasure to discuss the project with him. He helped me forming the research question and he gave me valuable feedback on my work throughout the project. Furthermore, he helped me putting an end to my project which was hard to do at first. Thank you for always having enough time and space to discuss my progress with me!

Teddy was my daily supervisor at the TU Delft and the RdGG. From his clinical background he was able to give a very valuable view on my project. Together, we discussed a lot about the possibilities of computer vision in and around the operation room (OR). Thank you for keeping me sharp!

Furthermore, I want to thank Maarten van der Elst and the rest of the staff at the OR-complex of the RdGG. Maarten is a surgeon at the RdGG and presented the clinical challenges that resulted in my project. He also gave me the opportunity to attend many surgeries and he introduced me to many other staff members. I did not expect that during my project I could do my research physically in a hospital during the Covid pandemic. For these special opportunities, I would like to thank Maarten in special but the rest of the OR staff as well! Moreover, I want to thank both the OR assistants and the surgeons that participated in my survey for giving their valuable opinions and for thinking along about the project!

Finally, I want to thank my parents, sister and friends. They supported me extensively throughout the course of the project by discussing the project with me, by giving me time to relax and by proof-reading the initial versions of this thesis. Thank you all!

J.C. Keizer
Delft, December 1, 2021

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Abstract

Problem: One of the biggest challenges in hospitals today is improving efficiency, (patient) safety and quality of care while cutting on costs. A current reoccurring challenge in the operation department is the coordination of the components involved in making a surgery successful. One of those components is the set of surgical instruments. They undergo a cyclic process using reprocessing methods during which various challenges arise. A few of these challenges are the complex and time-consuming instrument counts before, during and after surgery.

Research question: Various technological aids have been proposed to automate the instrument counts. Previous technologies all showed their own flaws when they were tested in the operation room (OR). A new research field for the purpose of instrument counting is the use of computer vision. Computer vision shows great promise as it is already widely used to detect and recognize objects in digital images. However, before developing an algorithm to be used specifically for surgical instrument counting in and around the OR, the various activities, working methods and environmental factors are investigated first. This is done using the following research question: *"What is the feasibility of using a computer vision algorithm to automatically detect and count surgical instruments and what are potential factors that influence the performance and the implementation in the OR?"*.

Methods: The research question is answered using a converting thesis structure. Firstly, the most general steps of the instrument cycle are outlined and a description is given of a SIFT computer vision algorithm. SIFT is the proposed algorithm type for the investigated application. Secondly, the more specific steps of the instrument cycle at the Reinier de Graaf Gasthuis (RdGG) are described. The result of this description are different application options and different design scenarios. Thirdly, one application type and design scenario is selected: instrument counts in the OR. A blueprint is given for testing a SIFT algorithm in the OR. This blueprint could result in numerical results, valuable observations in the OR and staff survey results.

Results: A total of 35 surgeries were attended. Only results from observations and the survey are shown as the algorithm itself was not tested yet. The observations showed factors that could negatively influence the algorithm's performance. The survey results gave valuable insights into personal opinions on the value, use and implementation of the algorithm.

Conclusion: The feasibility of a current SIFT algorithm in a current ORs is low as it will not be able to automatically detect and count all instruments. There are a lot of factors that need to be taken into account to improve performance and possible implementation. They are formulated in 5 design focus points: 1) a line of sight between camera and the instrument(s), 2) dealing with instruments being taken away from and added to the table, 3) controlling the light conditions around the instrument table, 4) recognizing the specific type of some instruments and 5) showing clear feedback.

Contents

1 Introduction

Since the year 2010, the three cabinets of Dutch Prime Minister Mark Rutte have made several cuts in the healthcare sector [1]. Disadvantageous consequences of the cutbacks are staff and resource shortages. Hospital management must ensure that the hospital does not run a loss, but the staff has high standards and wants to keep the quality of care as high as possible. Improving quality while reducing costs is one of the biggest challenges that hospitals face today [1].

To cope with the challenges that are associated with the cutbacks, hospital staff has to work more efficiently and safely to keep the costs down and the quality high. In order to do this, a lot of research is being done into the use of technology in healthcare. The technology should facilitate hospital staff in their work to make the quality of patient care higher. In recent years, various technological solutions have already been applied in hospitals to improve efficiency and (patient) safety. A few examples are advanced technology for minimally invasive surgery, (digital) checklists in the OR and the use of virtual reality during training of surgeons.

When it comes to improving efficiency and (patient) safety in a hospital, one department is always interesting to look at: the operation department. The operation rooms (ORs) are one of the main sources of waste and cost in the hospital [2], [3]. Three of the reasons why are the use of expensive (disposable) equipment, the necessary sterility of equipment and the necessary amount of staff present.

The processes in the OR are very complex and dynamic. Many components are involved in order to make a surgery successful. These components are, for example, the patient, the surgeon, the anesthetist, supporting staff, surgical instruments and other equipment. Ideally, all of these components are ready and available in the right place at the right time. However, due to a variety of known and unknown reasons, many operation departments encounter challenges with coordination of resources. Eventually, this can result in additional costs, unsafe situations, inefficient activities and the loss of costly operating time.

This thesis focuses specifically on improving efficiency and safety around one OR component: reusable surgical instruments. The thesis describes a project in which the use of computer vision for the automation of instrument counts in and around the OR was investigated. These counts are currently performed manually by OR assistants. The project was carried out for and at the Reinier de Graaf Gasthuis (RdGG) hospital in the city of Delft.

Computer vision is a type of computer algorithm that tries to automate and take over tasks that humans normally do with their visual system. The algorithm can detect and recognize objects in digital input images.

1.1. Problem statement

Surgical instruments, both reusable and disposable, undergo a cyclic process through the hospital called the instrument cycle. The instrument cycle includes various sub-processes like sterilization, instrument tray assembly and utilization in the OR. These sub-processes are performed by either the OR staff of the RdGG or by CombiSter, which is the external Central Sterile Services Department (CSSD) of the RdGG. During the instrument cycle at the RdGG and CombiSter, various instrument related challenges and problems arise that can reduce the efficiency and (patient) safety.

Staff from the OR-complex at the RdGG experience various challenges around the preoperative, operative and postoperative instrument counts. For some types of surgery, the amount of different instruments used can be up to 200 [4]. Consequently, the counts can be very difficult and time-consuming processes. However, they are very important for efficiency and (patient) safety as they ensure that the surgery is not started until all required instruments are present, that no instruments go missing during the surgery and that every instrument is returned to CombiSter. Any absent instruments during the surgery could lead to unnecessary delays, instruments being left in the patient or too many door openings leading to an increased risk of surgical site infection.

Another point of interest from the OR staff at the RdGG is the unnecessary sterilization of some instruments. The content of each instrument net is determined by the operation team that is going to use the instruments. However, not every instrument in the net is used as frequently as others. Some instruments are almost never used. However, when the sterile wrapping of the instrument net is removed, all instruments inside are labeled 'non-sterile' and must be sterilized again, even the unused ones. Sterilizing unused instruments leads to unnecessary costs and an unnecessary reduction of the service life. The content of the instrument nets should be redefined looking at how often the individual tools are used.

1.2. Research question

In the last 20 years, a lot of research has been done on solving the mentioned problems and challenges involving surgical instruments in and around the OR. Track and trace technology is opposed as a possible solution. Various techniques are researched. Examples are Radio-Frequency Identification (RFID), scanning QR codes on the instrument surface, instrument weighing, computer vision algorithms or a combination of these techniques. However, until now, the researched technologies did not function properly in the OR and no functional instrument detection technique has been developed yet.

The biggest problem is performance of the technique in the OR. The technique is usually developed in a setting where conditions are made as ideally as possible without any knowledge about the real setting in which it has to perform: the OR. RFID, QR-code scanning and instrument weighing all show their own performance flaws when they were tested in the OR. Using computer vision has not yet reached the point of testing. The promise of using computer vision for the instrument counts in the OR is high, as various computer vision algorithms are already able to recognize a broad range of objects in input images.

However, while developing an algorithm for surgical instrument detection in the OR, it is important to first investigate the working methods and possible factors that can negatively influence the performance or the implementation of the algorithm in the OR. Otherwise, an algorithm will be developed with little knowledge about its working environment, just as with the development of the other detection techniques. Therefore, the following research question was formulated for this thesis:

> *" What is the feasibility of using a computer vision algorithm to automatically detect and count surgical instruments and what are potential factors that influence the performance and the implementation in the OR?"*

This thesis does not show test results that numerically assess the performance of a computer vision algorithm in the OR. This thesis does show the investigation of the various processes and activities during the instrument cycle at the RdGG and CombiSter. A description of the instrument cycle is used to find possible application options for computer vision in the instrument cycle. These application options, in turn, lead to design scenarios. Each design scenario is unique as it tests the use of computer vision for different applications and different rooms of the cycle. Eventually, the design scenario in the OR is elaborated further. The test procedures that can be used in the OR, can be used in the other design scenarios as well when the design requirements and wishes important for those specific scenarios are taken into account. The test procedures lead to observations in the OR and results from a staff survey. These results are used to form new design focus points, which should be taken into account when designing a computer vision algorithm to automate the instrument counts.

All together, this thesis shows 2 important things. Firstly, a blueprint (i.e. the test procedures) for future computer vision tests in the OR and other rooms involved in the instrument cycle. Secondly, a new set of design focus points is given that can improve the performance of a new algorithm in the future.

1.3. Thesis structure

This thesis has a converging structure. It starts very broadly in part I in which the situation at a general Dutch hospital is investigated. The general steps of an instrument cycle are outlined in chapter 2. Furthermore, in chapter 3, a short introduction is given about Scale-Invariant Feature Transform (SIFT) algorithms. This type of computer vision algorithm is used as a basis for the rest of the thesis while investigating the situation at the RdGG. The chapter also discusses why a SIFT algorithm would be a good first algorithm to look at for the investigated applications.

In part II, the specific situation at the RdGG is investigated. All steps of the instrument cycle at the RdGG and their external sterilization company CombiSter are outlined in detail in chapter 4. This detailed description results in various application options for the SIFT computer vision algorithm. Chapter 5 describes the general design requirements and wishes when using a SIFT algorithm for instrument recognition in the instrument cycle. Furthermore, the instruments pass different rooms during the instrument cycle. The different application- and room-specific design factors are discussed for 4 different design scenarios.

Part III describes the performed case study in the OR of the RdGG. The specific situation for 1 design scenario is described. Chapter 6 gives a short introduction about why the OR was chosen for the case study. In chapter 7, the test procedures for testing the performance of a SIFT algorithm in the OR is given. Chapter 8 and 9 respectively discuss the results from observations made in the OR and the results from the conducted staff survey. No numerical results about the performance of a current SIFT algorithm are given.

Part IV contains the discussion and the conclusion. Chapter 10 discusses the results from part III. This includes new design focus points that should be used during the future development of a computer vision algorithm for the automatic counting of instruments in the OR. Finally, chapter 11 gives the answer to the research question of this thesis.

I

Part 1 – Theory

2
The instrument cycle

To start looking at the instrument cycle, also called the surgical instrument life cycle, this chapter gives the most generic overview of the cycle. The sequence and purpose of each step in this generic cycle are generally the same for each hospital, as the steps and the hospital itself are bound to law and regulations. However, within the steps, there are major differences in the execution. This chapter only discusses the sequence and purpose of the main steps.

In section 2.1, the different types of surgical instruments will be discussed. Different types go through different parts of the instrument cycle. Section 2.2 describes the main steps that the different instrument types go through.

2.1. Different types of surgical instruments

Different types of equipment are used during surgery. This thesis only looks at surgical instruments. Surgical instruments go through a cyclic process called the instrument cycle. However, not all types of surgical instruments go through all steps of the instrument cycle. This section describes the different types of surgical instruments.

Regarding the instrument cycle, there are two types of surgical instruments:

1. Single-use, disposable instruments
2. Reusable, non-disposable instruments

Disposable instruments are surgical instruments that can only be used for one patient or one surgery. These instruments cannot be reused and are disposed after the first use. Disposable instruments are packed either individually or in small sets. Examples of disposable instruments range from simple plastic gloves, face masks, drapes and sponges to the more complex needles, scalpel blades, scissors and mono-/bipolar electrical forceps. Disposables are usually used to complete the total equipment set for surgery, or to quickly replace a contaminated, missing or broken instrument during surgery.

The Food & Drug Adminstration defines reusable, non-disposable instruments as follows: "devices that health care providers can reprocess and reuse on multiple patients" (Food & Drug Administration, 2018). Reprocessing instruments includes activities like (hand) cleaning, disinfecting and sterilization in order to get the instrument ready for reuse. This is done by an internal or external Central Sterile Services Department (CSSD). Reusable instruments can be grouped in three subgroups according to the extent of which the instruments have to be cleaned [5],[6]:

- non-critical instruments, which come into contact with intact skin;
- semi-critical instruments, which come into contact with mucous membranes;
- critical instruments, which come into contact with non-intact skin, blood or sterile body parts.

Non-critical instruments usually do not have to go to the CSSD. Examples are stethoscopes, crutches, wheelchairs or blood pressure cuffs. Simple disinfection using disinfectant wipes, gel or spray is enough. This process is called Low-Level Disinfection (LLD) [7], [8]. Non-critical reusable instruments will not be discussed further.

Semi-critical and critical instruments require reprocessing by the CSSD before reuse. These instruments have to undergo multiple cycles of reprocessing during their service life and are therefore made from robust materials. Semi-critical instruments undergo High-Level Disinfection (HLD) and critical instruments undergo complete sterilization [7], [8]. Materials of (semi-)critical instruments have to withstand disinfection/sterilization processes using high temperatures and chemicals.

There are different reasons for hospitals to choose either a disposable or a reusable instrument. The first reason is the outcome of a cost-benefit analysis. Disposable instruments only have the one-time cost of purchase. Reusable instruments have the recurring cost of sterilization as well. However, disposable instruments are environmentally unfriendly as they create a lot of waste. The results of a cost-benefit analysis determines the type that will be used at the concerned hospital. The outcomes varies per hospital. The second reason is the possibility to sterilize an instrument. Some instruments cannot be made reusable as they cannot be reprocessed. This can be due to either the construction or the material of the instrument.

2.2. General instrument cycle

The instrument cycle can differ a lot between hospitals. It is, however, possible to recognize some general, main steps. This section describes these steps together with their purpose. The main steps can be seen in the diagram in figure 2.1.

After utilization in the OR, critical reusable instruments go through the entire instrument cycle. Hospitals either buy or get granted a lease on new reusable instruments. Figure 2.1 shows that these new and non-sterile instruments enter the instrument cycle at the cleaning and disinfecting phase. When an instrument is broken or at the end of its life cycle, it will be disposed in the care and maintenance phase.

Figure 2.1 shows that disposable instrument enter the instrument cycle sterile at the sterile supply phase and leave at the disposal phase. These disposable instruments are purchased from an external manufacturer and stored before being used in the OR. New reusable instruments usually enter the cycle at the CSSD during the cleaning & disinfection phase and leave at the care & maintenance phase.

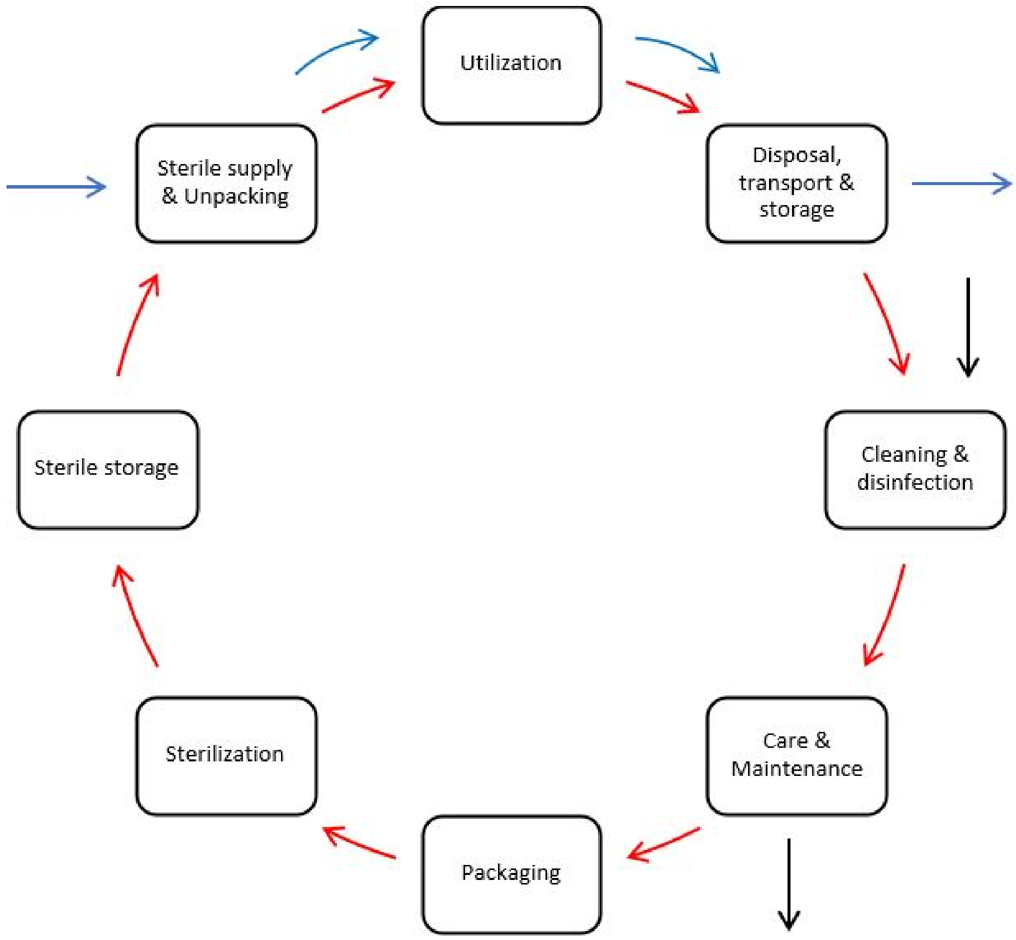


Figure 2.1: The steps of the general instrument cycle are shown. The blue arrows show the path of disposable instruments. The red arrows show the path of reusable instruments. The 2 black arrows show where reusable instruments enter and leave the cycle.

Utilization – The instrument nets are unpacked and the instrument tables are prepared for surgery. The equipment includes both reusable and disposable instruments. During this phase, the instruments are used for their intended purpose. This purpose can for example be grasping, clamping, occluding, retracting, cutting, holding, etc. Usually, not all prepared instruments are used. However, every instrument is marked as 'contaminated' which means reprocessing for reusable instruments and disposal for disposable instruments.

Disposal, transport and storage – After surgery, all instruments are collected on the instrument table. Disposables are thrown away and reusable instruments are put back in the nets. Consequently, disposables and reusable instruments are split again. The waste from the disposables and the reusable instruments are transported out of the OR. The waste is thrown in several different waste containers for the necessary waste separation. The nets with the dirty reusable instruments are transported to the CSSD. At the CSSD, the nets are sometimes stored before they are cleaned. Storage time should be as short as possible because the body fluids and other debris on the instrument will harden or dry over time [9], [10]. This process makes the cleaning process significantly more difficult and can damage the material of the instrument.

Cleaning and disinfection – Only reusable - both semi-critical and critical - instruments are included in this step. This is also the step where new reusable instruments enter the cycle. The first part of reprocessing reusable instruments is cleaning and disinfecting. This step partly begins in the OR but is mostly done by CSSD staff. During surgery, a surgical sponge with a sodium chloride (NaCl) solution is continuously used to roughly clean the instruments periodically. The purpose of cleaning is to remove as much contaminating material from the instrument as possible. Body fluids like blood or pus reduce the effect of disinfectants [9], [10].

The cleaning and disinfection parts at the CSSD can be done either by hand or by a machine. When it is done by hand, contaminated instruments are first placed in a bath with detergents. Hinged instruments have to be placed open and composite instruments have to be disassembled first. In this bath, some contaminating material dissolves. Thereafter, the instruments are dried and placed in another bath. This bath contains disinfectants that include, for example, chlorine compounds, phenols, alcohols, etc [10]. Furthermore, in this bath, the instruments are (manually) brushed. Afterwards, the instruments are washed with pressurised distilled water. An optional last cleaning step is an ultrasonic cleaning bath [10]. This bath is used for tough stains and complex instruments with tight cavities and crevices. After the ultrasonic bath, the instruments have to be washed with distilled water to remove all the chemicals. Then, they are dried with pressurised air.

Cleaning and disinfecting can also be done using a machine called the Washer Disinfector (WD) [10]. Instruments nets are placed into the WD and are both cleaned, disinfected and dried. Using the WD is usually preferred to hand cleaning because it is more effective and time-efficient.

Note that the described process is not the same as sterilization. In section 2.1, the distinction between semi-critical and critical instruments was made because of the different body fluids they come into contact with. Semi-critical instruments only need high-level disinfection (HLD) and can therefore skip the sterilization part. Critical instruments do need sterilization because HLD does not remove all the important infectious agents on critical instruments [7], [9].

Table 2.1, which is based on an image from the paper [7], shows for various infectious agents the susceptibility or resistance to various infectious agents. It shows that HLD does remove almost all infectious agents, except for bacterial spores and prions. Sterilization also removes the bacterial spores. No method from the sterilization department can remove prions. Prions may end up on an instrument when it has come into contact with a patient who has Creutzfeldt-Jakob Disease (CJD). When there is a suspicion or confirmation of CJD, the used instruments are usually disposed directly [7], [9].

Infectious microorganisms	Sterilization/disinfection method
Prions	–
Bacterial spores	Sterilization
Coccidia	Chemical sterilant
Mycobacteria	HLD
Non-enveloped viruses	ILD
Fungi	LLD
Vegatative bacteria	LLD
Lipid enveloped viruses	LLD

Table 2.1: This table shows which sterilization / disinfection kills certain infections microorganisms. Every sterilization/disinfection method can kill the microorganisms on the left and those below. No method can kill the resistant prions [7].

Care and maintenance – The instruments are cleaned, disinfected and dried, and are now visually inspected by CSSD staff. The purpose is to check whether the instruments are clean and ready for surgery [10]. Hinges must turn smoothly, cutting edges have to be sharp and there should be no (micro-)cracks on the instrument surface. Care and maintenance is important to reduce the possibility of breakage or malfunction of an instrument in the OR.

Furthermore, the hinges are lubricated with special lubricant. It is important that this is done before the sterilization process. Lubricating the hinges improves the functioning of the instruments.

Packaging – Sets are made of all kinds of reusable instruments. Different types of surgery require different sets of instruments. Together with the surgeons of a hospital, agreements are made about the content of these instrument sets. These agreements can change regularly over time. The content differs from a single instrument to around 100 instruments. CSSD staff is responsible for ensuring that the content of every instrument set is complete.

The net is wrapped in sterile cloths together with its content. These cloths are usually white on one side and light blue on the other. Sometimes, small sets of instruments that belong together are packed separately in sterilization bags. These bags are placed inside the instrument net. After wrapping the net, the light blue side is facing the outside. This is the non-sterile side. Non-sterile staff should only touch the light blue part of the cloth when unwrapping the net. Otherwise, the net and its content become non-sterile and have to be reprocessed again. The material of the packaging is compatible to the sterilization process of the next step [10].

After packaging, the package should be labeled. This label contains data about the date of sterilization, the staff member who packed it, the sterilization expiration date and the content of the net.

Sterilization – During this process, the last bacterial spores on the instruments are removed. Afterwards, the reprocessing process is completed and the instruments are ready for surgery.

There are different sterilization techniques. The choice depends on the content of the packed instrument net and the packaging material. Examples of sterilization techniques are steam sterilization, hot air sterilization, gas sterilization, (gas) plasma sterilization and liquid sterilization [8], [10], [11].

Steam sterilization uses saturated pressurised steam at a temperature of 134°C [10]. The process of steam sterilization starts by removing the air inside a pressure chamber to increase the pressure inside. Thereafter, the instrument net is heated and steam enters the pressure chamber. Finally, the steam is removed and the pressure inside the chamber is decreased.

Hot air sterilization is one of the oldest sterilization methods. Hot air, usually of around 180°C, is blown into an enclosed space containing the instrument net [10]. This air heats the outside of the instruments using convection. Through conduction, the entire instrument will heat up. When the instrument has reached a certain temperature throughout, sterilization is complete.

Sterilization at low temperatures, like gas sterilization, uses chemically active substances that usually operate at temperatures between 37 and 75°C [10]. This method is mostly used when the instruments cannot stand the high temperatures. For these types of sterilization, it is very important to know possible negative effects of the chemicals on the instruments. The used gasses cause a chemical reaction in the bacterial cells which kills them.

Liquid sterilization is used in heat-sensitive situations as well. The process includes immersing the instruments in a bath with a chemically active sterilant that kills the infectious microorganisms [8], [11].

Sterile storage – When the instrument nets are completely reprocessed, they will be stored until ordered by the OR department. It is important that the package material remains intact during storage. This material ensures the sterility of the instruments. Moreover, it is important that the storage location is dust-free, dry and has limited temperature fluctuations to prevent condensation en therefore corrosion [10]. Finally, the instruments should not be stored together with chemicals as these can damage the instruments on contact. When all the necessary conditions are met, the instruments can be stored for up to 6 months.

Sterile supply and unpacking – The instrument trays are brought from the CSSD to the OR complex by sterile supply. According to OR schedule, instrument nets are ordered and delivered to the OR-complex. During this delivery, it is important that the packaging stays intact and the conditions in the delivery tray stay as ideal as possible. After arrival at the OR-complex, the instrument nets are temporarily stored. When a net is needed for surgery, it will be taken out of storage and unpacked on the instrument table. This is done right before surgery in order to keep the time between unpacking and usage as short as possible. When instrument nets are unpacked and the instrument table is ready for surgery, the table is driven into the OR and surgery begins. This concludes the general instrument cycle.

3

Scale-invariant feature transform algorithm

In this project, the use of a computer vision algorithm in the instrument cycle is researched. There are many types of computer vision algorithms. For the application during the instrument counts, a Scale-Invariant Feature Transform (SIFT) algorithm is proposed. This chapter first explains what computer vision is and which class a SIFT algorithm is (section 3.1). Secondly, it is explained why a SIFT algorithm was chosen and which characteristics of the SIFT algorithm are important for the intended application.

3.1. Computer Vision

Computer vision is a branch of computer science that deals with issues of how computers can automate actions normally performed by the human visual system [12]. This means that the computer is trained to understand and "perceive" what is in a graphic input (i.e. an image or video). This is an easy task for humans, even when an image is blurred or when it contains overlapping objects. It is, however, a difficult task for computers as the physical world is constantly changing. No photo or video is exactly the same. There are many variables which makes it difficult for a computer vision algorithm to understand what is in the image or video [12].

The field of computer vision is multidisciplinary. It can be seen as a combined subfield of artificial intelligence and machine learning [12]. Within this subfield there are many subdomains which arise due to specific applications of computer vision and due to the information you want about an image or video. A few examples of subdomains are image classification, object recognition, motion analysis, scene reconstruction and image restoration.

The subdomain of computer vision that is especially interesting for this project, is object recognition. In object recognition, the algorithm can have various tasks, for example classifying, localizing and sometimes segmenting every object in an image [12]. The complexity of the algorithm's output ranges from simple classification of the object(s) without localization to a detailed description that couples every pixel to a class. Figure 3.1 shows a figure from the paper of Liu et al. (2020) [13]. This figure shows the range of complexity of object recognition problems. For the purpose of this project, a generic object detection algorithm is enough. This algorithm should classify every object in the image (i.e., every surgical instrument) and locate them in the image. This localization is done using a so called bounding box (see figure 3.1), which is described by 5 variables: a position (x- and y-coordinate), an orientation, a width of the bounding box and a height of the bounding box.

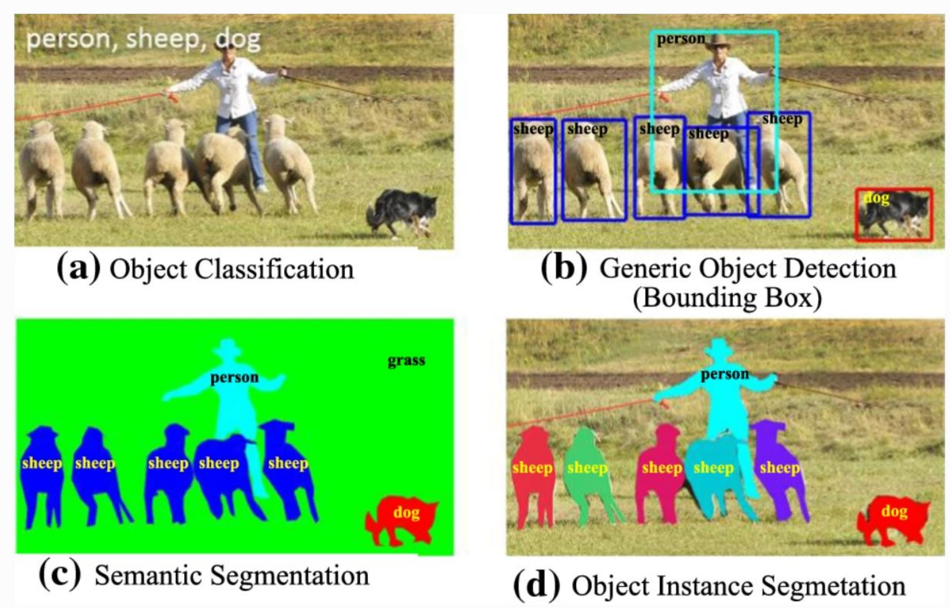


Figure 3.1: 4 types of object recognition are shown [13]. They increase in the level of detail of the output. Subfigure (a) shows object classification in which objects in the image are classified without localization. Subfigure (b) shows generic object detection in which bounding boxes are added to achieve generic localization. Subfigure (c) shows semantic segmentation in which every pixel is classified, but it makes no distinction between objects from the same class. Subfigure (d) shows object instance segmentation in which only the pixels from objects are classified. The 'gras' is not classified. Furthermore, a distinction is made between objects from the same class by using different colours.

3.2. SIFT algorithm and its general steps

There are various types of computer vision algorithms in the domain of generic object detection. A broad classification is whether the algorithm uses an artificial neural network or not. When it does use one, the algorithm does not have to define features before classification. Non-neural algorithms do have to do this.

The algorithm used in this project is a non-neural, feature-based algorithm called Scale-Invariant Feature Transform (SIFT). Feature-based means that the classification of the objects in the image is done using features extracted from the analyzed image. These features describe the object(s) in that image. The extracted features of each object are compared with a database of extracted features from test images. When there is a good enough match between the extracted and the predefined package of features that is good enough, classification is completed.

SIFT algorithms are unique because the features they extract from the image are, as the name implies, scale and orientation invariant. This is caused by the way the feature is defined. A feature is a keypoint linked to a keypoint vector. A keypoint is a maximum or minimum pixel intensity point in the analyzed image. This intensity point is scale-invariant as it is found by using different scales of the same image [14]. The keypoint vector is a description of the contrast between pixels around the keypoint. The direction in which the pixel intensity contrast is the highest becomes the orientation of the keypoint. The rest of the descriptive vector is coupled to this orientation. Therefore, the SIFT feature is orientation invariant [14]. Furthermore, the features are partially invariant to illumination and camera viewpoint [14].

Because of these special characteristics, SIFT algorithms are mostly used in problems involving images in which the objects appear in different scales, orientations and illuminations. This is expected to be the case in the images of the surgical instruments on the instrument table in the OR.

3.3. Important characteristics

For the purpose of object recognition, various neural and non-neural based algorithms can be used. This project focuses on testing an object recognition algorithm in the surgical instrument cycle for instrument recognition. The chosen algorithm is SIFT. This section shows why this type was chosen by describing which characteristics of SIFT are important for analyzing the images of the instrument table and recognizing the instruments in these images.

SIFT is invariant to a lot of variable factors that can complicate the recognition of surgical instruments. The major advantages of using SIFT are listed below using [14] and [15]:

- *Scale- and orientation-invariant* – Firstly, the camera that takes the images of the instrument table can be placed at different distances. This variability results in different scales of the same instrument in different images. Secondly, orientation of the instruments on the table changes constantly and the orientation is almost never the same as on the test images. As SIFT features are scale- and orientation-invariant, the algorithm is able to deal the described variability in scales and orientations of the instruments in the images.

- *Partly invariant changes in camera viewpoint and varying illumination* – Due to contamination issues, it might be impossible to take the images right above the table. They are taken under an angle to the vertical axis. This completely changes the way the instruments will look in a 2D image. Moreover, the different rooms involved in the instrument cycle, especially the OR, have different types of lamps. Sometimes only the ceiling lights in the OR are on, sometimes the bright operation lamps are on as well and sometimes most of the lights are off. The algorithm needs to be able to recognize the instruments under all these different light conditions. SIFT algorithms are partially invariant to viewpoint and illumination changes. Therefore, slight changes will not affect the performance of SIFT algorithms.

- *Robust and local features* – During the instrument cycle, it can happen that instruments overlap each other or that the disposables cover some instruments. As a result, parts of instruments are not visible. However, SIFT features are so robust that sometimes a single feature from a small recognizable part in the image can lead to object recognition. This could help solve the problem of partly visible instruments.

- *Distinctive features* – When there are a lot of possible instruments on the table, there are also a lot of features from test images in the database to choose from. However, the different features in the database are very distinct due to the large descriptive keypoint vectors. Consequently, it is often possible to find a single, distinct match between extracted feature and a feature in the database.
- *Quick* – In order to be more efficient than current staff, time is of importance. Therefore, the algorithm needs to be quicker than humans. Furthermore, at different stages in the instrument cycle, direct (i.e. almost live) feedback could be favoured. SIFT is able to analyze images quickly as the amount of computations in the algorithm is low.
- *Effective for small objects* – Some surgical instruments look very much alike and only have very small differences. Some surgical instruments are already very small and some appear very small in the image. Consequently, it is difficult to recognize them. For these instruments too, SIFT algorithms are able to generate many distinctive features.

II

Part 2 – Surgical instrument detection at the Reinier de Graaf Gasthuis

4 Instrument cycle at the Reinier de Graaf Gasthuis

The instrument cycle, as described in chapter 2, is applicable to most Dutch hospitals. However, between hospitals there are also important differences that change activities within the phases of the instrument cycle. Therefore, it is important to investigate the instrument cycle of the corresponding hospital in detail before designing an instrument detection technology for that specific hospital. The description in this chapter concerns the Reinier de Graaf Gasthuis (RdGG) in the city of Delft. This description gives insight into where and when the technology can be used most effectively at the RdGG. The moments that are most suitable for the RdGG are not necessarily also suitable for another hospital.

The RdGG does not sterilize its own instruments. An external sister company called CombiSter takes on this task. The instruments are delivered to order by truck between CombiSter and the hospital. CombiSter was not visited during the project. Therefore, there is no detailed description of the sterilization activities at CombiSter. These activities will be described as detailed as possible using the available (online) sources.

The chapter starts with an overview of the information sources that were used during the preparation of the cycle overview in section 4.1. Then, in section 4.2, a detailed description of the instrument cycle at the RdGG follows. The subsections each deal with a phase of the cycle. Finally, in section 4.3, application options for instrument detection technology in the RdGG are addressed. These options follow from the description in section 4.2 and from questions directly from OR staff.

4.1. Information gathering

In order to establish the detailed overview in section 4.2, various types of information sources were used. The two sources that are used the most are results from a literature study and observations in the OR-complex.

Before the start of the project, an extensive literature study was conducted. Results of this study are used in chapter 2 as well. The general steps described in that chapter are used as a starting point in this chapter. Those general steps are further described in detail for the RdGG and some (sub)steps are added to comply more with the specific situation at the RdGG.

During the project, the various spaces that appear in the instrument cycle were visited. These include the delivery room, the storage room, the deck space, the OR and the 'dirty'/waste space. The instruments are, as it were, 'followed' through these rooms and observations were written down. These observations include, among others, remarks about environmental factors of the different rooms, the various activities that take place in these rooms and the staff members that execute these activities. A total of 35 surgeries were attended.

4.2. Outlining the instrument cycle phases

This section addresses the different instrument cycle phases at the RdGG in detail. All the activities are described in chronological order, starting at the ordering phase in the RdGG. Each subsection is a cycle phase and addresses, if applicable, the activities for reusable instruments and disposables separately. Furthermore, for most activities a mention is made of the persons that are involved in each activity.

Figure 4.1 shows an oversight of all the phases in the instrument cycle from the RdGG. This figure shows the participation of each instrument type in each phase as well. The disposables enter the cycle at the ordering phase and leave at the disposal phase. During most of these steps, the disposables are still separated from the reusable instruments. However, only during the preparation and utilization phases, the disposables are mixed with the reusable instruments. Reusable instruments are both ordered and disposed by CombiSter, representing the black arrows in figure 4.1.

4.2.1. Ordering

In the ordering phase, OR staff from the RdGG orders instrument nets and disposables at respectively CombiSter and various instrument manufacturers.

Reusable instruments

- OR staff that is responsible for ordering instruments looks at the schedule of the OR-complex on a daily basis. This schedule shows the confirmed schedulable surgeries for approximately the next 3 days. These do not include the emergency surgeries. The schedule is very susceptible to change. Therefore, only instrument nets needed for the scheduled surgeries of the next day are ordered. Specific instrument nets are used for specific surgeries. These nets are ordered together with some other nets that are kept in storage for emergency situations. The total order list is sent to CombiSter.

- CombiSter offers a special service for emergency situations. During surgery, it can happen that an instrument is missing, broken or inoperable and it needs to be replaced. Furthermore, sometimes an emergency surgery is required. Usually, these instruments are taken from the emergency storage in the OR-complex. However, it is possible that the required instrument is not in stock. For those situations, CombiSter can be in the OR-complex within 20 minutes with the requested instruments despite being an external company. This rush order is made by the OR staff that is responsible for ordering instruments.

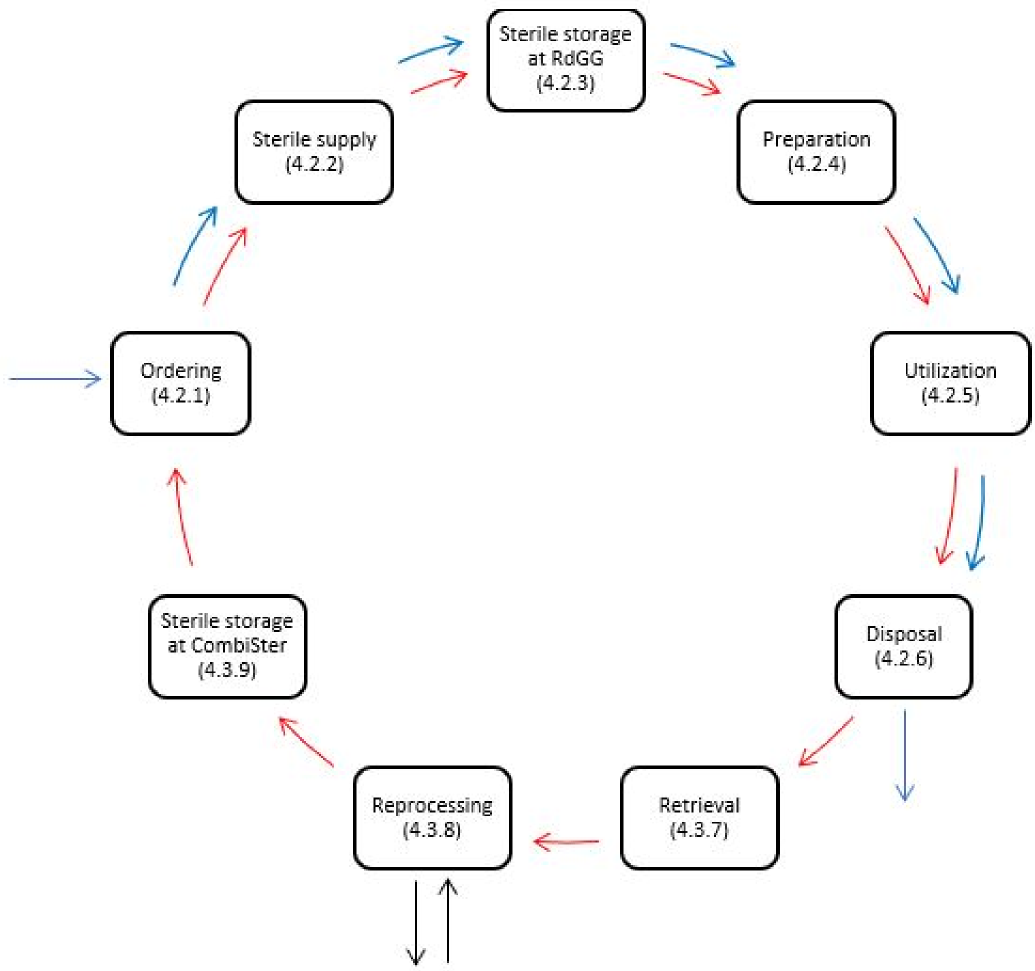


Figure 4.1: The more detailed steps of the instrument cycle at the RdGG are shown together with the corresponding subsections in which they are discussed. The blue arrows show the path of disposable instruments. The red arrows show the path of reusable instruments. The 2 black arrows show where reusable instruments enter and leave the cycle.

Disposables

- The stock of disposable instruments is checked daily. A list has been made of all the different disposables, indicating how many of each disposable should be in stock. A wide safety margin is used as the chance that the stock will be exhausted should be close to nil. Staff responsible for ordering instruments orders new disposables according to stock shortages. When a specific disposable has a shortage in stock, a card is placed on the door of the cupboard where the ordered disposable is stored. This card indicates that the disposable should be ordered.

- An OR staff member walks past all the storage cupboards and makes an order list. The order is placed with various manufacturers of medical instruments. This usually happens on a daily basis, but especially on Sunday through Thursday.

4.2.2. Sterile supply

After the surgical equipment is ordered, it is transported to the RdGG. This transportation has to be completely sterile. Both the instrument nets and the disposables are sterile packed and this package must not be damaged in any way.

Reusable instruments

- Instrument nets are wrapped up in a sterile cloth. During the transportation of the nets between CombiSter and the RdGG, the nets are placed in transportation carts. Multiple times a day, between 05:00 AM and 12:00 midnight, transport trucs from CombiSter bring these carts to the RdGG. For some delivery times, there is a deadline for the submission of orders. This deadline is usually around 30 to 45 minutes before delivery at the RdGG. Table 4.1 shows the delivery times. The delivery times differ between weekdays and Saturday. CombiSter does not deliver on Sundays. There are almost no deliveries during weekends as no surgeries are planned on these days. However, emergency surgeries can take place. During weekdays, the first delivery each day is usually the biggest as it includes all the ordered instrument nets for the scheduled surgeries on that day.

Delivery times of CombiSter	
Weekdays	Saturday
5:00	10:00
8:15	14:00
10:00	17:00
13:15	
15:30	
16:30 (only on Friday)	
18:00 (only on Monday-Thursday)	
19:00	
21:45	
00:00	

Table 4.1: Delivery times of CombiSter during weekdays and Saturday. This table is based on a schedule that was hung at the OR-complex.

Disposables

- Disposables are packed sterile and separately. The disposables are delivered at the delivery room on the ground floor of the hospital. The packages are collected and brought to the OR. Delivery times can vary greatly on a daily basis.

4.2.3. Sterile storage at Reinier de Graaf Gasthuis

Between delivery and use of the instruments, they are stored at the OR-complex. The instrument nets and the disposables are stored at a different location. There are rules for the storage conditions, in particular for the storage of the reusable nets. The storage room for reusable nets should be dry and dust-free. Furthermore, only very limited temperature fluctuations are allowed to prevent condensation on the instruments.

Reusable instruments

- When the carts containing the instrument nets enter the OR-complex, a few things are checked first. For example, whether the net is also the ordered net, whether the sterile packaging is still intact, whether the sterilization expiration date has not passed, etc. This is done by the OR staff member that puts the instrument nets in the storage room.
- The instrument nets are moved to the storage room by an OR staff member. Records are kept of which instrument nets are stored.
- At the start of the day, all the instrument nets that will be used for the scheduled surgeries are brought to the deck space and placed in carts per OR. Figure 4.2 shows a deck space at the RdGG with these carts. The same carts are used in the other deck space.

Figure 4.2: The deck space used for ORs 1 through 4. In the back corners of the room, seen from the camera's point of view, are 2 carts containing the instrument nets used in the associated OR that day. A third cart can be seen on the right hand side of the figure. They can also be recognized by the light blue packages that are inside, which are the sterile wrapped instrument nets.

Disposables

- The delivered disposables are brought to the OR-complex. The delivery list and the sterilization expiration date are checked and the inventory list is updated by the OR staff member that received the disposables from the delivery room.
- The disposables are put in the correct storage cupboards in the hallway between the deck spaces using the content lists on the cupboard doors. The disposables are grouped by function in each cupboard. The storage hallway is shown in figure 4.3.

Figure 4.3: This is the hallway between the two deck spaces. On the left hand side you see the cupboards in which the disposables are stored. On every cupboard door there is a list with the content of that cupboard.

4.2.4. Preparation

Carts with the instrument nets stand in the deck space and disposables lie in the storage cupboards. In this phase the instrument table is prepared for surgery in the deck space and the reusable and disposable instruments get mixed. However, the activities around both types are still different.

In order to prepare the instrument table in a sterile manner, there is a 'sterile zone' in the deck space. This zone is marked by a blue rectangle on the floor in the deck space (see figure 4.2). In this zone there is a vertical airflow to blow away contaminating air from the equipment in the zone. This zone should only be entered with proper precautions. A staff member should wear sterile clothing and gloves before entering the sterile zone and touching the sterile equipment. The activities during this phase must be done very carefully to avoid contamination of any equipment.

During the activities in this phase, 2 OR staff members are involved: someone that works in the deck space and the OR assistant who prepares the table. The OR assistant puts on the sterile clothing and works in the sterile zone. He or she is also the staff member that helps the surgeon during surgery. The other staff member stays outside the sterile zone and will be called the 'non-sterile staff member'. An example of sterile clothing can be seen in figure 4.4.

Figure 4.4: Two types of clothing in the OR-complex are shown. The person on the right hand side wears regular scrubs and hair covering. She is not allowed to enter the sterile zone. The OR assistant on the left has taken extra precautions as she will enter the sterile zone in the deck space and the OR. She is wearing the appropriate sterile clothing and gloves [16].

Reusable instruments

- The correct instrument nets for the next surgery are taken out of the carts in the deck space. The blue wrapping of the net is removed by the non-sterile staff member by only touching the outside (i.e. the blue side). This is the non-sterile part of the wrapping. The sterile part should only be touched by the OR assistant. Otherwise, the instrument net is declared contaminated and sent back to CombiSter.

- The non-sterile staff member hands over the instrument net to the OR assistant in the sterile zone. The non-sterile staff member only touches the non-sterile part of the wrapping when holding and handing over the instrument net.

- The content of the net is usually very cluttered due to the transport to the RdGG. The OR assistant organizes the content and checks whether all instruments are present. This is called the preoperative count. It is useful to find out if any instruments are missing while the surgery has not started yet, because there is still time to replace the missing instruments without costly delays.

- Some instruments are delivered in parts and need to be assembled. Examples are some trocars and laparoscopic instruments. They were disassembled for proper disinfection and sterilization.

- The sterile staff member unpacks the instrument net. The instrument table is covered with a sterile cloth. On this cloth, a few instruments are laid out. These instruments are used most frequently during the upcoming type of surgery. Usually, they include extractors, retractors, needle holders, forceps, trocars, scissors and scalpels. There is a standard set of instruments that is laid out by every OR assistant. However, there is also some variability caused by a certain preference from the surgeon or the OR assistant. The rest of the instruments stay in the instrument net which is placed on the instrument table as well.

  During surgery, either one or two instrument tables are used. When one table is used, both the instrument nets and the laid out instruments are on the same table. When two tables are used, there is a 'storage table' and a 'usage table'. The laid out instruments are on the usage table and the instrument nets with the remaining content are on the storage table. Both tables contain a mix of reusable and disposable instruments.

- Before surgery starts, the staff member that prepares the patient comes to the deck space and takes a Tohoku towel clamp together with a surgical sponge. This is used to clean the surgical site to reduce the possibility of surgical site infections. This staff member is non-sterile. Therefore, the towel clamp becomes non-sterile as well. Consequently, it is not returned to the instrument net until the end of surgery.

Disposables

- Disposables are taken out of the storage cupboards by a non-sterile staff member. Different types of surgery require different disposables. They range from a bone cement mixing kit for total hip replacement surgery, to heart catheters for cardiac catheterization, to Kirschner wires for orthopedic surgery.

- The non-sterile staff member hands over the disposable to the OR assistant in the sterile zone. The disposables have a sterile packaging. The non-sterile staff members must only touch the outside of the packaging and the OR assistant must only touch the sterile content. Opening the packaging is done in a special manner to maintain sterility. This is shown in figure 4.5.

- Some disposables are packed disassembled. Before use, they are assembled by the OR-assistant. Furthermore, some disposables form a complete instrument together with a reusable part. For example, a surgical blade and the scalpel handle form the scalpel. They are attached by the OR assistant.

- Sometimes the disposable has a second packaging. This packaging can be opened by the OR assistant herself as it is sterile on the outside as well.

- Surgical sponges, sharp objects (e.g. surgical blades and suture needles) and other equipment that is lost easily are counted before the start of surgery by the OR assistant and another staff member. The counted numbers are written on a white board in the OR and entered in a computer.

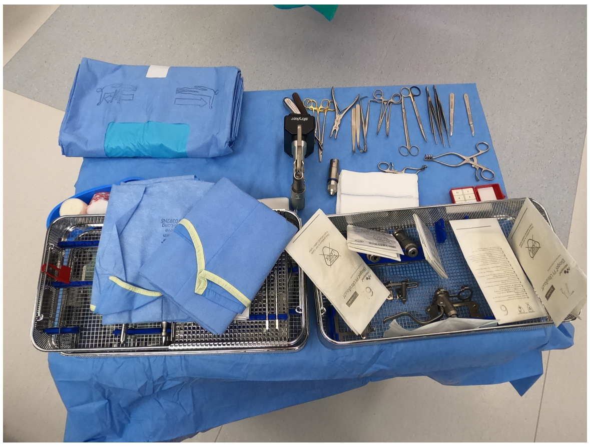
(a) The non-sterile staff member uses the outside (i.e. non-sterile part) of the packaging to hold the content and hand them over to the OR assistant.

(b) The non-sterile staff member holds both the front and the back side of the wrapping. She moves her hands away from each other and the sterile content of the packaging is grabbed by the OR assistant.

Figure 4.5: This figure has two subfigures in which a non-sterile staff member and an OR assistant demonstrate opening a sterile packaging [16].

4.2.5. Utilization

This phase covers the surgery itself. The prepared instrument table is driven into the OR. At the start of this phase, the instrument table looks like the ones in figure 4.6. This figure shows the situation for 1 instrument table (subfigure 4.6a) and for 2 instrument tables (subfigure 4.6b) before orthopedic surgery.



(a) This image shows the use of 1 instrument table just before orthopedic surgery. On the top right corner you see the instruments laid out. On the bottom you see the two instrument nets that are used. Disposables are scattered across the table and on top of the instrument nets.

(b) This image shows the use of 2 instrument tables just before orthopedic surgery. The right table is the 'usage table' and the left table is the 'storage table'. Reusable instruments and a few disposables are laid on the usage table. The instrument nets and some other disposables are on the storage table.

Figure 4.6: This figure has two subfigures in which images are shown of instrument tables just before they are driven into the OR.

The OR has a sterile zone as well. The operation table is in the middle of this zone as shown in figure 4.7. The surgeons and the OR-assistant stand closest to the patient. They are dressed in sterile clothing so they are allowed in the sterile zone. Other staff walks around the sterile zone and hands over equipment to the OR assistant. They are not allowed to touch or hang above the instrument table(s). The surgeons and the OR assistant are the only staff that operate the instruments during surgery.

Figure 4.7: This is an OR in the RdGG. The blue rectangle on the floor marks the sterile zone. The operation table stands in the middle of this zone. When properly dressed, you may enter this zone. Other staff walks around this zone control or hand over other equipment [17].

Reusable instruments

- During surgery, the instruments are constantly taken from and put back on the instrument table. This is especially true for the instruments that were laid out and expected to be used frequently. Sometimes the instruments are not directly put back on the instrument table after use. Actually, they are put on the sterile cloth that covers the patient. Consequently, the surgeons have easier access to these instruments.

- Dirty instruments with, for example, stains from body fluids are cleaned regularly by surgical sponges soaked with sodium chloride solution.

- When an instrument breaks during surgery, the instrument is depreciated. It is taken away from the instrument table and CombiSter is noted about the incident. If it was a necessary instrument, a staff member is sent to the storage room to get a new one. At the end of surgery, the instrument is still returned to the net to be transported back to CombiSter.

- When an instrument falls on the ground, it cannot be used anymore. It is taken away from the instrument table and returned after surgery. If the instrument was a necessary instrument, a staff member is sent to the storage room to get a new one.

- During surgery, the OR assistant is responsible for returning all instruments that were given to the surgeon at the operation table. This is called the surgical or perioperative count. This is done to ensure that no instruments stay behind in the patient.

- Usually, when surgery has progressed to the point where some instruments are no longer needed, these instruments are already returned to the instrument net. For instance, only retractors, needle holders and tweezers are found on the table when the surgeon sutures the wound. Other instruments are already returned to the net.

- At the end of surgery, the wound is closed and all instruments are returned to the instrument net. Contaminated instruments, like the Tohoku towel clamp or fallen instruments, are returned as well. Assembled instruments are disassembled before they are returned. The instruments may now also be touched by non-sterile staff members.

Disposables

- Sterile cloths, clothing and gloves that are laid over on the table are used directly at the start of surgery. The cloths are used to cover the patient except for the surgical site. The clothing and gloves are used to properly dress the surgeons and the OR assistant.
- A few disposable blue cups are filled with various liquids like surgical site disinfectant or sodium chloride solution.
- The surgical sponges are used during surgery to remove for instance excess blood from the surgical site or other instruments.
- The rest of the disposables are used for their own intended purpose during surgery. Sometimes, the disposable is only taken out of its packaging just before use during surgery.
- Some disposables are given to the OR assistant during surgery. The non-sterile staff member hands over this disposable to the OR assistant in a sterile manner and the packaging is thrown away.
- Before the surgeon closes the wound, a final count is performed by the OR assistant together with another staff member. The same objects are counted as just before surgery: surgical sponges, sharp objects and other objects that are lost easily. When the numbers match the numbers on the white-board, the surgeon is given green light to close the wound.
- At the end of surgery, packaging material and the disposables themselves are thrown away in a garbage bag. The surgical cloths, clothing, gloves, etc. are thrown away as well. Sharp objects (e.g. needles, surgical blades and suture needles) are collected in a separate red or yellow 'needle box'.

4.2.6. Disposal

This phase marks the end of surgery. All reusable instruments have been counted and collected in the instrument nets, disposables are thrown away and the sharp objects are collected in the needle box. The instrument nets, the garbage bag(s) and the needle box are driven to the 'dirty'/waste room on the instrument table. Figure 4.8 shows what the instrument table looks like at this stage.

Figure 4.8: The 'Basis (1)' instrument net is shown after a Lichtenstein inguinal hernia surgery. The net is about to be put in the transportation carts from CombiSter in the 'dirty'/waste room.

Reusable instruments

- The instrument nets containing the reusable instruments are placed back in the delivery trays from CombiSter. All instrument nets from a certain part of the day are collected before they are transported back to CombiSter. The nets should be collected by CombiSter as soon as possible to prevent hardening and drying of biological material on the instruments.

Disposables

- The garbage bag and the needle box arrive at the 'dirty'/waste room (see figure 4.9. Garbage bags are thrown away in a big black container. Needle boxes are disposed in a special container. Figure 4.10 shows this container. Furthermore, there is a Pharmafilter TONTO. This is a grinder that drains specific waste and biodegradable materials through the hospital's drainage system to the Pharmafilter system in a separate building next to the hospital.

4.2.7. Retrieval

In this phase, CombiSter brings carts with dirty instrument nets back to their facility. At the fixed delivery times from CombiSter, they also pick up the dirty instruments. The disposable instruments are no longer in the cycle from here on.

On weekdays between 30 to 60 minutes after CombiSter delivered sterilized instrument nets, they leave with the used dirty instruments. On Saturdays they leave with the dirty instruments directly after delivery. On Sundays, CombiSter does not deliver nor retrieve instrument nets. However, if there is an emergency delivery, they take any present dirty nets back to their facility. Table 4.2 shows the departure times together with their corresponding delivery times.

Figure 4.9: This is the 'dirty'/waste room. On the left hand side you see the big black containers in which the garbage bags with disposable material is thrown. The instrument nets are placed in the metal cart in the back of the picture. On the right hand side you see the Pharmfilter TONTO and the blue needle box container.

Figure 4.10: This is the container for the red or yellow needle boxes. Furthermore, this container is meant for glass with medication residue and Kirschner wires.

Departure times of CombiSter with corresponding delivery times			
Weekdays		Saturday	
Delivery	Departure	Delivery	Departure
5:00	6:00	10:00	ASAP
8:15	9:00	14:00	ASAP
10:00	11:00	17:00	ASAP
13:15	13:45		
15:30	16:00		
16:30 (only on Friday)	Unk.		
18:00 (only on Monday-Thursday)	Unk.		
19:00	20:00		
21:45	22:30		
00:00	00:45		

Table 4.2: Departure times of CombiSter during weekdays and Saturday. This table is based on a schedule that was hung at the OR-complex.

4.2.8. Reprocessing

After arrival at CombiSter, reprocessing of the dirty instruments begins. Not much is known about the different reprocessing techniques used at CombiSter. However, their website offers some information about their three-stage sterilization process. These stages are addressed shortly [18]:

- *Cleaning and Disinfection* – Before the instruments are put in a Washer Disinfector (WD), they are precleaned. All instruments are opened and instruments with lumen are flushed thoroughly. When instruments are very dirty, they are sprayed clean using a shower head and laid in an ultrasonic bath. This ultransonic bath removes material from lumen, crevices, cavities and joints which are sometimes hard to reach. After the cleaning phase, the instruments are placed in the WD. Instruments with lumen, like laparoscopic instruments, are attached to the WD using small water hoses so the inside is cleaned as well. The WD disinfects the instruments using hot water.

- *Inspection and Assembly* – The instruments are maintained after disinfection. Furthermore, their functionality is tested and they are checked for micro-cracks. Instruments that were disassembled before disinfection are assembled and checked whether they are complete. Thereafter, the instrument nets can be assembled according to content lists. There are different content lists according to the different types of surgery at the RdGG. Some instruments are put separately in the net, others are bundled in smaller sterile bags first. After assembly, the content is checked first for completeness. Afterwards, the instrument nets are wrapped using a sterile cloth. Finally, each net is given a label containing information about the content, assembly date and sterilization expiration date.

- *Sterilization* – CombiSter sterilizes its instruments using 134°C steam. This process kills all the necessary contaminating microorganisms. This stage takes around 2 hours and completes the sterilization process at CombiSter.

4.2.9. Sterile storage at CombiSter

As steam sterilization on its own already takes about 2 hours, CombiSter needs to have instrument nets in stock to be able to deliver sterilized instruments to the RdGG in case of an emergency. Therefore, CombiSter stores extra sterilized nets at their facility. The storage conditions should be ideal in order to keep the instruments undamaged and sterile. From here, the cycle is completed and starts again at the ordering phase (subsection 4.2.1).

4.3. Potential application options

In this section, the various challenges during the instrument cycle in general and specifically at the RdGG are mentioned. Using the instrument cycle description in section 4.2, these challenges become more clear. The challenges lead, in turn, to potential application options for the computer vision algorithm. The challenges will be addressed in the same order in which the instrument cycle phases at the RdGG are covered in section 4.2. Note that some challenges in the instrument cycle can be solved using other techniques than the proposed technique of instrument detection using computer vision. However, this section aims to provide a broad range of application options for computer vision in the instrument cycle.

The following challenges were found in the instrument cycle of the RdGG:

- *Tracking 'status' of the instrument* – During the entire instrument cycle, especially just before and after surgery, it can be important to keep track of the instrument's 'status'. The status is the cycle phase in which the instrument is currently in. During the sterilization process, it is important to known in which stage of reprocessing the instrument is. Only when the instrument has gone through all steps, the instrument is fully sterilized. After surgery, all instruments are marked as 'used' and therefore have to be reprocessed. Actually, not every instrument is used, so some instruments are reprocessed unnecessarily. This leads to unnecessary costs. Information about which instruments are used frequently and which are not can be used to efficiently change the content of the instrument nets.

- *Hospital storage administration* – When sterile instrument nets are delivered at the RdGG, they are placed in sterile storage. It is important to keep a clear overview of all instrument nets at the OR-complex, especially in order to keep enough stock for emergency situations. This can be a real challenge as the number of nets can increase quickly with the amount of scheduled surgeries or the amount of ORs. Detection on instrument-level is not possible here, as the nets are still wrapped. Detection will have to take place at net-level. When the nets come in or out of stock, they have to pass a camera. Computer vision can then, for example, identify a marker on the net that belongs to a specific net content.

- *Preoperative count* – The preoperative count occurs when the instrument net is unpacked. This count is important to detect missing instruments. For complex surgeries, a total of more than 100 different instruments could be used. Consequently, the count quickly becomes a very complex and time consuming task. Computer vision can be used to automate this process using pictures of the instrument table.

- *Surgical/perioperative count* – The surgical or perioperative count is the same process as the preoperative count, but with another purpose. The OR assistant must keep track of every instrument that goes to the patient. Before the surgeon sutures the wound, every instrument must return to the OR assistant. In a dynamic and complex environment, with a lot of stressful moments, it can be hard to keep track of all instruments at all times. Computer vision can give feedback to the OR assistant about the present instruments on the instrument table and whether any instruments are missing before suturing.

- *Checking completeness at the 'dirty'/waste room* – A final check if all instrument are present before the instrument net is returned to CombiSter is useful to detect any items that went missing during the final stage of surgery and during the disposal phase. It can happen that instruments get missing because they become entangled in the sterile cloths or fall on the ground.

- *Feedback during net assembly* – While a CombiSter staff member assembles the instrument net, computer vision can keep track of whether every instrument is put in the net. Every instrument is passed by a camera and noted by the computer vision. When the staff member has doubts about whether all instruments are in the net, feedback about the current content can be requested.

- *CombiSter storage administration* – This application is the same as the storage administration application at the RdGG. When the RdGG orders nets at CombiSter, it is important that CombiSter can check their stock quickly. As a sterilization service, they should always be able to deliver enough instruments at any time.

Storage administration at the RdGG and CombiSter is already done using labels on the instrument net and its packaging. These labels contain a barcode which gives information about the content of the net. By scanning the barcode they can be placed in the system of the hospital or CombiSter. Computer vision could be used for storage administration, but as there is already a functional solution, this application option is not addressed further in this thesis.

5
Design scenarios

Computer vision algorithms are already able to detect certain objects in digital images. It is widely implemented in fields like automated driving and medical image analysis. For every new application, a new set of design requirements and wishes is required. There are specific design requirements and wishes when using computer vision for surgical instrument recognition as well.

Moreover, during the instrument cycle, the surgical instruments pass various rooms. In these rooms, the instruments are in different states, the rooms themselves are different and the application options differ. These differences result in different factors to be important while implementing a computer vision algorithm.

This chapter starts by giving general design requirements and wishes in section 5.1. Most of them are based on the scope of the thesis and information given in the previous chapters. In the following sections, 4 design scenarios are addressed. Each scenario discusses a different 'room' where computer vision can be used. The rooms are the deck space (section 5.2), the OR (section 5.3), the ´dirty´/waste room (section 5.4) and CombiSter (section 5.5). Each scenario has its own application options. The goal is to describe various factors that are expected to be important for the performance of the computer vision algorithm during the different design scenarios. This overview is made before any tests were done.

5.1. General design requirements and wishes

Design requirements:

- *Only look at reusable instruments.*
  Reusable instruments are made from rigid materials and cannot be deformed. A lot of disposables are deformable and therefore extra hard to recognize for the algorithm. As the tests are meant to test the algorithm for as simple conditions as possible in a realistic environment, tests should first only look at reusable instruments.

- *The instrument set that is used in the tests should be relatively simple.*
  Tests should start by investigating simple sets of instruments. As a result, the instrument table is relatively well-arranged. Complex instrument nets and very messy tables should be investigated later when the algorithm has proven that it can handle simple instrument sets. Examples of surgeries where simple sets are used are laparoscopic/open inguinal hernia surgeries and cholecystectomies.

- *The entire instrument table should be on 1 image.*
  When the images are taken from the instruments, the entire instrument table should be on the image. Only then you will know exactly which instruments are missing from table. Furthermore, the goal of the tests is to see if computer vision can give valuable feedback about the present instruments by using only 1 image of the table.

- *Use a camera with high resolution.*
  The more pixels the image has, the more data the algorithm has to work with. Consequently, the algorithm can find more distinctive features and the detection rate will be higher. As the algorithm is only successful with a very high accuracy, a high resolution like 4K is a must.

- *Use a camera that has minimal 'fisheye effect'.*
  Some cameras have a wide-angle lens. This lens feature often results in distortions in the image, especially at the outsides. This is called the 'fisheye effect'. When such a lens is used, the instruments near the outside of the image appear distorted. This makes it hard for the algorithm to recognize this instrument because the proportions of the instrument are unrecognizable.

- *The images should be taken in a sterile manner.*
  Between the sterilization phase and the utilization phase of the instrument cycle, the instruments are sterile. Therefore, the tests in the deck space, in the OR and at CombiSter should occur in a sterile manner. When you want to use the camera during surgery, the camera should either be sterilized itself or should not be above the instrument table.

- *The tests should not hinder staff and interrupt the workflow.*
  Most activities during the instrument cycle are bound to regulations and occur in a strict manner. Furthermore, staff is very focused and concentrated on their tasks. Therefore, it is important that the computer vision helps the staff without interrupting the workflow in the different rooms involved in the cycle. The technology is primarily intended to facilitate the staff member by giving useful feedback. If a staff member is hindered by the technology, it will not be used.

- *The algorithm should be able to tell the amount of instruments.*
  The output of the algorithm can have different detail levels. The lowest one is giving feedback about the number of reusable instruments on the instrument table. In order to help with various instrument counts during the instrument cycle, knowing the amount of instruments is the first thing you should know. This output can be compared with the expected amount of instruments to know how many are missing.

- *Time between taking the image and receiving output from the algorithm should be minimal.*
  No time should be lost because staff is waiting for the algorithm to give feedback about the amount of instruments on the table. Especially in the OR, time is very costly. Delays could results in an increased risk of surgical site infection and in keeping the patient under anesthesia for an unnecessarily long time.

Design wishes

- *The algorithm should be able to tell the type of instruments.*
  Next to the amount of instruments on the table, it is desired to know which instruments are on the table and which are not. This requires a higher level of detail in the output. In this way, the OR assistant knows directly which instrument(s) to look for when they are missing.

- *The images should be taken straight above the table.*
  If sterilization precautions can be taken, it is desired that the images are taken straight above the table. When the images are taken from an angle, the instruments appear a bit distorted in the image. Consequently, it will be more difficult for the algorithm to recognize these instruments.

5.2. Scenario 1: Deck space

The first design scenario is in the deck space. In the deck space, the computer vision algorithm can be used for the preoperative count of the instruments. Computer vision can assist during this count by providing feedback about the amount of instruments that are on the table and the amount that is missing. Furthermore, feedback about which instrument types are missing would be valuable. Knowing which instruments are missing before surgery starts could prevent unnecessary delays. However, there are some factors that could influence the ability of the algorithm to detect all instruments.

Subfigure 4.6a showed how full the instrument table can be after the preparation phase. When an image of the table would be taken, not all instruments are visible. Especially the disposables take up a large part of the table. In order to prevent occlusions, it is important to take the images before most disposables, especially the large sterile cloths and clothing packs, are grabbed.

Moreover, there is usually more than enough time in the deck space for the OR assistant to prepare the table. Therefore, time should be taken to neatly lay out the instruments on the table. This will aid the algorithm as there will be less occlusions and overlapping instruments in the net.

Next, there is a lot of space in the deck space. It can be used to prepare tables for 4 different ORs. However, these preparations almost never take place at the same time. One could set up a separate station where the instruments are counted. The instrument net could be placed under a fixed camera that checks the content. Consequently, the images could be taken straight from above the table as well.

Finally, it is important to take into account that the Tohoku towel clamp is taken away from the instrument table before surgery starts. This clamp is used for surgical site disinfection. If the algorithm tells that this clamp is "missing", the OR assistant will know where it is and there will be no need to delay surgery.

5.3. Scenario 2: Operation room

The OR is the most dynamic room in which the instruments are used. The instruments are constantly taken off the instrument table(s) and used for their purpose. An instrument can be lost if the OR assistant does not pay close attention. Therefore the surgical/perioperative count is done. Automating this count could be an important application of computer vision. The algorithm should give feedback about missing instruments. These missing instruments are either in the surgeon's or assistant's hands, on the sterile cloth over the patient, labelled non-sterile and taken away or actually missing.

In the OR it is important to know when you want to take images of the instrument table. Which feedback does the staff prefer? Do you want real-time feedback or feedback on certain critical moments during surgery? Real-time feedback requires a camera which is constantly above the instrument table. Sterilization challenges and hindrance for the OR assistant could become an issue. When feedback is only given at certain critical moments, these issues are less present. However, when are these critical moments? They can vary between OR assistant and type of surgery, and will result in different challenges.

For both feedback types, the algorithm should work fast . Real-time feedback requires minimal delay. For feedback on certain moments, feedback should be given quickly after the image is taken. Every second that the OR assistant or the surgeons have to wait for the feedback is a second too much. When it takes too long, the value of the technology quickly decreases.

During surgery, the instruments becomes dirty. Stains from blood or other body fluids make it harder to recognize the instruments. Furthermore, the instruments are not put back as neatly as during the preparation phase. Overlapping instruments and disposables could be an issue. Packaging of disposables should be thrown away immediately to keep the instrument table as clean as possible.

A final issue could be any occlusions caused by the OR assistant. The image is taken from above, but the assistant is constantly busy with the instruments. Consequently, the assistant's hands and other parts of the arm could be in the image covering some instruments. The assistant should stay away from the table when the images are taken. However, that requires the assistant to adjust the working methods in order for the algorithm to work.

5.4. Scenario 3: 'Dirty'/waste room

The third scenario in which computer vision could have an application is the 'dirty'/waste room. Here, a final completeness check could be performed before the instruments are sent to CombiSter.

A big advantage in the deck space could be the absence of disposables. Only the instrument net with all reusable instruments is on the table. Consequently, there are no disposables that overlap the instruments and there will be no confusion about which instrument is reusable or disposable.

However, there is a big disadvantage as well. As all instruments are put back in the net, there are a lot of overlapping instruments in the net as seen in figure 4.8. Only when there are enough recognition points of each instruments for the algorithm, it is able to recognize all instruments. One should consider to take the instruments out of the instrument net and spread them on the table to improve performance. However, this will take more time which, in turn, decreases the technology's value.

Furthermore, the waste room is often a lot darker than the deck space and the OR. This makes the images a lot darker as well and possibly harder to analyze.

Finally, some instruments could still be dirty from surgery. The stains on these instruments could make it hard for the algorithm to recognize them.

5.5. Scenario 4: CombiSter

The final scenario is the use of computer vision at CombiSter. The 2 possible applications options are keeping track of the reprocessing phase in which the instrument is and giving feedback during net assembly. The activities at CombiSter are not researched and described in detail in this project. Therefore, not much can be said about the special conditions at CombiSter.

An advantage at CombiSter, especially at the end of the sterilization, is that the instruments are clean. Stains will not hinder the algorithm in recognizing the instrument(s). Disposables are no issue as well as they are not present in the sterilized instrument net.

A potential disadvantage is the time it takes to update the status of every instrument during reprocessing. There should be enough time between reprocessing stages to make images of every instrument. Perhaps, this time needs to be created which will not be ideal. During the assembly of the nets, time is less of an issue as the staff member already handles the instruments one by one. For this application, the instruments should either be passed by a camera one by one or the entire instrument is checked at once at the end of the assembly.

III

Part 3 – Case study: computer vision in the operation room

6
Introduction

In the previous chapters, 4 different design scenarios emerged from descriptions of the instrument cycle and the SIFT algorithm. This part of the thesis looks further at a case study in which the use and implementation of computer vision is investigated specifically for use in the OR and only for the application during instrument counts. Looking at a current off-the-shelf SIFT computer vision algorithm, what are important design focus points when using it for the instrument counts? Where does the current technology itself fall short for the intended application in the OR? Which environmental and practical factors could make the technology useless? It is important to investigate these questions first before further development of a SIFT algorithm more specifically for surgical instruments and use in the OR.

The scenario in the OR was chosen primarily because most questions from staff at the OR-complex of the RdGG were about the various instrument counts in and around the OR. Furthermore, the OR is by far the most complicated environment to implement the technology in. The other scenarios are less dynamic and coordinated. Therefore, most complications and challenges are likely to arise during implementation in the OR.

The computer vision algorithm investigated in this thesis is an off-the-shelf SIFT algorithm. Such an algorithm is able to recognize objects in new images using test images of these objects. However, no SIFT algorithm has been tuned specifically for use in the OR. This case study has the goal to come up with new design focus points that can be used for future development of the algorithm.

This part of the thesis starts by looking at the test procedures in chapter 7. These test procedures are set up using the general design requirements and wishes given in section 5.1 and OR-specific design factors discussed in section 5.3. The procedures describe how the images of the instrument table in the OR can be taken and how these images can be analyzed. It answers the question about how to properly test a computer vision algorithm in the OR. However, no output results are discussed and therefore no numerical results showing the actual performance of a SIFT algorithm are shown. The described test procedures do form a blueprint for future tests in the OR and for tests in the other scenarios. Note that for the other scenarios this blueprint could be used as well, but it should be modified somewhat using room- and application-specific factors as those are not the same as for the OR.

Next to the test blueprint, the goal of this thesis is to investigate which specific technical and practical requirements apply to the use of the algorithm in the OR. While investigating a new technology, the implementation issues should be addressed before the technology is developed and tested. In this thesis, the new design recommendations follow from two types of results. The first type is observations made in and around the OR. These observations describe factors that could potentially influence the performance of the algorithm and the successful implementation of the technology (see chapter 8). The second type is results from a staff survey. These results give insight into OR staff opinions on issues about the challenges around the instrument counts, the expected implementation difficulties, the preferred output feedback of the algorithm, etc. (see chapter 9). The resulting design focus points and recommendations themselves are addressed in the discussion (chapter 10) as they follow from the results.

7
Test procedures

This chapter describes a blueprint of the tests that should be performed in the OR in order to investigate the performance of a SIFT computer vision algorithm and the various important factors that could (negatively) influence its performance and implementation.

Firstly, the test setup in and around the OR is discussed in section 7.1. How and when are the images taken and the observations noted? Section 7.2 describes the test procedures in the OR. How do you get the results that you eventually need during the analysis and how do you write down the observations? Section 7.3 describes the procedures outside the OR. How are the acquired images analyzed? Finally, in section 7.4, the setup of the staff survey is discussed. How do you set up a survey that gives you valuable feedback about the use and implementation of the computer vision algorithm?

7.1. Test setup

This section describes the test setup in the OR. A big advantage of using a (SIFT) computer vision algorithm is the small amount of equipment that is used. A good camera with high resolution and low 'fisheye effect' is the most important. During the tests performed for this thesis a GoPro Hero 8 Black action camera is used. The GoPro has a 12 megapixel camera which corresponds to images with the following pixel resolutions: 4256×2848 for size ratio 3:2 or 4048×3040 for size ratio 4:3. Furthermore, the GoPro weighs only 126 g and is very small, making it manageable and easy to take the GoPro with you to the OR. Finally, the GoPro was attached to a 3-way foldable grip. This was used to keep the GoPro more steady and as close to the instrument table as possible without being in the sterile zone of the OR. Next to the GoPro and the grip, no other equipment is used.

At first it was decided to only look at inguinal hernia surgeries, both the open (also known as Lichtenstein) and the laparoscopic variants (e.g. TEPP and TREPP). These surgeries were chosen because the used instrument nets are relatively simple and are usually done frequently at the RdGG. In this way, it would be possible to quickly build a database with images.

However, after a few weeks, it was decided to look at trauma surgeries as well because there were not as many scheduled inguinal hernia surgeries as expected due to the postponement of many surgeries during the COVID-19 pandemic. The instrument nets used during trauma surgeries are relatively standard and simple as well but can be a lot more complex than the ones for inguinal hernia surgery due to the variety of special orthopedic instruments.

Eventually, the following instrument nets from CombiSter were investigated the most during the project:

- *'Basis (1)'* – used during Lichtenstein inguinal hernia surgery.
- *'Basis bot klein'* – used during trauma surgery.
- *'Handvat accu boor standaard'* – used during trauma surgery.
- *'Laparoscopische basis instr. 300gr. optiek'* – used during TEPP/TREPP inguinal hernia surgery.
- *'Laparoscopische tangen chirurgie'* – used during TEPP/TREPP inguinal hernia surgery.

The goal was to make images during at least 30 different surgeries. As a result, there would be a sufficient amount of images in the test database in order to form a well-founded performance assessment. Furthermore, the influence of the various variable factors on the performance of the algorithm becomes more clear with an increasing amount of investigated surgeries. These factors are for instance illumination, reflections, occlusions and overlapping instruments. These factors vary on their own because of differences between surgeries, working methods of surgeon/OR-assistant, positions of the instrument table in the OR, using 1 or 2 instrument tables, etc.

Next to the images, observations were made during the surgeries. These observations include remarks about the various environmental factors that change the images of the instrument table. Are the lights bright or dim? Is there shadowing on the instruments? Furthermore, observations are noted about factors that could influence the performance of the algorithm. How messy is the instrument table? Does the OR assistant immediately put used instruments back on the table after use? In short, write down everything that could influence the performance or implementation of the technology during that specific surgery.

7.2. Procedures inside the operation room

This section describes what a test day looks like. Which procedures are followed inside the OR during surgery in order to get the required results?

During each surgery, 3 feedback moments of the algorithm are very valuable. These moments are the most important moments to take images during the tests. These moments are:

- Before the instrument table is driven into the OR or just after it is driven into the OR. This is the moment you want to check whether all instruments are present before the start of surgery.
- Before the wound is closed. This is the moment you want to check whether all instruments are back on the table. This check prevents that any instrument is left inside the patient.
- Before the instrument nets are put back in the transportation carts from CombiSter. You check whether no instruments went missing while cleaning the OR at the end of surgery and whether all instruments return back to CombiSter. This check can also be performed just before leaving the OR.

Next to these 3 important moments, you should take as many images as possible. Especially in the beginning stages of research on computer vision in the OR, you want as many images of the instrument table as possible in order to test its performance for various different looking instrument tables. When 2 instrument tables are used, images from both tables should be taken during each moment. Do make sure that you do not disturb the activities in the OR while making the images. Make clear agreements on how and when you will take the images.

During surgery, you are not allowed in the sterile zone. Therefore, the images are not taken above the instrument table, but just next to it. Figure 7.1 shows what this looks like in an OR. Because the images are taken under an angle, the instruments can be distorted in the image. Therefore, images should be taken from both the long and the short side of the table in order to have an image of the instrument from 2 different perspectives. Taking images from straight above the table is preferred, but this option has not been explored as this included the impossible sterilization of the GoPro camera.

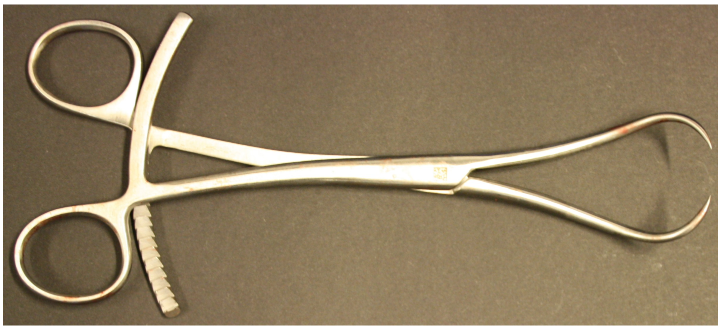
At the end of a test day, you want images from at least the 3 crucial moments mentioned earlier of each attended surgery. Images at these moments are expected to give the most valuable feedback to the OR assistant. Furthermore, as many images should be taken during and between these crucial moments in order to increase the test database. Next to the images, the observations made during each surgery are written down in a notebook.

Figure 7.1: This figure shows how images are taken in the OR during surgery. The instrument table is positioned in the sterile zone and the person on the left hand side is taking the images next to the instrument table.

7.3. Procedures outside the operation room

After a test day, the images and the observations should be stored properly. The images should be stored together with information about the type of surgery during which it is taken, the table side it is taken from and the involved instrument nets. The observations should be typed out and saved together with the images taken at the corresponding surgery.

Before analyzing the images using the SIFT algorithm, some preparation is necessary. First of all, a SIFT algorithm needs test images of each instrument in order to build up a keypoint/feature database. Test images were taken from individual instruments in different forms. These test images should be taken from all reusable instruments that could be used during surgery. Otherwise, the SIFT algorithm will not be able to recognize the instrument or will match the instrument on the table with the wrong instrument. Taking the test images does not have to be done with sterile instruments, so you can make the test images from straight above. Furthermore, make the conditions as ideal as possible. This means bright, even light conditions without shadowing and using a black background. This background can be created for example by laying the instrument on a black paper sheet (see subfigure 7.2a) or making the background black using a photo editing program (see subfigure 7.2b). A black background will make it easier for the SIFT algorithm to 'see' the contours of the instrument on the test image. For the project described in this thesis, test images were made of all the instruments in the 5 nets mentioned in section 7.1. They all look like the one seen in subfigure 7.2a.



(a) This figure shows a large Weber reposition forceps with a black background using paper. A little shadowing is seen, although uniform lighting is used.

(b) This figure shows a curved artery forceps with a black background made using a photo editing program. No shadowing is seen, but the image is a lot darker overall.

Figure 7.2: These subfigures show how a test image of an instrument is made and prepared for the SIFT computer vision algorithm. For improved feature extraction, you want a black background behind the instrument. This can be done in 2 ways as shown in the subfigures.

When assessing the performance of the algorithm you need a control test. As you want to know whether the algorithm can take over the counting tasks from OR assistant, humans are the control group. The images you want to analyze with the SIFT algorithm, should also be analyzed by a human. This can be done using a so called annotation or labelling tool. Examples are LabelBox, LabelImg and Supervisely.

An annotation tool is used to draw rectangles over the instruments in the image and couple a label (i.e. the instrument name) to it. Disposables should not be labelled. The rectangles are similar to the bounding boxes used by the SIFT algorithm. The human is able to do this process very precisely, so you can assume that the control group will miss almost no instruments. Eventually, you end up with images like the one in figure 7.3. Using the results from the annotation tool, you know how many reusable instruments are on each image and where in the image they are. This data can be compared with the output of the SIFT algorithm and a detection percentage follows. Furthermore, you can check whether the SIFT algorithm recognizes the correct instrument by checking the label of the annotation tool and the label that the SIFT algorithm gave the bounding box. During the project described in this thesis, all images taken in the OR were annotated as preparation for analysis. The result looks like the image in figure 7.3.

Figure 7.3: The result after an image is processed with the annotation tool LabelBox. You see rectangles drawn over the reusable instruments. Note that the disposables are not labelled. This figure forms the control group together with all the other labelled images.

The images of the instrument table can now be analyzed by the computer vision algorithm. The output of the algorithm should at least contain information about the amount of instruments and where these instruments are on the table. When the algorithm is further developed, it should preferably contain information about the type of the recognized instruments as well. Consequently, the user will also receive feedback about which instruments are missing. The output of the algorithm can be compared with the control group. This comparison results in a numerical assessment of the algorithm's performance.

Low performance results could be due to various factors. Use the corresponding images to see which instruments are not recognized and to assess which factors limit the algorithm's performance. This information could be used to form new technical and practical requirements for future algorithms.

The results from the observations are grouped into 5 different groups. The performance could either be influenced by factors due to the OR environment, due to a specific type of surgery, due to a specific instrument net, due to a specific instrument or due to working methods of the operation team. Knowing in which group a certain factor belongs, helps determining where to implement a new design requirement for future tests.

7.4. Setting up a staff survey

When a technology does not operate in a way that it facilitates the staff, they will most likely not use it. For example, when the counting results from the technology are less reliable than their own actions, they will fall back on manual counting. Therefore, it is important to receive feedback from staff about their requirements and wishes while designing a new technology intended to be used in the OR.

For the design of a computer vision algorithm for instrument counts, there are various interesting questions to ask OR staff. Important subjects are current challenges during the process that the technology should automate, trust in the technology, implementation issues, feedback preferences, etc. A few general example questions are:

- Which challenges do you experience during the instrument counts?
- When do you consider the algorithm to be trustworthy to take over the surgical counts and when is it considered effective?
- What aspects are important during the implementation of the algorithm in the OR?
- What kind of feedback do you want to receive from the algorithm?

In the survey, use as less open answer questions as possible. The example questions above can be used, but do not give the participant the opportunity to give long open answers as these are very hard to analyze. Instead, use checkbox answers. The result is multiple choice questions with clear, defined answers that can be grouped more easily. For multiple choice questions, always leave the option open to select multiple answers and add an option 'Other...' where the participant can still add their own answer.

The questions can differ between the different design scenarios as each scenario has its own applications, design requirements and wishes. The entire survey used for this project is shown in appendix A. For the application discussed in this thesis, feedback from OR assistants is most valuable as they are responsible for the counts. However, surgeons are also asked to fill in the survey as they are part of the operating team as well.

The results of the survey should be shown clearly in graphs and tables. As a result, the most frequently mentioned answers are the first to emerge. These answers should be considered when designing the algorithm as they are the most important among the staff. Answers that are only given by 1 participant should be mentioned, but are only included last in a future design process. Note that survey results are likely to vary between hospitals and between applications.

8

Results from observations in the operation room

During the project, a total of 35 surgeries were attended. Table 8.1 shows the types of surgery that were attended. During each surgery, a situation sketch is made together with a list of factors that could influence the algorithm's performance. These factors are eventually divided into 5 groups: due to the OR environment, due to the type of surgery, due to the used instrument net, due to a specific instrument and due to working methods of the operating team. They are discussed respectively in sections 8.1, 8.2, 8.3, 8.4 and 8.5. Figures are often used to visualize what is meant by some factors. These figures show images that were all made during the attended surgeries.

8.1. Factors due to the OR environment

This section addresses influential factors caused purely by the room conditions and a specific spot in that room where the instrument table was standing at the moment the image was taken. The factors are discussed separately.

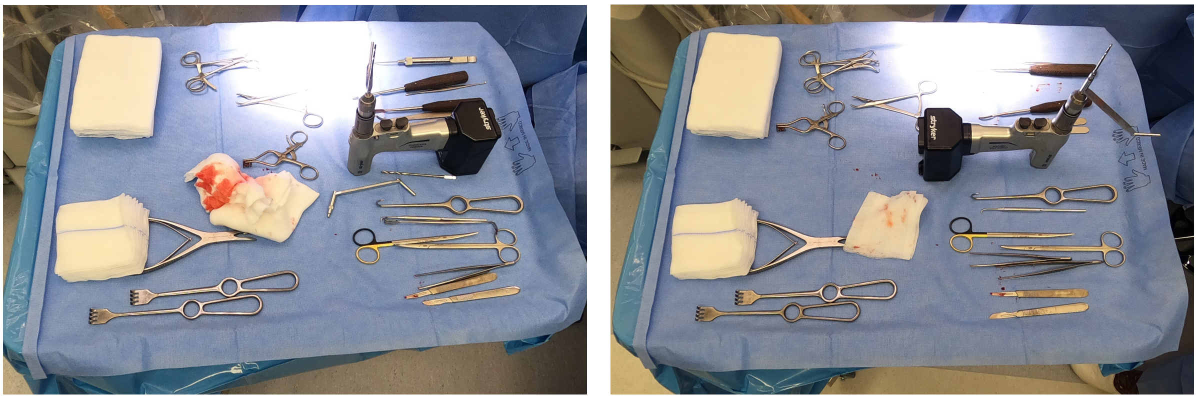
Shadowing – There are different lights in the OR. Above the sterile zone, there are relatively dim lights. Above the rest of the OR, there are bright TL lights. Finally, there are 2 large bright operation lamps attached to movable arms.

There is no shadowing when the instrument table is completely in the sterile zone because the light above the sterile zone shines evenly on the table. However, the bright lights above the rest of the OR do create shadowing when the table does not completely stand in the sterile zone. Furthermore, there is shadowing when an operation light shines (partly) on the instrument table. The result is a darker part next to the instruments that reduces the contrast between the instrument and the background.

Attended types of surgery				
Inguinal hernia surgery 13		Trauma surgery 22		
Type of surgery	Attended amount	Location	Type of surgery	Attended amount
Lichtenstein	2	Ankle	ORIF / VOSM	6
TEPP	9	Olecranon	Zuggurtung / VOSM	4
TREPP	2	Radius (head)	ORIF	4
		Clavicle	ORIF Variax plate	3
		Hip	KHP / γ-nail	2
		Glenoid	ORIF	1
		Tibia	T2 Stryker pen	1
		Carpals	K-wire fixation	1

Table 8.1: This table shows all the different types of surgery that were attended during the project. Here, the various types are explained shortly. *Lichtenstein* is open treatment of the inguinal hernia using a synthetic mesh. *TEPP* and *TREPP* are both laparoscopic surgery types to treat the inguinal hernia with a synthetic mesh. *ORIF* is orthopedic surgery in which the fractured bone is accessed via an incision, realligned for proper healing and fixated using osteosynthesis material. *VOSM* is surgery in which osteosynthesis material is removed. *Zuggertung* is a technique used to dynamically fixate olecranon fractures. *Variax plates* are osteosynthesis material that is used to fixate clavicle fractures. *KHP* is a femoral head-neck replacement where the human bone is replaced by prosthetic material. γ*-nail fixation* is a treatment of proximal fractures of the femur using intramedullary osteosynthetic material. The *T2 Stryker pen* is an intramedullary nail used to fixate tibia fractures. *K-wire fixation* is fixating fractures of the (meta)carpals using Kirschner wires.

Bright 'blind' spot – The operation lights above the operation table sometimes shine straight on the instrument table. Because these lights are so bright, they can create a blind spot in the image. The camera is unable to cope with the light and no contrast can be seen. Even human eyes are not able to recognize the instruments in the blind spot (see figure 8.1).

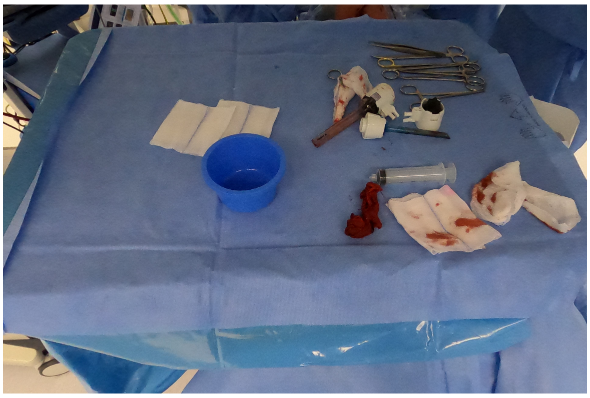


(a) This subfigure shows a bright blind spot on the usage table at the top of the image.

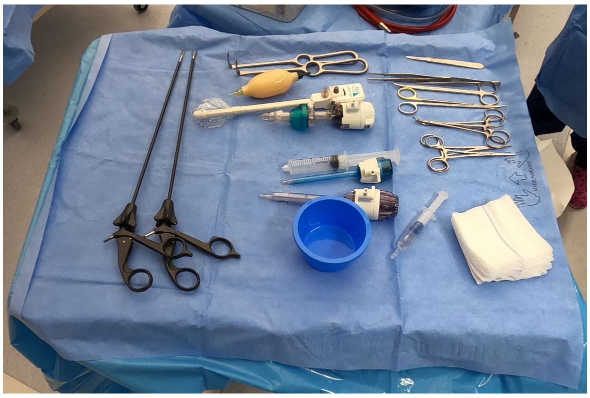
(b) This subfigure shows a bright blind spot on the usage table at the top of the image.

Figure 8.1: This figure shows 2 images made during an ORIF surgery treating an ankle fracture. The operation light was shining on the usage table during a large part of the surgery which caused a blind spot in the images.

Illumination changes – During some surgeries, the light conditions change regularly. For example, most of the lights in the OR are dimmed during the laparoscopic part of TEPP and TREPP inguinal hernia surgery. During this part, the bright lights around the sterile zone and the operation lights are turned off. Only the lights above the sterile zone remain on. As a result, the images are a lot darker during this part of the surgery. However, before and after the laparoscopic part, all the lights are on and the images will be brighter. Figure 8.2 shows a dark (subfigure 8.2a) and a bright image (subfigure 8.2b) taken during the same TEPP surgery. It can be seen that in the dark image the contrast is worse and the instruments are hard to distinguish. The algorithm should be able to cope with these illumination changes.



(a) This subfigure shows the dark situation during the laparoscopic part of the surgery. Especially the instruments at the top right of the image are hard to distinguish due to bad contrast.



(b) This subfigure shows the bright situation before and after the laparoscopic part of the surgery. The contrast in the image is better.

Figure 8.2: This figure shows illumination changes during the same inguinal hernia TEPP surgery.

8.2. Factors due to the type of surgery

This section addresses influential factors caused by the type surgery. A lot of factors vary between types of surgery. However, the algorithm should perform during each type of surgery and should therefore be able to cope with these variations.

Using 1 or 2 instrument tables – Depending on the type of surgery performed, the OR assistant uses 1 or 2 instrument tables. It is noticeable that during some complex trauma surgery with a relatively large instrument set, only 1 instrument table is used and when the instrument set is relatively small, 2 tables are used. This is due to the varying amount of available space around the patient. During inguinal hernia surgery there is usually a lot of space, but during, for example, an ORIF surgery treating a radius fracture there is little space. Both surgeons and the OR assistant already stand or sit around the patient's arm, so there is not much space for a second instrument table. Consequently, OR assistants usually do not want to use 2 tables. However, the amount of instrument tables used makes a huge difference in how ordered the tables look. Figure 8.3 shows the difference in how ordered the tables look when using 1 table (subfigure 8.3a) and 2 tables (subfigure 8.3b and subfigure 8.3c). The result of using 1 table is a lot of overlapping equipment.

(a) This subfigure shows the instrument table when only 1 table is used. This image is taken during an ORIF surgery of a radius fracture. On the top right of the image, instrument are laid out. On the right, two instrument nets are stacked and overlap some instruments.

(b) This subfigure shows the usage table when 2 instrument tables are used during an ORIF surgery treating an ankle fracture. The instruments are laid out neatly on this table.

(c) This subfigure shows the storage table when 2 instrument tables are used during an ORIF surgery treating an ankle fracture. No stacked nets are seen.

Figure 8.3: This figure shows the difference in how orderly the instrument tables look when using 1 (subfigure 8.3a) or 2 instrument tables (subfigures 8.3b and 8.3c).

The amount of instrument nets used – Depending on the type of surgery performed, the amount of instrument nets used in the different attended surgeries varied between 1 and 5. Most types of surgery use a basic instrument set belonging to the type of surgery. Additionally, special instrument nets are brought in for special types of surgery. For example, during a femoral head-neck replacement a net containing bone graters is used and during the placement of a Variax plate a net containing sample plates is used. With an increasing number of nets, the instrument table becomes more cluttered. This could result in too little space on the table(s) for all instrument nets. Consequently, the nets are stacked causing both the bottom nets to be invisible for the camera and the top nets to partly overlap with instruments on the table. Subfigure 8.3a shows the use of 3 nets of which 2 are stacked. The bottom net is only partly visible and the top net hangs over some instruments on the table.

8.3. Factors due to the used instrument net

This section addresses influential factors caused by the instrument nets that are used during surgery. The content of instrument nets varies greatly between different surgeries. Some content items could cause problems.

The presence of sterile instrument bags – A lot of instrument nets contain sterile instrument bags. These instrument bags contain several (parts of) instruments. Figure 8.4 shows an instrument net containing sterile bags. Sometimes these bags are taken out of the net, but usually they are left in. The material of the instrument bag seems transparent, but due to light reflections it sparkles a lot. Consequently, the content is poorly visible. Furthermore, when the sterile bag is left in the instrument net, it covers some of the contents of the net. The underlying instruments are not visible for the camera anymore.

Double-layered instrument nets – Some instrument nets used during trauma surgery have 2 layers. Some OR assistants take the top layer out, but some let it in. The top layer blocks the view of the instruments below. Figure 8.5 shows 2 double-layered instrument nets of which the bottom layers are not visible for the camera.

Figure 8.4: This figure shows an image of the instrument table during an ORIF surgery treating an ankle fracture. You can see 3 sterile bags in the right instrument net and 1 in the left instrument net. Light reflections are seen on the material of the sterile bags. Furthermore, the bags cover (parts of) the instruments in the net.

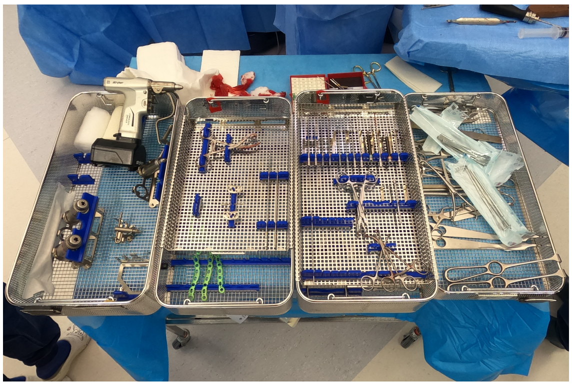
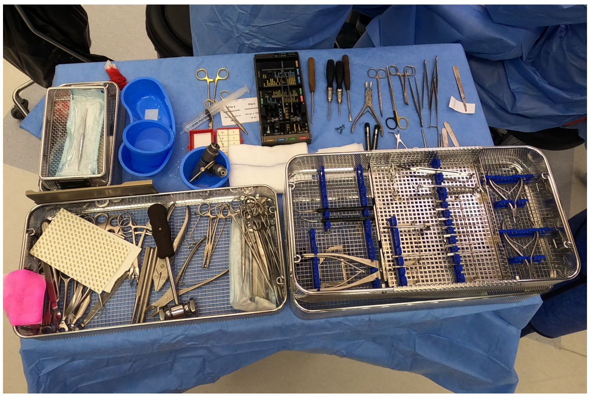


Figure 8.5: This figure shows an image of the storage table during a Variax plate surgery treating a clavicle fracture. The 2 middle instrument nets are double-layered. The instruments below the top layers are not visible.

The presence of screw boxes – At the attended surgeries, 2 types of screw boxes are seen: the Medartis Aptus box and a box containing cannulated screws. These are shown in figure 8.6. The Medartis Aptus screw box contains screws and plates used during fixation of radius head fractures (see subfigure 8.6a). The box containing cannulated screws was seen during an ORIF prodecure treating an ankle fracture (see subfigure 8.6b). The box with cannulated screws was included in the instrument. The same cannot be said for sure about the Medartis Aptus screw box. There are a lot of small screws in both boxes. Some screws taken out of the box used during surgery, of which some end up in the patient and some do not. For the algorithm, it will be very difficult to keep track of all these screws. Even more because the cover of the boxes is closed most of the time.



(a) This subfigure shows an instrument table containing the Medartis Aptus screw box used for radius head fractures. The box is black and is seen at the top middle of the image. The colored dots in the box are the screw heads.

(b) This subfigure shows an instrument table containing the screw box with cannulated screws. The box is metallic and can be seen with its cover open in the middle instrument net.

Figure 8.6: This figure shows two screw boxes used during different trauma surgeries: the Medartis Aptus screw box (subfigure 8.6a) and the box with cannulated screws (subfigure 8.6b).

Lack of clamps in the instrument net – Some instrument nets have (blue) clamps in which the instruments can be clamped. Consequently, the instruments are laid down orderly and separately in the instrument nets as seen in figure 8.7. These instruments will be easier to recognize by the computer vision algorithm. When the net lacks these clamps, the instruments lie very mixed up in the net. A lot of overlapping instruments are the result. The algorithm will most likely not be able to recognize all the instruments in such a messy net.

Figure 8.7: This figure shows an instrument table during an ORIF surgery treating an ankle fracture. The instrument net on the bottom left contains blue clamps. Due to these clamps, the instruments lie orderly in the net.

8.4. Factors due to a specific instrument

This section addresses influential factors caused by specific instruments. These factors are not caused by all instruments and during all surgeries. During some surgeries, special instruments are used that could cause specific factors.

Multi-component instruments – Some instrument nets contain components that need to be assembled into a complete instrument. For example, the reusable trocars in the basic laparoscopic instrument net consist of a trocar sleeve (possibly with a gas tip) and an obturator that goes into the sleeve. The components for the drilling machine are another example. The complete machine consists of 5 components: a battery holder, a cordless drill machine, a drill head, a bone drill and a surgical drill guide. The components are brought in separately in the instrument nets. When being used, the components are put together. Between different moments of use, the total drilling machine is put on the table as seen in figure 8.8.

When the components are together, it can be hard to distinguish the individual components. Should the algorithm recognize the individual components, the entire multi-component instrument or both?

Figure 8.8: This figure shows an instrument table during a Variax plate surgery treating a clavicle fracture. The complete drilling machine is seen at the bottom left of the image. This machine is a multi-component instrument.

Same instrument, different sizes – A lot of instrument types come in different sizes. Examples are curved forceps, needle holders, drills, chisels, scissors, etc. The different sizes look like scaled versions of the same instrument. When the algorithm has to type the instruments it sees, it will also have to recognize the size of some instruments. When the algorithm cannot compare the instruments with a known size in the image, it will not be able to know the size of some instruments as well. Consequently, the type of these instruments is not recognized.

Reusable instruments looking like disposables – Some reusable instruments from the instrument nets look a lot like disposable instruments. It could be hard for the algorithm to distinguish reusable and disposable instruments. For example, during laparoscopic TEPP and TREPP surgery both reusable and disposable trocars are used. The difference could be hard to tell for the algorithm. Another example is determining whether there is a drill or a Kirschner-wire in a drill head. From a distance, they can look a lot like each other, but the Kirschner-wire is disposable and should not be counted.

Deformable instruments – The computer vision algorithm extracts very specific features from the test images made of the instruments. Therefore, the algorithm could have a hard time when instruments can change their shape. The "Cerclage/Kirschner" instrument net used during Zuggurtung surgery contains both Kirschner and Cerclage wires as seen in figure 8.9. These wires are very deformable and sometimes woven into each other. They will be hard to recognize, but are especially important to include during the instrument counts.

Reusable instruments looking like osteosynthetic material or implants – Instrument nets used during Variax plate surgery contain reusable sample Variax plates of different sizes and colors (see figure 8.10). These are used to find a good match between a specific Variax plate size and the patient's clavicle. However, these sample plates resemble in shape exactly the osteosynthetic plate that is eventually put into the patient. The algorithm should know the difference between the sample plate and the osteosynthetic plate.

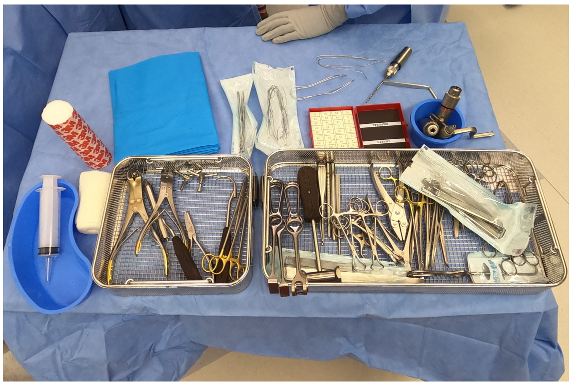


Figure 8.9: This figure shows an instrument table during a Zuggurtung surgery treating an olecranon fracture. In the top middle of the image the Cerclage/Kirschner wires are shown. You can see both the sterile bag in which the wires are packed together and the wires themselves on the table.

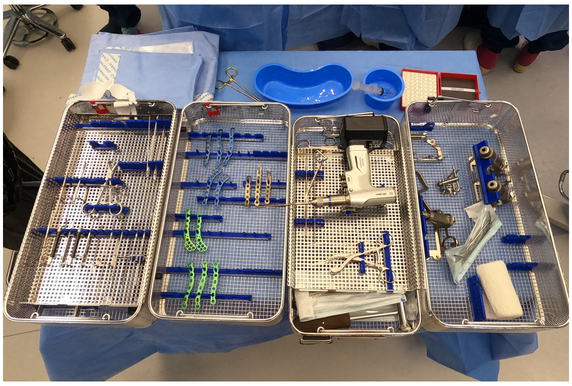


Figure 8.10: This figure shows an instrument table during a Variax plate surgery treating a clavicle fracture. The second instrument net from the left contains the sample variax plates in different colors.

Blood stains on the instrument – During surgery, large blood stains may appear on the instruments or the instrument table. When there is a lot of blood, it becomes harder to recognize the contours of the instrument as the contrast with the bloody cloth on the table is reduced. Figure 8.11 shows bloody instruments on the instrument table during a γ-nail revision surgery. The image shows that for a few instruments, the contrast between instrument and background is reduced by blood stains.

Figure 8.11: This figure shows an instrument table during a γ-nail revision surgery. In the middle of the table, 2 bloody surgical tweezers are seen. The background of these tweezers is very bloody as well. Consequently, there is very little contrast between the bloody instruments and the bloody cloth.

Sterile bag of the endoscope – During laparoscopic TEPP and TREPP surgery, a stiff endoscope is used. A sterile bag is pulled over the wire that is attached to this endoscope. During the preparation phase, this bag is rolled up and stuck to the endoscope. When the endoscope with the sterile bag lies on the instrument table, the bag could cover a part of the instruments on the table (see figure 8.12). Furthermore, the sterile bag covers a large part of the endoscope itself causing it to be partly invisible.

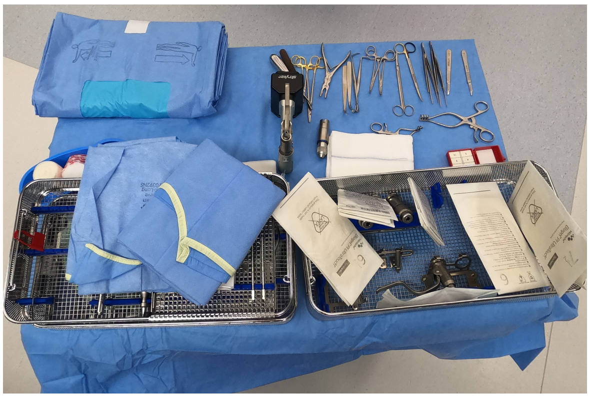
Figure 8.12: This figure shows an instrument table prior to a laparoscopic TEPP surgery. In the middle of the table you seen the endoscope with the sterile bag rolled up.

8.5. Factors due to working methods of operation team

This final section addresses influential factors caused by the specific working methods of the OR assistant or other members of the operation team. Working methods vary significantly between OR assistants. Some work very neatly and some are a bit messier. This usually does not affect their work, but could affect the performance of the algorithm.

Disposable material on the table and in the instrument net – Especially at the start of surgery, a lot of disposable material lies on the instrument table. This includes among other things sterile cloths, clothing and gloves. Consequently, the table is very messy and disposables overlap with the reusable instruments. As a result, a lot of the reusable instrument are not visible for the camera.

During surgery, a lot of disposable material remains on the table. This includes for instance packaging material, clean/dirty surgical sponges, a sterile cover for the C-arm, a electrical cutter and bandages. These disposables do not have to be a problem, but when numbers pile up, there is not enough space on the instrument table causing some reusable instruments to be covered. Figure 8.13 shows a messy instrument table before the start of surgery (subfigure 8.13a) and one during surgery (subfigure 8.13b).



(a) This subfigure shows an instrument table just before an ORIF surgery treating a radius fracture. On the bottom left of the image there is sterile clothing covering an instrument net. On the bottom right sterile gloves packaging cover the other instrument net.

(b) This subfigure shows an instrument table during an ORIF surgery treating a radius fracture. On the bottom left you see sterile gloves (packaging) covering an instrument net. On the top middle you see dirty sterile sponges partly covering some instruments.

Figure 8.13: This figure shows an instrument table before and during surgery. This figure shows how disposables cover reusable instrument causing them to be (partly) invisible for the camera.

Instruments on the patient's legs – When instruments are used during surgery, they are away from the instrument table. When the surgeon is done using an instrument, it should be returned to the instrument table to keep a good overview. However, sometimes instruments are not returned to the instrument table between moments of use. Instruments are placed near the patient, for example on the legs. This allows the surgeon to quickly access the instrument again without asking the assistant, but the instrument will not be visible for the camera. This should be taken into account when the computer vision algorithm performs the count.

Instruments becoming non-sterile or unusable - There are various reasons for an instrument to become non-sterile or unusable during surgery. For example, the instrument could fall on the ground causing it to become non-sterile. This instrument is removed from the instrument table and only returned to the instrument table at the very end of surgery.

Furthermore, during each attended surgery, the Tohoku towel clamp was removed from the instrument table before the surgery started and used to disinfect the surgical site. Consequently, the towel clamp has become non-sterile and is not returned to the table. At the end of surgery, this clamp is usually clamped to the sterile cloth hanging over the side of the instrument table. The instrument is not visible for the camera during the entire surgery.

A final example of how an instrument could become non-sterile is when a non-sterile (part of a) staff member touches the instrument. During an attended surgery, the OR assistant used a curved forceps to scratch her nose. Sterile instruments are not allowed to touch non-sterile body parts. Consequently, the instrument becomes non-sterile and is removed from the instrument table.

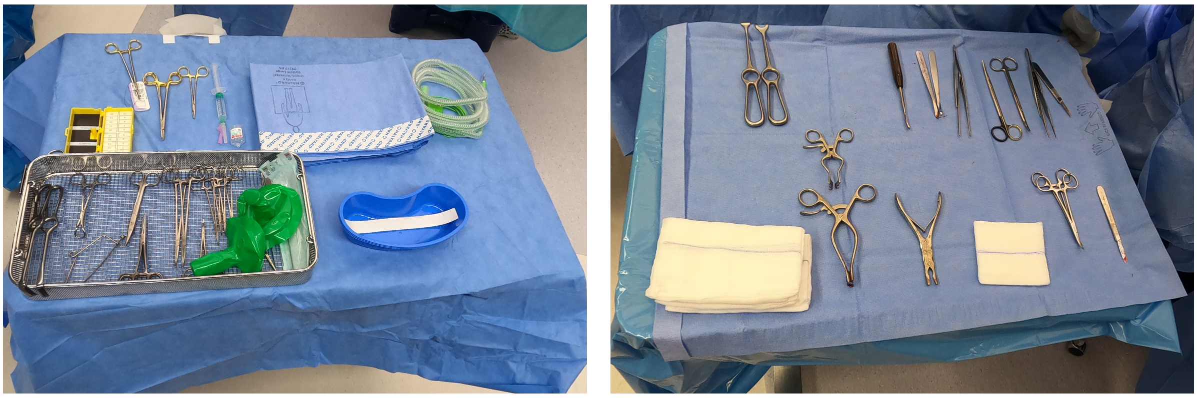
All together, the computer vision algorithm should know that these instruments are removed from the instrument table and returned only at the end of surgery. Otherwise they are marked as 'missing' when they are knowingly kept away from the instrument table.

Instrument table is not ready when driven into the OR – The schedule of the ORs is very tight. However, it often happens that a surgery takes longer than expected. To compensate for these delays, the time between surgeries is shortened. Consequently, the OR assistant has less time to prepare the instrument tables for the next surgery. As a result, instrument tables are sometimes driven in the OR when they are not properly prepared. This means that instruments are not laid out on the table and disposables are thrown on the instrument nets. During the course of surgery, the instrument table is prepared further. However, the preoperative instrument count will be difficult to perform.

Adding an instrument (net) during surgery – It occurs frequently that instrument nets are added to the total set during surgery. This has several causes. Firstly, an instrument gets missing, broken or non-sterile during surgery. When this instrument is crucial for the surgery and there is no replacement in the net, a new net is brought into the OR. Secondly, something unexpected occurs during surgery that requires a different set of instruments.

When a new instrument net is brought in, its content should be added to the total list of instruments that are present in the OR. Otherwise, the performance of the computer vision algorithm cannot be assessed properly. Furthermore, adding more instrument nets to the table makes it increasingly messier. As a result, instrument nets are usually stacked.

Instruments hanging over the edge of the instrument net or table – Some instruments are recognized by only a small part of that instrument. This is the case for some retractors, forceps, reposition clamps and tweezers. When the characteristic part is not visible for the camera, the algorithm will not be able to recognize the type. This can happen when other equipment covers the characteristic part, but it can also happen when this part hangs over the edge of the table or the net. Figure 8.14 shows an image in which retractors hang over the edge of the instrument net (subfigure 8.14a) and the table (subfigure 8.14b). The recognizable parts of these retractors are poorly visible.



(a) This subfigure shows an instrument table during an ORIF surgery treating an ankle fracture. On the bottom left of the image 2 Langenbeck retractors hang over the edge of the instrument net.

(b) This subfigure shows an instrument table during a Lichtenstein surgery. On the top left of the image a Langenbeck (left) and a Middeldorf (right) hang over the side of the table.

Figure 8.14: This figure shows instrument tables on which retractors are shown hanging over the edge of an instrument net (subfigure 8.14a and the side of an instrument table (subfigure 8.14b).

Instruments standing against the side of the instrument net – Sometimes instruments are placed upright against the edge of an instrument net. Consequently, the instruments appear very different on the images compared to how they appear in the test images. The algorithm will have a hard time recognizing these instruments due to their distorted appearance. Figure 8.15 shows an image in which instruments stand upright against the edge of the instrument net.

Figure 8.15: This figure shows an instrument table during laparoscopic TEPP surgery. The red arrow points at a surgical clamp standing upright in the instrument net.

OR assistant leaning on the instrument table – When there is a quiet period during surgery, the OR assistant sometimes leans on the instrument table. Consequently, a hand or a part of the arm covers a part of the instrument table and sometimes even some instruments as well. As a result, the instruments are (partly) invisible for the camera. Figure 8.16 shows an OR assistant partly covering instruments while leaning on the instrument table during a Lichtenstein surgery.

Figure 8.16: This figure shows an instrument table during a Lichtenstein surgery. On the top right of the image you see the OR assistant leaning on the table partly covering 3 instruments and creating shadowing.

Light reflections due to liquid – Sometimes there is liquid on the instrument table. This liquid can be a sodium chloride solution used for cleaning, the (pink) disinfectant used for preoperative surgical site disinfection or a kind of gel used when inserting the first trocar during laparoscopic surgery. Liquid is usually contained in a bowl and is sometimes spilled on the cloth over the table. When a bright light shines on the instrument table, these liquids could cause light reflections into the camera's lens. Figure 8.17 shows how a blue bowl with sodium chloride solution and liquid spots on the table cause bright light reflections. When an instrument lies in these liquid spots, the contrast between the instrument and sterile cloth is reduced and the instrument is possibly not recognized.

Figure 8.17: This figure shows an instrument table during a femoral head-neck replacement. On the bottom right you see liquid on the sterile cloth and in the blue bowl. The bright, white spots are light reflections caused by the bright lights in the OR.

Wrapping sterile sponge around instrument – During some surgeries, the OR assistant wraps a surgical sponge around a clamp. This is used to clean the inside of a trocar or spots in the wound that are hard to reach using fingers. Figure 8.18 shows the sponge-clamp combination during a laparoscopic TEPP surgery. The surgical sponge covers a large part of the instrument, potentially causing the instrument type to be unrecognizable.

Figure 8.18: This figure shows an instrument table during a laparoscopic TEPP surgery. On the top right of the image, you see a surgical sponge wrapped around a surgical clamp. Only the 'eyes' of the clamp are visible. The rest is covered.

9

Results from survey for OR staff

A survey consisting of 10 questions has been sent to the OR assistants and the surgeons. The entire survey can be seen in Dutch in appendix A. The goal of the survey was to give more insight into the personal opinions from OR staff about challenges and problems around the instrument counts and the use of a computer vision algorithm in the OR. Feedback from OR staff is very valuable as they are the intended end-users of the final product.

This chapter shows the results of the survey together with some remarks about salient points in these results. Each section in this chapter discusses a few survey questions on the same topic. The order of the sections is the same as the order of the questions in the survey. Pie charts, bar charts and tables are used to support the results. In the discussion, chapter 10, the important points of attention that follow from the survey are used to form new design focus points.

9.1. The participants

A total of 18 OR staff members participated in the survey. Questions 1 and 2 were about the position and experience of the participants. Experience was asked because it was expected that experience with current working methods would influence openness of a staff member towards new technology in the OR. The following questions were asked:

1. What is your position in the RdGG?
2. How many years of experience do you have in your current position?

The results are shown in table 9.1. From the 18 participants, there were 3 surgeons, 13 OR assistants, 1 practical trainer of OR assistants and 1 student OR assistant. For the rest of the discussion of the survey results, the OR assistants, the practical trainer and the student are taken together in one group called the 'OR assistants' as they mostly have to perform the same tasks at the OR-complex. Therefore, we have 3 surgeons and 15 OR assistants.

The results from question 2 are used in section 9.2, where they are combined with the results from statement 3.

Position	# participants
Surgeon	3
OR assistant	13
Practical trainer of OR assistant	1
Student OR assistant	1

Table 9.1: This table shows the amount of participants per position at the RdGG.

9.2. Challenges and problems regarding instrument counts in and around the OR

It is important to know whether the OR staff thinks that there are challenges/problems at all during the instrument counts. Furthermore, if they do experience challenges or problems, you want to know what these are. A statement was presented with which the participant could agree or disagree. Moreover, a question with checkboxes was asked about the experienced challenges and problems. The participants could also add extra answer options themselves. This question was only to be answered if the participant agreed with the preceding statement. The statement and the question were:

3. I sometimes do experience challenges and/or problems during the instrument count prior to and during surgery.

4. If you agreed, what challenges and/or problems do you experience while counting surgical instruments?

The results of the statement are shown in figure 9.1. A total of 11 (61%) participants agreed with the statement and 7 (39%) participants disagreed. Both sides are a mix of surgeons and OR assistants. Therefore, for these results, no clear correlation can be seen between the position in the RdGG and agreeing to this statement. However, the amount of participants is to low to conclude that in general.

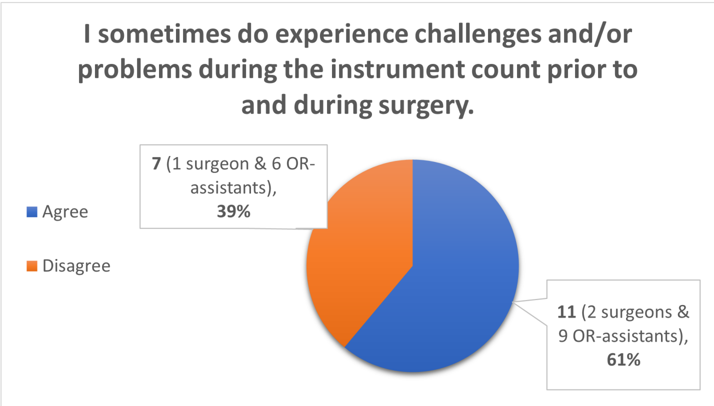


Figure 9.1: This pie chart shows the results from the statement number 3. A total of 11 (61%) participants agreed with the statement and 7 (39%) participants disagreed.

The results from question number 2 and statement number 3 were investigated as well. Table 9.2 shows the years of experience of the participants that agreed or disagreed with the statement. Furthermore, the average years of experience is shown for both sides. The averages do not differ enough to say that there is a correlation between the answer to the statement and average years of experience.

Years of experience	
Group that agreed (11 participants)	Group that disagreed (7 participants)
32	33
32	32
25	25
18	23
17	18
17	7
17	1
12	
8	
5	
4	
Average	
17	19.86

Table 9.2: This table shows the years of experience for the group that agreed (11 participants) and the group that disagreed (7 participants) with the statement about experiencing challenges/problems during instrument counts. The average years of experience for both groups are calculated as well.

The results from question number 4 are shown in figure 9.2 using a bar chart. 2 of the 4 checkbox answers are given the most. The staff especially experience that the instrument counts take a lot of time and that it is difficult to pay attention on other perioperative tasks when counting the instruments.

Furthermore, it is interesting to look at the 4 answers that participants gave themselves. They experience that the instrument count is harder when there is only one copy of the instrument in the instrument net. Usually, instruments from the same type are easily found in the net and counted. Secondly, it is experienced that the instrument count becomes harder when there is an emergency setting in the OR. The assistant's attention will be less focused on the instruments and this could lead to errors. Thirdly, it becomes harder to keep track of all the instruments when there are multiple nets of the same type on the instrument table. Finally, there is not always someone available to do the counts with. Usually, there is another staff member who double checks next to the assistant. When that person is not available, the count is delayed or done by the assistant alone. The latter could lead to an increased possibility of mistakes.

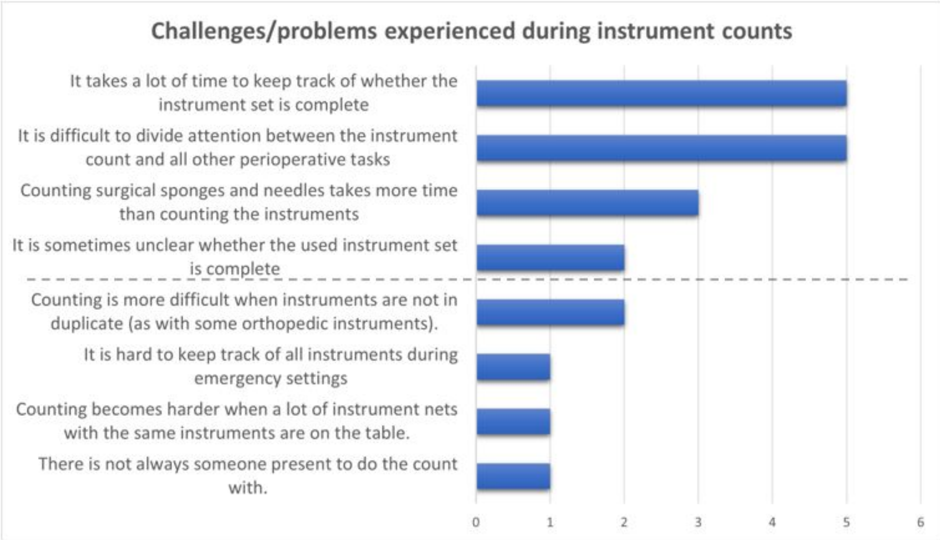


Figure 9.2: This figure shows the results of question number 4 in a bar chart. On the left you see the answers given by participants. The checkbox answers are shown above the dotted line and answers added by participants are shown below the dotted line. On the right you see the amount of participants that gave the answer.

9.3. The added value of computer vision during the instrument counts

The purpose of using computer vision in the OR was explained in the survey. Furthermore, a small explanation was given about how it is roughly going to work. With this information, the participants were asked about their opinion on the potential added value of computer vision for the instrument counts in the future. This is done using a statement that participants could agree or disagree with, followed by an open question:

5. I think that a computer program that can automatically count surgical instruments would be a valuable addition to the OR of the future.

6. On the previous question: why do you agree/disagree?

The results of statement number 5 are shown in the pie chart in figure 9.3. A total of 14 (78%) participants agreed with the statement and 4 (22%) participants disagreed. It is seen that all surgeons agreed with the statement. When these results are compared with the results to statement number 3, it is seen that especially the participants that do not experience challenges and/or problems during the instrument count also think that computer vision would not be a valuable addition. However, some of them did think that computer vision could support them in their activities although they do not experience difficulties during the counts.

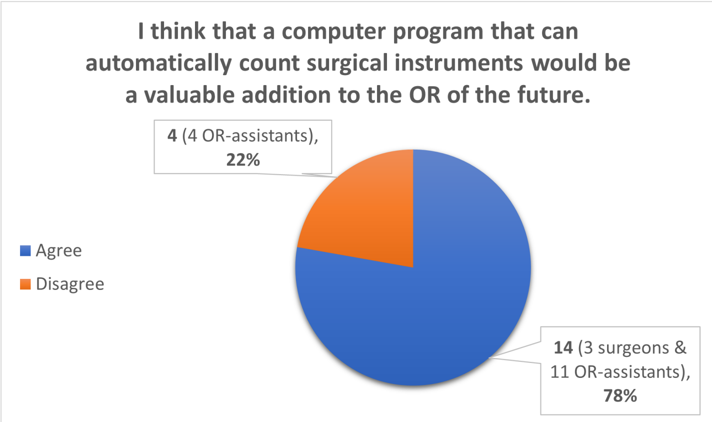


Figure 9.3: This pie chart shows the results from the statement number 5. A total of 14 (78%) participants agree with the statement and 4 (22%) participants disagreed.

The results of open question 6 are a wide range of reasons why the participants thought that computer vision would or would not be a valuable addition to the OR of the future. Table 9.3 shows the given answers together with the amount of times this answer has been given by participants. The answers have been grouped as best as possible.

Reasons why computer vision would be useful	
Reasons	# participants
As a backup / double check – used complementary to or as a substitute of double checks done by present OR staff.	5
Eliminate the human factor, reduce counting errors.	4
It makes the counting processes a lot easier.	1
It is useful for staff (self-employed/secondment services) who are not familiar with the relevant set of instruments.	1
Finding instruments during the final count that have been put back in the wrong net.	1
Use computer counts when there is not enough time for manual counts. Results from the computer are used during counts later on.	1
Reasons why computer vision would not be useful	
The OR assistant is ultimately responsible. If the computer makes a mistake, you have not been able to overcome this yourself.	1
Instruments rarely get lost and if something it usually lies on the floor or in the trash, but it has never been found in the patient.	1
The OR assistant will notice faster when instruments are lost.	1
The algorithm cannot detect if anything has fallen on the floor or been given to other staff. This has to be entered into the computer again, which leads to extra work and an extra chance of errors.	1

Table 9.3: This table shows the reasons given by participants why they think computer vision would or would not be a valuable addition to the OR of the future. The left column shows the answers and the right column shows the amount of participants that gave that answer.

Among the answers in table 9.3, 2 reasons for using computer vision for the instrument counts are used most frequently: it serves as a helpful backup / double check and it eliminates the human factor, both reducing the possibility of errors. Computer vision can be used both complementary to or as a substitute of the double check performed by other present OR staff nowadays. Next to the more common given answers, four other answers were given. These answers are only given once but are still very valuable. They give more insight into possible application options and where to use the computer vision.

A total of 4 reasons why computer vision would not be a valuable addition are given. First of all, responsibility for the counts will remain with the assistant. Handing over the counts and listening to a computer could be a difficult transition. Secondly, an OR assistant noted that during her working years an instrument was never left in the patient. She does not see the added value as missing instruments are usually found on the floor or in the trash. The third and fourth answer complement each other. It is believed that the OR assistants themselves spot missing instrument quicker than the algorithm as it is not able to detect instruments that have fallen on the floor or have been given to other staff (i.e. the surgeon or staff around the sterile zone). Consequently, these 'missing' instrument should be entered in the system, which leads to extra work and an extra possibility of errors.

Next to the reasons listed in table 9.3, 2 additional useful remarks were made in the answers of question 6. Firstly, a participant questioned whether it would be useful if the computer vision is also able to detect and count suture needles. During large surgeries, a lot of needles are used and they are very small. The count is already done together with another staff member, but it remains a complex task. Secondly, a participant noted that the counts are already done regularly by hand during surgery. For the algorithm to have added value, it should be used at the right times. For example, when the OR assistants are unable to do it themselves or when it is better for the OR assistants to spend time on other tasks.

9.4. Important aspects for successful implementation

Question 7 is a checkbox question asking participants about the importance of various aspects when implementing an algorithm for the instrument counts. 5 answers were already given, but participants were able to add answers themselves as well. The question was formulated as follows:

7. Several aspects are important when using new technology in the OR. What aspects are important to you regarding the use of a technical aid during the counting of surgical instruments?

The results from checkbox question 7 are shown in the bar plot in figure 9.4. From the 18 participants, 17 participants think that accuracy is important and 15 participants think that the technology should be fast and simple to use. These 3 aspects are the most important. Furthermore, 8 participants also think that the technology should cause no hinder during other activities in the OR and that the type of feedback from the algorithm is very important. Questions 8 and 9 elaborate more on the feedback and are discussed in section 9.5.

Next to the 5 checkbox answers, 2 additional answers were given by participants. The first one is a remark about the feedback the algorithm should give. No error should occur when an instrument is 'missing'. This only slows down the surgery unnecessarily. Do show which instruments are missing. Usually, the OR assistant or other OR staff will know where the instrument is.

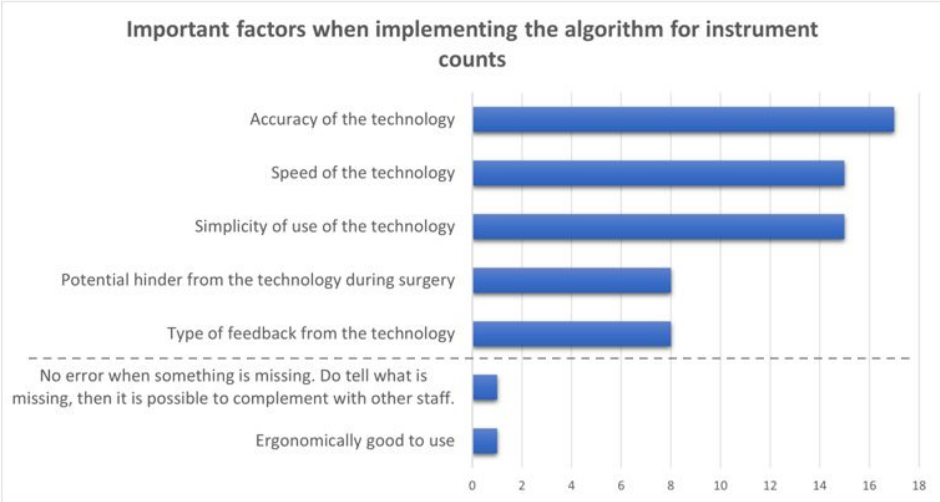


Figure 9.4: This figure shows the results of question number 7 in a bar chart. On the left you see the answers given by participants. The checkbox answers are shown above the dotted line and answers added by participants are shown below the dotted line. On the right you see the amount of participants that gave the answer.

9.5. Feedback from the computer vision algorithm

The feedback from the algorithm should be compact, clear and easy to read. It is important to know what data should be included in the feedback and when this feedback should be given. This information can be used to develop an algorithm that better fits the staff's needs. In order to get this information, checkbox questions 8 and 9 were asked:

8. The feedback that the computer program eventually gives to the OR staff should be very clear. The idea is that the feedback contains information about the presence of instruments on the instrument table. What feedback do you think is important?

9. Feedback about the presence of instruments can be given at various moments during surgery. At what moments would you like to receive feedback from the computer program?

The results from checkbox question 8 are shown in a bar plot in figure 9.5. According to the 3 most given answers, the feedback from the algorithm should contain information about how many instruments are missing together with their type. Furthermore, when not all instruments are present on the table, there should be a clear indication that one or more instruments are missing (e.g. a screen that turns red when instruments are missing). Finally, the number of instruments that the algorithm should count and actually counts can be added to the feedback as well. However, this information is also combined in the feedback that tells the number of instruments that is missing, so it may be considered redundant by some.

A participant added an answer as well. It contains a remark that OR assistants should be able to continue their tasks even if the algorithm gives an error. This error should not mean 'stop', but should only give information about the type of instruments that are missing. It is often the case that the surgery can continue without the missing instrument.

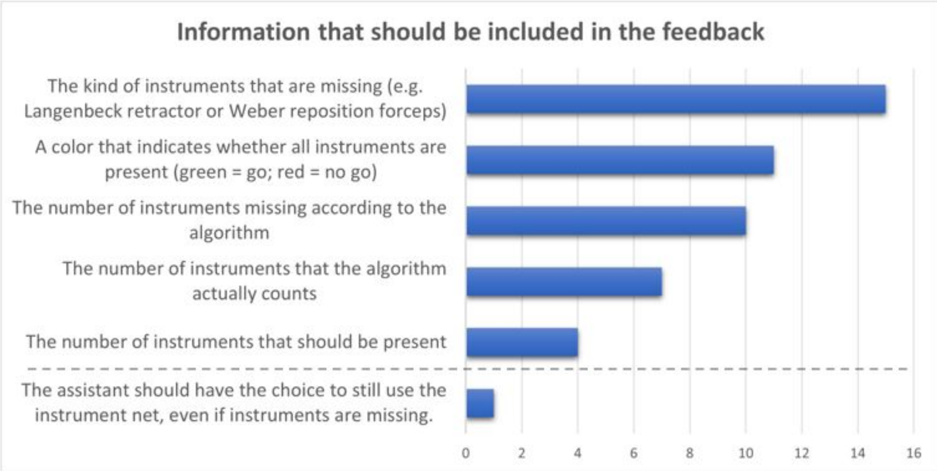


Figure 9.5: This figure shows the results of question number 8 in a bar chart. On the left you see the answers given by participants. The checkbox answers are shown above the dotted line and answers added by participants are shown below the dotted line. On the right you see the amount of participants that gave the answer.

The results from checkbox question 9 are shown in a bar plot in figure 9.6. The 2 most important moments to receive feedback from the algorithm are just before closing the wound and prior to surgery in the deck space. These answers are respectively given by 16 and 14 of the 18 participants. Furthermore, participants are not interested in live feedback throughout surgery. Feedback would only be useful at certain times during surgery.

A participant also mentioned the moment just before the surgeon closes, for example, the fascia or abdomen during open abdominal surgery. Closing the wound occurs in several steps during these surgeries and the risk of leaving instruments behind is relatively high. Therefore, instrument presence should be checked multiple times during the various closing steps.

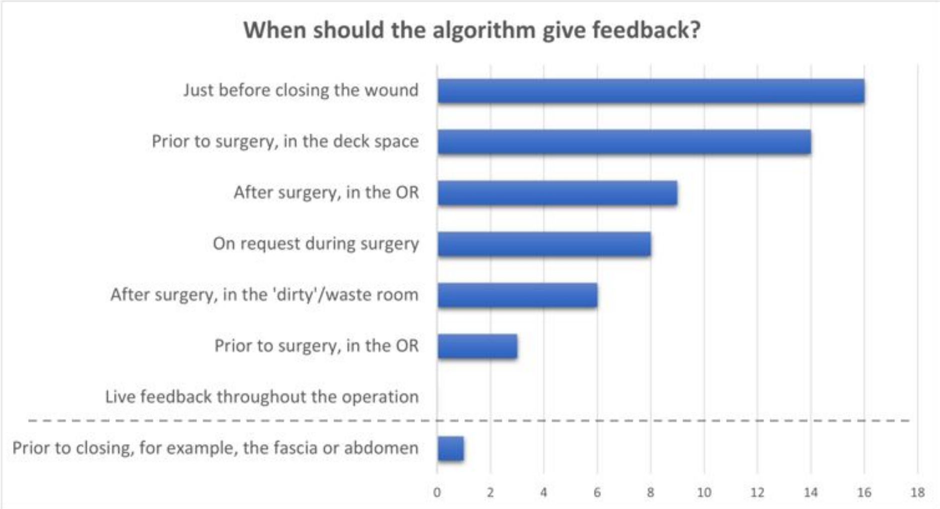


Figure 9.6: This figure shows the results of question number 9 in a bar chart. On the left you see the answers given by participants. The checkbox answers are shown above the dotted line and answers added by participants are shown below the dotted line. On the right you see the amount of participants that gave the answer.

9.6. Additional remarks

The final question of the survey is an open question that asks the participant to make some final comments and suggestions about the use of a technical aid in the OR for the instrument counts. Question 10 was formulated as follows:

10. Do you have any other comments or suggestions regarding the use of a technical aid for automatic counting of surgical instruments in the OR?

The results of the open question are shown in table 9.4. A total of 8 answers were given and 2 participants gave the same suggestion. They suggested that it would be useful if the algorithm was also able to find the instrument in the room. This would help the OR assistant in locating the missing instrument(s). Another remark was made about detecting instruments that are being used by the surgeon. These instruments should be counted, but are not on the instrument table. Most of the other remarks and suggestions are about when and where to use the algorithm. The final remark in table 9.4 questions the added value of using computer vision for counting instruments in the OR. This shows that some staff members are more difficult to convince of the potential of a new technology.

Final remarks and suggestions

Remarks and suggestions	# participants
It would be useful if the technology can also find the instrument.	2
Speed and ergonomics are the most important during implementation.	1
How are instruments that are in use but should already be counted (e.g. needle holders and tweezers) included in the automatic counting process?	1
When the instruments are counted in 2 different rooms, it is important that the algorithm knows what happens between those 2 moments.	1
The count should take place on time. In the ´dirty´/waste room you are too late. The count should have happened before the wound is closed!	1
The algorithm should not be used in every OR, but only during high-risk surgery with many instruments and with an open abdomen.	1
I wonder if the technology has any added value.	1

Table 9.4: This table shows the final remarks and suggestions from the participants. A total of 8 participants made a final remark or suggestion and 2 participants gave the same suggestion.

IV

Part 4 – Discussion & Conclusion

10
Discussion

This chapter discusses the results found in chapters 8 and 9. Both the observations made in the OR and the staff survey gave insights into what is important when implementing a computer vision algorithm in the OR for instrument counts. These insights resulted in a new set of design focus points for the algorithm and the test setup. These focus points are discussed in section 10.1. In section 10.2, recommendations are given on what future research should look at. What should be the next steps in the research on automatic instrument counting in and around the OR?

10.1. Focus points during the implementation of computer vision algorithms in the OR

The results from the observations and the staff survey showed that the most important focus points during implementation should be:

- a line of sight between the camera and the instrument(s);
- dealing with instruments being taken away from and added to the instrument table;
- controlling the light conditions around the instrument table;
- recognizing the specific type of some instruments;
- showing clear feedback.

These focus points are discussed in order of importance in the following subsections.

10.1.1. A line of sight between the camera and the instrument(s)

When using computer vision, having a line of sight is the most important requirement. A lot of the influential factors discussed in chapter 8 decrease the performance of the algorithm because they remove the line of sight between the camera and the instrument(s). Consequently, the accuracy of the algorithm decreases making it unusable. According to the staff survey, accuracy should be the most important characteristic of the technology.

Various objects can block the view of the camera. These objects are, for example, disposable material, instrument nets, other instruments, sterile instrument bags, top layers of double-layered instrument nets, screw boxes and sterile sponges. Because instrument tables are often very messy and overcrowded, there is no space to neatly lay out all the equipment on the table. Consequently, equipment (partly) covers instruments causing them to be invisible for the camera. It is absolutely crucial that all instruments are visible for the camera. However, with the current working methods, it is often impossible to achieve this.

One should consider to only look at the instruments that are taken out of the net and laid out on the instrument table. These are the instruments that are used most frequently during surgery. They either lie on a small part of the instrument table or on a separate table: the usage table. Scanning only these instruments might already give valuable information about instruments that go missing during surgery. The instruments that remain in the net will not go missing during surgery as they are not handled. Only the handled instruments, which are on the table, could go missing. It should be investigated if scanning only the laid out part of the instruments could already give valuable feedback to the operation team.

The line of sight is also blocked when an instrument is in the hands of the staff or on the patient's legs. In both situations, the instrument is being used and removed from the instrument table. A survey participants gave the example of needle holders and tweezers being in the surgeon's hands during the final counts before the wound is closed. Other survey participants remarked that a possible error given by the algorithm in these situation should not stop the surgery. The OR assistant knows that these instruments are being used and should have the opportunity to ignore the error. The algorithm should tell which instruments are missing and the assistants should complement on that information with their own knowledge of the situation.

10.1.2. Dealing with instruments being taken away from and added to the total set

It often occurs that instruments are taken away from or added to the total instrument set on the table(s). In these cases, it is important that the algorithm's expectation of which instruments should be on the table is updated.

Instruments are for example taken away from the table when they become non-sterile or unusable. These instruments do not return to the table until the end of surgery when the wound is closed. Therefore, they are not important during the operative instrument counts and the algorithm should not give an error because they are not on the table. The OR assistant should be able to let the algorithm know that the non-sterile/unusable instrument should not be considered in upcoming counts.

Instruments are added to the total set of instruments when a crucial instrument becomes unusable or when something unexpected occurs that requires different instruments. The algorithm's list of present instruments should be updated to prevent unnecessary errors because it counts too many instruments.

The goal of using computer vision is to assist in or even take over the instrument counts. This means that the computer vision has to reduce the amount of tasks of the OR assistant and not add new ones. This resulted from the staff survey as well. Therefore, is it not preferable that the OR assistant updates the list of present instruments herself. This list should be updated automatically without human interference.

10.1.3. Controlling the light conditions around the instrument table

The factors in section 8.1 showed that the light conditions in the OR could be a large influential factor for the algorithm's performance. Shadowing, bright 'blind' spots and illumination changes could all have a negative influence. Changing the ceiling or operation lights in the OR is not an option but it is recommended to determine the light conditions around the instrument table yourself.

Two possible additions to the test setup are a flash or an additional light. It is very important that this light shines evenly and straight on the instrument table. This will reduce shadowing and increase the contrast between the instrument and the background cloth. Furthermore, it reduces the illumination changes enough for the SIFT algorithm to deal with them. The additional light is preferred over the flash as the flash will disturb the operation team more.

The bright 'blind' spots are likely to remain a problem. Within these spots, the algorithm is unable to recognize any instrument. A flash or additional light is most likely not able to prevent these spots as the operation lights are so bright. The only option will be to move the instrument table away from the operation light before making the image.

10.1.4. Recognizing the specific type of some instruments

The survey showed that the algorithm's feedback should contain information about the amount and the type of instruments that is missing. However, observations in the OR showed that it can be difficult for the algorithm to always tell the specific type of the detected instruments. Even when the algorithm is able to determine that it 'sees' an instrument, it cannot always know the specific type. The value of the algorithm's feedback could drop sharply when it cannot tell which specific instrument type is missing.

Factors that decrease the ability of the algorithm to determine the instrument's type can have to do with the presence of specific instrument(s). This includes for instance the presence of instrument types in different sizes, deformable instruments and instruments that look like disposables, osteosynthetic material or implants. When these instruments are present, the algorithm will have a hard time determining either the size of an instrument or whether an object is an instrument that should be counted or not. Consequently, the algorithm will not know if all instrument types are present and give incomplete feedback to the end-user.

Different sizes of the same instrument can be distinguished when the algorithm can compare the length or width of the instrument with a fixed measure. This fixed measure can for example be the known length of a side of the instrument table. Using this measure, the algorithm should be able to determine the specific type of an instrument. Deformable instrument, like Cerclage or Kirschner wires, will be very hard to recognize as they will never exactly look like the instrument in the test images. It should be considered to skip the deformable instruments during the automatic counting and to leave the responsibility for their presence with the OR assistants. To prevent that reusable instruments are confused with disposables, osteosynthetic material or implants, the algorithm should be able to recognize equipment material and color as well. Material and color are characteristics that make the reusable instruments distinctive.

Other factors that make it harder to recognize an instrument type are instruments that appear in a weird position or incomplete in the image. This happens, for example, when the instruments stands upright against the side of the net or when the recognizable part of the instrument hangs over the side of a table or net. In these situations, the algorithm might be able to recognize that the detected object is a surgical instrument, but it will not recognize the type.

Although stating the specific type of a missing instrument is seen as valuable feedback, the algorithm is most likely not able to always do that. Therefore, it should be investigated how bad it is if the algorithm cannot recognize the specific type of instrument. What added value would the algorithm have when it can only describe an instrument more generically? Maybe the specific type of a retractor cannot be recognized but it can be recognized that it is a retractor. Furthermore, what is the added value when the algorithm can only count the instruments? You would still automate the count and know that there are instruments missing and how many.

10.1.5. Showing clear feedback data

The staff survey showed that live feedback is not preferred. At the RdGG, feedback on request at certain moments prior to, during and after surgery is preferred. The preferred moments at the RdGG are just before the wound is closed, prior to surgery in the deck space and after surgery in the OR.

The mentioned moments are not necessarily the same for each hospital. Just before the wound is closed and prior to surgery are interesting moments for each hospital. However, perhaps other hospitals will see more value in live feedback. This thesis primarily investigated the use of the algorithm for snapshots of the present instruments. The development of an algorithm with live feedback requires a large set of new design and feedback requirements Therefore, the important feedback characteristics are discussed only for the snapshot application.

Even when the algorithm is able to recognize all the instruments on the instrument table, the technology will not be used when the feedback is unclear and incomplete. According to the staff survey, the feedback should especially contain information about the kind of instrument that is missing and the amount of instruments that is missing. Adding more numbers to, for example, a feedback screen is unnecessary and makes the feedback less clear. Knowing which instruments and how many are missing does result in a clear assignment for the staff. Information about the number of instruments that the algorithm actually counts and the number of instruments that should be present could be made available as well on request. The basic premise remains that the feedback should be easy to read and understand.

The staff survey showed also that the feedback should include an indication about whether all instruments are present. This could be a screen that turns green when all instruments are present and red when they are not. This feedback system is used in the Digital Operation Room Assistant (DORA) in the ORs of the hospital as well. This system detects whether most larger necessary equipment is present in the OR, maintained properly, up-to-date regarding software and ready to use. When the display of the DORA is green, the surgery can start. Another example could be to give an auditory signal when an instrument is missing. As a result, the OR assistant will not have to look at the feedback extensively but will quickly know whether something is wrong.

10.2. Future research

The research into the use of computer vision for surgical instrument detection is still in a preliminary stage. Computer vision shows great potential in other research fields, but it has not yet been tested for detecting surgical instruments in the OR. This section describes the recommended follow-up steps in developing the algorithm and testing it in the OR.

The suggested research approach in this thesis is to first look at the workflow and the activities regarding surgical instruments before extensive development of an algorithm. This resulted in the focus points discussed in section 10.1. Most of the focus points can be tackled by further development of the algorithm and the test setup. However, a line of sight between the camera and the instrument(s) cannot always be guaranteed, even with an improved algorithm or test setup. Therefore, the approach of future research should still focus on the workflow and activities as an absent line of sight is often caused by working methods.

Future research should primarily look into the possibility to change working methods in the OR. This change should focus on creating a line of sight between the instruments and the camera during the counting moments. When the changes in the working methods can be applied in and around the OR, research can focus on improving the algorithm and the test setup using the other focus points.

One of these focus points is the possibility of the algorithm to recognize the exact type of an instrument. However, one should consider whether it is necessary to recognize the type of instrument. Knowing the amount of instruments present and absent could already be very valuable.

There is a possibility that OR staff will not like to implement any changes in their working methods. However, guaranteeing a line of sight will be impossible without changes in the working methods. Consequently, future research should shift its focus.

Investigating the combined use of different object detection techniques is recommended. Previous methods for surgical instrument detection/tracking that were researched are the use of radio-frequency identification (RFID), scanning laser-etched QR-codes and instrument weighing. Each method has its own flaws, including computer vision. The combined use of multiple methods could overcome these individual flaws. For example, combining RFID with computer vision could resolve the problems regarding the line of sight as RFID does not need one.

11
Conclusion

This thesis described a project in which the use of a computer vision algorithm during instrument counts is investigated in the OR of the RdGG. This is done using the following research question:

> *" What is the feasibility of using a computer vision algorithm to automatically detect and count surgical instruments and what are potential factors that influence the performance and the implementation in the OR?"*

This question is answered in the following steps. Firstly, the instrument cycle and the SIFT algorithm, a specific type of computer vision algorithm, were described in general. Thereafter, the specific instrument cycle of the RdGG was described in detail. This description resulted in different application options for computer vision and different design scenarios. Thirdly, the test procedures that can be used specifically for the design scenario in the OR were outlined. These procedures could result in numerical detection results, observations and staff survey results. This thesis did not include numerical detection results. Finally, using the observations and survey results, 5 important focus points for the potential implementation of the algorithm in the OR were described and recommendations were made for future research. These focus points and recommendations are used to answer the research question.

The current feasibility of using computer vision to automatically detect and count surgical instruments is low. SIFT computer vision algorithms seem well-suited for the task at hand, but current SIFT algorithms are not able to automatically perform the instrument counting process yet. Observations in the OR and the staff survey showed that there are a lot of factors that need to be taken into account before the feasibility of using a computer vision algorithm is high enough to implement it successfully in the OR. These factors could all negatively influence the algorithm's performance.

The first factor is realizing a line of sight between the camera and the instruments when an image is taken. Without this line of sight, computer vision is not able to detect any instrument. This line of sight can only be created by changing working methods of the operation team or complementing the algorithm with data from other detection techniques.

The second factor is being able to update the table content list which could change during surgery. Instruments and nets are taken from or put on the table sometimes. The algorithm must always know the up-to-date amount of instruments that should be on the table.

The third factor is making sure that you can create your own light conditions on the instrument table. Light conditions change often in the OR and can create shadowing, illumination changes and bright 'blind' spots. It is recommended to do this by adding a light to the test setup that shines evenly on the instrument table.

The fourth factor is being able to recognize the specific type of instruments. Many factors make it difficult for the algorithm to do this. However, recognizing the instrument type is necessary to distinguish between reusable instruments and other equipment and to give feedback about which specific instruments are missing.

The fifth factor is showing very clear feedback to the operation team. The preferred feedback includes the amount of missing instruments together with their types. The algorithm should also show a 'go' or 'no go' to the team, for example, in the form of visual or auditory feedback. Without clear feedback, the technology becomes worthless.

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A

Staff survey for OR-assistants and surgeons

<The staff survey starts on the next page.>

“Alle instrumenten aanwezig?! Of toch niet?”

Vragenlijst voor chirurgen en operatieassistenten RdGG

Technische Universiteit Delft & Reiner de Graaf Gasthuis

Auteurs: Jasper Keizer & Teddy Vijfvinkel

De handmatige telling van chirurgisch instrumentarium kan veel tijd en aandacht in beslag nemen. Een goede controle op de aanwezigheid van alle instrumenten is essentieel en leidt direct tot hogere patiëntveiligheid. Het beoogde doel van onze nieuwe technologie is om ondersteuning te bieden tijdens perioperatieve instrumententellingen.

Deze vragenlijst bevat 9 vragen en is opgesteld voor een project vanuit de TU Delft in samenwerking met het Reinier de Graaf ziekenhuis. Tijdens dit project wordt er gekeken naar een techniek genaamd ‘Computer Vision’. Dit is een soort computerprogramma, ook wel een algoritme genoemd, dat automatisch instrumenten kan detecteren, typeren en tellen vanaf een foto door middel van beeldherkenning. Tijdens verschillende operaties (liesbreuk & trauma ingrepen) zijn er afbeeldingen gemaakt van het gebruikte instrumentarium. Momenteel zijn we aan het testen hoe goed het algoritme de instrumenten op de afbeeldingen kan detecteren. Deze vragenlijst is vooral bedoeld om een beter beeld te krijgen van uw mening over het gebruik van ‘Computer Vision’ op de OK in de toekomst en wat u verwacht van een dergelijk hulpmiddel.

De resultaten van de vragenlijst zullen door ons gebruikt worden om een beter beeld te vormen van de implementatiemogelijkheden van de onderzochte technologie en om een beeld te krijgen van het draagvlak voor de technologie binnen het personeel van het RdGG.

Alle vragenlijsten en resultaten worden anoniem verwerkt. Voor eventuele vragen of opmerkingen kunt u Jasper Keizer benaderen (tel: … of email …)
Alvast bedankt voor uw tijd en medewerking!

1. Wat is uw functie in het Reinier de Graaf ziekenhuis?

____

2. Hoeveel jaar ervaring heeft u in uw huidige functie?

____

3. Ik ervaar wel eens uitdagingen en/of problemen tijdens de instrumententelling voorafgaand aan en tijdens de operatie.

- *Eens*
- *Oneens**

**U kunt vraag 4 overslaan als u dit antwoord hebt aangekruist.*

4. Welke uitdagingen en/of problemen ervaart u tijdens het tellen van chirurgisch instrumentarium? U mag meerdere opties aanvinken.

☐ *Het kost veel tijd om bij te houden of het instrumentarium compleet is*

☐ *Het is moeilijk om aandacht te verdelen tussen het tellen en alle andere perioperatieve taken*

☐ *Het is onduidelijk of de gebruikte set compleet is*

☐ *Het tellen van gazen en naalden kost meer tijd dan het tellen van de instrumenten*

☐ *Anders:*

____

____

5. Ik denk dat een computerprogramma dat automatisch chirurgisch instrumentarium kan tellen een waardevolle toevoeging kan zijn op de OK van de toekomst.

- *Eens*
- *Oneens*

Waarom bent u het eens/oneens met de stelling?

____

____

____

6. Er zijn verschillende aspecten belangrijk tijdens de ingebruikname van nieuwe techniek op de OK. Welke aspecten zijn voor u belangrijk met betrekking tot het gebruiken van een technisch hulpmiddel tijdens de telling van chirurgisch instrumentarium? U mag meerdere antwoorden aankruisen.

- ☐ *Nauwkeurigheid van de techniek*
- ☐ *Snelheid van de techniek*
- ☐ *Feedback van de techniek*
- ☐ *Mogelijke hinder van het hulpmiddel tijdens de operatie*
- ☐ *Eenvoud van gebruik van het hulpmiddel*
- ☐ *Anders:…*

7. De feedback die het computerprogramma uiteindelijk geeft aan het OK-personeel moet heel duidelijk zijn. Het idee is dat de feedback informatie bevat over de aanwezigheid van instrumentarium op de instrumententafel. Welke feedback is volgens u belangrijk? U mag meerdere antwoorden aanklikken.

- ☐ *Aantal instrumenten dat het computerprogramma daadwerkelijk telt*
- ☐ *Aantal instrumenten dat mist volgens het computerprogramma*
- ☐ *Het soort instrumenten dat mist (bv. wondhaak Langenbeck of repositietang Weber)*
- ☐ *Aantal instrumenten dat aanwezig zou moeten zijn*
- ☐ *Een kleur die aangeeft of alle instrumenten er zijn (groen = go; rood = no go)*
- ☐ *Anders:…*

8. Feedback over de aanwezigheid van instrumenten kan op verschillende momenten tijdens een operatie gegeven worden. Op welke momenten tijdens een operatie zou u graag feedback willen ontvangen van het computerprogramma? U mag meerdere antwoorden aanklikken.

- ☐ *Voorafgaand aan de operatie, in de opdekruimte*
- ☐ *Voorafgaand aan de operatie, in de OK*
- ☐ *Op aanvraag tijdens de operatie*
- ☐ *Vlak voor het sluiten van de wond*
- ☐ *Na de operatie, in de OK*
- ☐ *Na de operatie, in de retour-/'vieze'-ruimte*
- ☐ *Live feedback tijdens de hele operatie*
- ☐ *Anders:…*

9. Heeft u nog andere op- of aanmerkingen aangaande het gebruik van een technisch hulpmiddel voor automatische telling van chirurgisch instrumentarium op de OK?