University of Twente

Master thesis

Multimodal user interface for robotized flexible endoscopy

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Contents

Abstract

This thesis has set out to describe the creation of a multimodal interface that is to be used in combination with a robotized system for controlling a flexible endoscope. It falls within the TeleFLEX project that is conducted as a cooperation between Demcon, located in Oldenzaal, the University of Twente and several hospitals located in the Netherlands.

First, an introduction about the main topics is given. These topics include endoscopic procedures, the TeleFLEX project, the human factors that are associated with endoscopic procedures and the reason behind the steps taken in the process. Following the introduction, an analysis was conducted which resulted in information about the working environment in which endoscopic procedures are conducted, the end users of the interface and the tasks that the end users perform now and are going to perform in the future when using the interface. The future tasks will be executed using a system to help the therapist perform

Based on the information gained in the analysis, requirements were created for the system. The requirements consist of critical requirements (for example, the endoscopic output should always be visible), situation dependent requirements (for example, the settings of the system should be adjustable) and additional requirements (for example, the system should have setting profiles).

The information from the analysis and the requirements were then used in iteratively designing the interface, with each iteration consisting of creating one or more designs and letting these designs be evaluated. After three iterations, a prototype was created consisting of two screens with one screen presenting the endoscopic output and the other additional functionalities.

After completing the iterations and having one prototype and two possible setups for that prototype (seperate screens or a console setup), an experiment was conducted to test the prototype on effectiveness, efficiency and satisfaction in a high workload situation, comparing the two different setups. In this first experiment, there appeared a small preference for the seperate screen setup, with this setup scoring a bit better on all three factors. Several observations were made in regard to the usage as well as the layout of the interface.

The results from the first experiment and the made observations were then used to finalize the prototype into a system. Still using two monitors, the system has more color and better distinguishes between important and less important information.

The final system was again tested in an high workload setting. The system in itself scored acceptable on the three factors earlier mentioned. Compared to the first experiment, the results remained mostly the same. Again some observations regarding the complete system were made.

After the second experiment, it was concluded that the information that is present in the system is at this time sufficient. Considering the information gathered in the analysis and during the two experiments, a choice was made to combine the two setups and give therapists the possibility of deciding themselves which setup they prefer. The addition of audio is imperative in the system, but should mostly be used for errors and warnings, as not to divert the attention of the therapist unnecessarily.

As soon as the mechanical parts of the TeleFLEX project are introduced, the interface should be tested in combination with the interface, as this will give a more thorough insight in which parts of the interface can and should be improved to optimally facilitate the therapists in their jobs. The experiments as used in this thesis could be used as prototypes for future testing.

1 Introduction

With the development of novel technologies it has become possible for therapists (doctors and surgeons) to conduct a procedure (examination or surgery) without having to make any external incisions into the body of the patient. By using this kind of technique, it can become possible to perform surgery on the inside of the body of the patient using one of the patients natural orifices. This kind of procedure is termed as Natural orifice transluminal endoscopic surgery (NOTES). To be able to conduct these kinds of procedures, flexible endoscopes are used.

An endoscope is a flexible tube that is entered into the body of the patient using natural orifices (mouth, anus or vagina). In this thesis, the focus will be on procedures that use the anus as the natural orifice for either colonoscopy (examination) or colon surgery. For both the colonoscopy as well as surgery, the endoscope has to be moved to the beginning of the colon (at the end of the small intestine). This is done by the therapist who uses the dominant hand (most often the right hand) to insert the endoscope and the non-dominant hand (most often the left hand) to control the tip of the endoscope. Once the beginning has been reached, the endoscope will slowly be retracted, stopping at locations which are of interest to the therapist (most often polyps). The polyp is photographed and will be filed for the planning of the follow up surgery. If the polyp is small enough, instruments that are used to remove the polyp will be entered through the endoscope and the polyp will be removed and collected. Once the examination or surgery is successfully completed, the endoscope will be completely retracted from the patients body.

There are both up- and downsides to an endoscopic procedure. The upside is that the postprocedure physical trauma for the patient is reduced and the post procedure care is shortened. The downside is that patients are semi conscious during the procedure and can experience pain due to the stretching of the colon. For therapists, the down side to the usage of the endoscope is the challenging control that is needed to successfully complete a procedure. The endoscope is considered to be hard to use due to non-ergonomic single hand control and the need for a team of medical professionals to assist with the use of the different instruments while controlling the endoscope (Shergill et al., 2009). These factors result in physical discomfort for the therapist and/or might also result in medical errors, which have a negative effect on the health of the patient.

To improve the comfort and performance of the therapist, the TeleFLEX project was started. The goal of this project is to create a multi modal system used for telemanipulating a robotized flexible endoscope. It is important to note that inserting the endoscope will be done manually because of the necessary force feedback. The system will be active during the insertion, but will not have any control over the entry of the endoscope.

The TeleFLEX project has four modules which will be added to the endoscope, making it possible to stepwise introduce the new system into the clinic. These modules are 1) the robotizing of the control of the tip of the endoscope with the manipulation done on a touchpad, 2) robotizing the endoscopic shaft movement, adding a master console for control, 3) robotizing the instrument insertion and usage, and 4) creating a multi modal master console for all of the existing functionality as well as additional features (e.g. vital signs, retrieving patient information). This thesis falls within the fourth module. A scientific approach will be taken in developing the multi modal part of the system that is responsible for communicating task relevant information to the therapist and providing required controls to manipulate this information. It will result in a prototypical system, with a validation of user friendliness and the goal of trying to increase the overall performance of the therapist.

To obtain this goal, certain steps in its development will be taken. Beuscart-Zéphir et al. (2007)

stress the importance of the more prominent role human factors engineering should play within the development of biomedical systems in the clinic. The authors propose a human factors engineering framework to be followed in the development of these systems. The first analysis done in the human factors engineering framework is to get the goals and expected benefits of the system clear. Next, an analysis of the work situation, also known as the socio-technical system, is done. This includes the users, tasks, technology, characteristics of the care process and local, national and possibly international constraints on the system. Then a cooperative design phase takes place in which the requirements for the system are created. This is followed by an iterative evaluation phase in which prototypes are tested on the created requirements. Once the requirements are met, the product can be used for placement. The last step following product placement consists of an ongoing monitoring on any changes to the working environment in which the product is placed, changing the system where necessary to obtain any new requirements that arise due to these changes.

Due to the smaller part of the TeleFLEX project and the prototypical product that will be the result of this thesis, a shorter version of the human factors engineering framework will be used. The analysis of the goals and expected benefits is skipped, as these are set by the TeleFLEX project. The analysis of the socio-technical system will be done, although no description of the characteristics of care process is given and the constraints to create a certified product that conforms to international standards and directives will not be discussed due to the prototypical product that is required. An addition is made by incorporating a specific task analysis of the procedure, both with pre- and postprocedure tasks. This analysis will be used to develop requirements for the system. After these requirements, the cooperative design phase will start in which one or more prototypes are created based on the requirements. During this phase, a prototype will become more sophisticated after several design phases, eventually resulting in an operational system. In the iterative evaluation, the operational prototype(s) will be tested in an experimental setting. The resulting system and future research in regard to that system will be discussed. The monitoring part is omitted, again due to the prototypical nature of the system.

2   Analysis of socio-technical system

Before the development of (a prototype of) a system can start, an analysis of the socio-technical system is done. This analysis entails a scenario description of a non sterile intraluminal colonoscopy without an in depth discussion of the colonoscopy actions taken. Although the system can eventually also be used for a sterile, transluminal intervention (NOTES), only a small amount of this thesis will be spend on design choices in regard to this procedure, because the procedure is not a common practice in hospitals at this time. More advanced interface developments that are needed for the NOTES procedure will be discussed further along in the TeleFLEX project.

The scenario of the colonoscopy is followed by a description of the users for which the system is being developed, the current working environment of these users and the technology they are familiar with, and concluded with the tasks that the users have to perform during such a procedure. This task analysis will consist of both the current procedure and the procedure using the new system, considering all of the four modules.

The analysis will be done based on information from several sources. The first source is semi-open ended interviews that were done with therapists that perform endoscopic procedures in different medical domains. These interviews were already conducted within the TeleFLEX project. The information gained from the interviews will be recapitulated here. A total of five therapists have been interviewed, consisting of two gastro-entereologists, two cardiac therapists and one urology therapist. In these interviews several topics in regard to current endoscopic usage were discussed with the main topics being procedural knowledge, feedback received by the therapist using a flexible endoscope, manipulation of the flexible endoscope, ergonomical issues, ethical issues and opinion of robotic technology in the clinic.

The second source of information is the attendance of a laparoscopic procedure using the DaVinci system and an examination using a flexible endoscope in the Meander Lichtenberg hospital located in Amersfoort, Netherlands. The DaVinci is a surgical system developed by Intuitive Surgical. It enables the surgeons to perform complex laparoscopic procedures with robotic arms and an isolated console (for an impression see figure 2.0.1) with advanced technologies like tremor filtering, scaling of movements and three dimensional vision. Next to the information from both attendances, videos of endoscopic procedures as created by Waye et al. (2009) are also used. The attendance is used to describe a scenario of the procedure which will be used for a general task analysis, including pre- and post procedure tasks. The videos enable a more specific task analysis of the examination or surgical procedure as it is conducted. The combination of the attendance and the videos is described in the *Scenario* section. The resulting task analysis of the existing procedure as well as the procedure including the new system is to be found in the *Tasks* section.

The knowledge obtained from the interviews, videos and attendance of the endoscopic procedures will be combined with current empirical research. This third source of information will broaden the acquired knowledge with the a higher number of user based information and information gained from endoscopic procedures. It will also grant experimental results about the socio-technical system that might not have been obtained with only interviews and observations of procedures.

Figure 2.0.1: Image of the DaVinci console as developed by Intuitive Surgical and used in the Meander Lichtenberg hospital

2.1   Current scenario: Colonoscopy

Figure 2.1.2: The setup as used in current colonoscope procedures

Before the procedure is started, the attending nurses prepare the outpatient room. The first nurse boots up all the needed electronical units. The second nurse goes to the so-called dry room where the endoscope was left to dry after being cleaned after the last procedure. The nurse then attaches the video output of the endoscope to the master information unit. The first nurse checks the settings of the system and sets them to the preferred values of the therapist if this is not already the case.

During this time, the doctor reads through the patient file. Based on this information, the therapist plans a course of action for the execution of the procedure.

The nurses get the patient. After the patient is brought in, the therapist and nurses introduce themselves to the patient. If the patient has any questions, they are answered by the therapist. The patient is then placed on the table. The nurse attaches the necessary tools for the vital sign measurement. A needle is entered into the blood vein of the patient. A nurse fills a syringe with a sedative. The patient is then injected with the sedative. After a check to see if the patient is sedated, the procedure is started.

The endoscope is entered at the anus. The therapist enters the endoscope with his right hand. He controls the direction of the endoscope with the use of gears on the control element of the endoscope. The endoscope goes through the rectum and moves through the sigmoid colon. If a loop in the sigmoid colon is present (see figure 2.1.3a and 2.1.3b), the therapist will take the necessary steps to remove the loop (figure 2.1.3c). Then the endoscope is moved through the descending and the transverse colon. The endoscope is moved in such a way that the transverse colon can be pulled straight (figure 2.1.4). As soon as the ascending colon is entered (figure 2.1.5) the entry to the small bowel has to be found. At this point, the therapist knows he has found the beginning of the large intestine and can start the planned procedure.

Figure 2.1.3: Figure showing the positioning of the sigmoid colon with a (a) 'N' loop and a (b) 'alpha' loop formation, as well as a (c) straightened formation
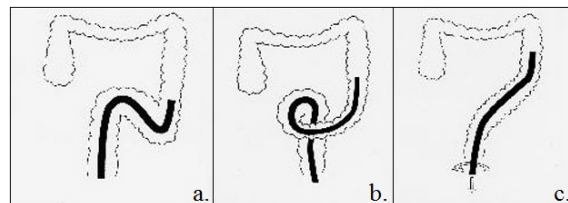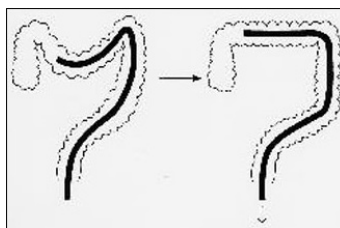

Figure 2.1.4: Figure showing the endoscope moving through the transverse colon

The therapist slowly pulls back the endoscope with his right hand. In the meantime, he looks at the video output from the camera and looks for any abnormalities (e.g. polyps, worms, dangerous

food remains like bones). A polyp is discovered and a picture is made which is saved digitally on the main information unit. The therapist studies the video input and decides that the polyp is small enough to remove at this time.

First he asks the nurse to get the saline solution. The therapist moves the endoscope just under the polyp and the nurse makes an injection of the saline. The polyp rises of the colon wall. The nurse then hands a snare to the therapist. The therapist enters the snare into the endoscope. The snare is moved over the polyp and is placed at the base of the polyp. The therapist instructs the nurse to close the loop. The loop is closed just under the polyp. The therapist then sends an electrical current through the loop. This dissects the polyp from the colon wall. The base of the polyp starts to bleed. The therapist looks at the vital signs of the patient to see if nothing is wrong. Seeing as the vital signs have not changed dangerously, the nurse is instructed to give the therapist the argon plasma coagulation. He removes the wire loop and enters the coagulation. Before using the burner, the therapist flushes away the blood using a spray of water. Then the burner makes a superficial burn to stop the bleeding as well as remove any remaining polyp tissue. He injects the wall near the base of the polyp with India ink making it easier to recognize in a possible check-up or follow-up procedure. A mesh basket is entered into the endoscope, which the therapist uses to retrieve the dissected polyp and pull it out of colon by extracting the endoscope from the patient's body.

After the endoscope is extracted, the polyp is released from the mesh basket and is moved to the laboratory for research. The patient is moved from the outpatient room to the recovery room. Another nurse disconnects the endoscope and takes it and the used instruments into another room where they are cleaned either by a nurse or by another assistant.

In the meantime, the therapist looks through the pictures that have been made and selects the ones that might be relevant for future referencing. He also uses a template report to describe what he did during the procedure, changing the template if deemed necessary. The pictures and the description are printed two times, one for the patient file and one for the overview of the procedures of the day. The complete procedure took 32 minutes.

Figure 2.1.5: Figure showing the endoscope moving into the ascending colon
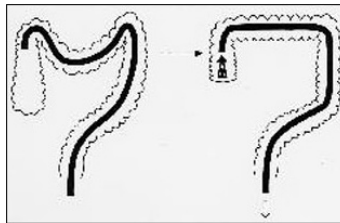
2.2 Users

The system is being developed for therapists that are specialized in the domain of the intestines, more specific colonoscopy and colon surgery. These therapists have a ranging experience in endoscopic procedures from junior to senior, with the former being able to learn new skills in minimal invasive surgery (which is comparable to NOTES) more easily (Salkini and Hamilton, 2010) and the latter being able to perform better with the current endoscopic technology (Datta et al., 2006).

Other users will be the nurses and any additional staff that perform the setup of the outpatient

room and conduct the additional tasks that come with an endoscopic procedure. Although they will not be the main operators of the system, the development of the system will also take their tasks into account.

2.3 Work environment: The outpatient room

The working environment of the therapists and staff consists of an outpatient room. The room is filled with equipment consisting of but not limited too a patient bed, a console showing the vital signs of the patient, an instrument table, main control unit for the flexible endoscope, screen for video output from the endoscope, and a computer console used for the postprocedure tasks. The therapist is standing on one side of the bed on which the patient is laying, with the endoscope unit and instrument table behind him. The screen showing the endoscopic output is located on the other side of the bed. The console showing the vital signs is located at the head of the bed on the same side as the screen with the video output. The post procedure computer console is located on a desk somewhere near the wall in the room. This setting was observed in the Meander hospital in Amersfoort, so is not expected to be generally used throughout hospitals. Around three staff members will be present in the room during the current procedure.

The outpatient working environment can have several factors that negatively influence the effectiveness (procedural quality) and efficiency (procedure time) of a procedure. These factors are physical (work clothing, space and product manipulation), visual (lighting, location of monitors, eye fatigue and headaches) and cognitive (product manipulation and complicated tasks) in nature (van Veelen et al., 2003). These factors will be taken into account during the development of the system.

2.4 Technology

The TeleFLEX project is focused on facilitating the current tasks of the medical staff. This means that the therapists are (expected to be) familiar with the use of flexible endoscopes and the instruments as described in section 7 (chapters 21 to 26) in Waye et al. (2009). The familiarity and experience is dependent on the level of expertise of the therapist as mentioned earlier (Datta et al., 2006). It can be assumed that the therapists are also familiar with more general computer systems as used in a medical or personal setting, with skills relating to using templates and forms, navigating through menus and using different input modalities like mouse, keyboard and touchscreen.

The technology that will be added within the TeleFLEX project will be a mechanized unit that will control the movement of the flexible endoscope, the instruments (both embedded and entered) and a touchpad to control the direction of the movement and several other functionalities of the endoscope. The mechanized unit will house the flexible endoscope which can be inserted and extracted from the unit. It will also have entries for the instruments that can be inserted into the endoscope. This unit will result in additional tasks for the users and will be incorporated in the task analysis. It will be considered as the slave unit for the remains of the thesis. Another unit will be used as the master console, which will depict information and grant control of the slave unit.

2.5 Tasks

The task analysis will take into account both the current working procedure of the medical staff and the procedure when the robotized system would be introduced. The analysis will be divided in preprocedure tasks, the tasks during the procedure and the postprocedure tasks.

Due to the availability of video material, the task analysis of the procedure itself will be more extensive than the pre- and postprocedure task analysis, which will only be based on the attended procedures.

The analysis will not give an extensive description of all the tasks that are done. The complete overview of the tasks can be found in appendix A. The most important tasks are described below. Each part of the procedure will have one or several lists. These lists will have three colums, with the first containing the tasks in the current procedure and the second column containing the tasks in the procedure as it wil be performed with the robotic system and the user interface. The third column will give a rational about why the current task is replaced with the future task.

2.5.1 Preprocedure

The tasks that are performed with the system before the procedure are listed here. These tasks as well as tasks that do not make use of the system can be found in the more thorough analysis which can be found in appendix A.1.

Task present	Task future	Rational
-	Placing endoscope in slave unit	To control the endoscope using the interface, the endoscope will have to be put in a slave unit which controls the movements of the endoscope based on the input from the therapist
Change settings of master console	Change settings of master console and slave unit on the master console	The amount of settings will increase in the new interface, with the settings having to be set for optimal performance by the therapist
-	Change settings of master console and slave unit on the master console, using an existing therapist settings profile	Using a master console makes it easier to make setting profiles and to use these profiles to make the preprocedure quicker
Accessing patient file in office	Accessing patient file on the master console	The patient file should be accessible at any time before, during or after a procedure. Incorporating the access to the file into the console makes this possible
Starting procedure by entering endoscope	Starting procedure by entering the endoscope, assisted by the system	The system will make it possible for the therapist to more steadily enter the endoscope, using a touchpad for more intuitive maneuvering

Table 2.5.1: Preprocedure tasks in the present and the future, with a description about the future tasks

2.5.2 Procedure

During the procedure, there are three main tasks that can be performed: maneuvering the endoscope (table 2.5.2), using the embedded instruments (table 2.5.3) or the additional instruments (table 2.5.4). The latter two task lists have tasks that are very similar, with the only difference being the used instrument. Tasks given can thus be applied to several instruments, as can be found in tables A.2.2 and A.2.3 in appendix A.2.

Task present	Task future	Rational
Manually controlling the direction of the endoscope during entry	Using touchpad to control the direction of the endoscope during entry	The touchpad is used for a more intuitive control of the direction of the endoscope as opposed to the gears that are currently used
Manually retracting the endoscope	Using console to retract the endoscope	By using the system, it is possible to control a more continuous movement of the endoscope
Using the gears at the end of the endoscope to control the movement of the tip of the endoscope	Using the touchpad to control the movement of the tip of the endoscope	The touchpad will make use of a more intuitive way of controlling the tip of the endoscope
Knowing the position of the endoscope by knowledge and experience	Knowing the position of the endoscope with help of a spatial orientation device	The spatial orientation device output will help the therapist in complex situations
Keeping the endoscope stable by letting an assistant hold the endoscope	Keeping the endoscope stable by letting it rest in the slave unit	No additional tasks need to be performed in the future, since the endoscope is already in a stable position

Table 2.5.2: Tasks performed to maneuver the endoscope in the present and the future, with a description about the future tasks

Task present	Task future	Rational
Executing the main feature of an embedded instrument (i.e. suctioning away fluids, blowing gas into intestine, cleaning lens, making photo or video) with a button located on the endoscope or a foot pedal	Executing the main feature of an embedded instrument by pressing the necessary button on the master console	All of the instrument options are combined into the master console, giving the therapist quicker access to all the functionalities

Table 2.5.3: Tasks performed with the embedded instruments in the present and the future, with a description about the future tasks

Task present	Task future	Rational
Inserting instrument in endoscope	Inserting instrument in slave unit	Once the endoscope is located in the slave unit, instruments will be entered through an entry in the slave unit
Maneuvering the entered instrument by manually moving the endoscope, possibly placing the instrument on the colon tissue	Maneuvering the entered instrument by using the controls at the master console	Moving the endoscope can be done with increased dexterity due to the sensitivity and scaling options of the controls of the system
Executing the main feature of an entered instrument (i.e. increase snare or mesh basket size, starting and stopping coagulation) with a button located on the endoscope or a foot pedal	Executing the main feature of an entered instrument by pressing the necessary button on the master console	All of the instrument options are combined into the master console, giving the therapist quicker access to all the functionalities

Table 2.5.4: Tasks performed with the additional instruments in the present and the future, with a description about the future tasks

2.5.3 Postprocedure

The tasks that are performed with the system after the procedure are listed here. A more extensive list of tasks can be found in appendix A.3.

Task present	Task future	Rational
-	Endoscope is removed from slave unit	Since the endoscope has been placed in the slave unit, it will have to be removed for cleaning
The therapist writes a report, with images, of the procedure on one of the desktop computers	The therapist writes a report, with images, on the master console	Immediately writing a report after the procedure will increase the report's accuracy

Table 2.5.5: Postprocedure tasks in the present and the future, with a description about the future tasks

3   Requirements

This section will discuss the requirements that the system will have to adhere to. They are created based on the previous section and any additional literature. A requirement consists of the requirement to the system, the rationale behind creating the requirement, the actors that are (possibly) involved, the objective the system tries to achieve by adhering to the requirement and the expected positive effects on the performance of the operators and the well-being of the patient that result from implementing the requirement. The negative effects should be seen as possible risks that might arise by implementing the requirement.

A subdivision is made between several requirements. The division consists of critical requirements which are imperative in the development of the system and will have the highest priority in the design of the system. These are followed by requirements that are situation dependent. These requirements are also imperative, but only in situations in which the need arises for the functionality. These requirements will also have a high priority in the design process, since the occuring situations might be life threatening for a patient. The last division of requirements are the system wishes, refered to as the additional requirements. These requirements do not have to be incorporated into the system, but do provide some additional value on top of the other requirements and to the overall system. They will have the lowest priority being incorporated in the design of the system.

3.1   Critical requirements

Requirement 1	**The video output of the endoscope should be visible during the complete procedure**
Rationale	As can been seen in a large number of tasks in the analysis of a procedure (e.g. task 17, 19, 21, 39, 41, 48, 83 in tables in appendix A), the endoscopic output is used for orientation during maneuvering. Visual feedback is needed to perform these tasks succesfully, without errors, resulting in the necessity to present the endoscopic video output at all times
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Granting the therapist continuous access to the video outut of the endoscope
Effects	No effects are discussed because this functionality will be implemented in disregard of any negative effects

Table 3.1.1: Requirement 1

Requirement 2	**A presentation of the information of the location of the endoscope in the body of the patient should be available during the complete procedure**

Requirement 2 continued from last page	
Rationale	A spatial orientation device was used during procedures as can be seen in the videos provided by Waye et al. (2009), with the therapists being able to identify loops in the intestine and deciding on the right interventions to remove these loops. Although not used by the interviewed therapists or in the attended procedures, the use of a spatial orientation device has proven to be useful in endoscopic surgery (Cao, 2001) as well as with NOTES (Fowler et al., 2011). So the possibility to depict this information is necessary within this system
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Granting the therapist and optionally the medical staff information about the location of the endoscope in the body of the patient

Effects	+	Knowing the location of the endoscope will increase the situation awareness of the therapist
	+	By knowing the location of the endoscope, the therapist will be capable of completing the procedure more quickly
	-	Having only partial information about the location of the endoscope will hinder the performance of the therapist

<div align="center">Table 3.1.2: Requirement 2</div>

Requirement 3	A representation of the spatial orientation of the endoscope tip should be available during the complete procedure
Rationale	Several therapists mentioned during the interviews that they would like information about the orientation of the tip of the endoscope. This has proven to reduce the amount of errors being made and would also decrease the workload (Cao, 2001)
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Granting the therapist and optionally the medical staff information about the orientation of the tip of the endoscope

Effects	+	Knowing the orientation of the tip of the endoscope will increase the situation awareness of the therapist
	+	By knowing the orientation of the tip of the endoscope, the therapist will make less errors during the procedure
	-	Having partial information about the orientation of the endoscope will hinder the performance of the therapist

<div align="center">Table 3.1.3: Requirement 3</div>

Requirement 4	**Vital signs measurements should be presented during the complete procedure**	
Rationale	Representing the vital signs of the patient is a common during an endoscopic procedure. It is needed to ensure the safety of the patient. Thus, it should be implemented in this system	
Actor(s)	Therapist; Additional medical staff (optional)	
Objective	Granting the therapist, and optionally the medical staff, information about the well-being of the patient	
Effects	+	The integration of the vital sign depiction with the system will remove the necessity for the additional equipment for vital sign measurement in the polyclinical room. The resulting space can be used by the staff, increasing the performance of the team
	+	Having the vital sign measurements integrated into the system will reduce the time spent looking at another screen by the therapist, decreasing possible errors by loss of attention
	-	An added source of information might lead to an cognitive overload or loss of attention

Table 3.1.4: Requirement 4

Requirement 5	**The system has to relay a warning signal using audio and visual modalities when a problem in the system or with the patient occurs**	
Rationale	Communicating warnings is common practice in the medical profession. The combination of audio and visual modalities works best with expert therapists, with the novice therapists often focussing on the visual part of the screen and missing the audio (Tien et al., 2010). The combination of video and audio will result in less errors and a higher level of usability (Brewster, 1997)	
Actor(s)	Therapist; Additional medical staff (optional)	
Objective	Granting the therapist and optionally the medical staff information about any problems or errors that arise during a procedure	
Effects	+	Due to the multi modality of the warning, the chances of detecting a problem by both novice and expert therapist increases, limiting the possibility for errors

Requirement 5 continued from last page		
	+	The warnings will result in the therapist becoming aware of his surroundings, having an increased situation awareness
	-	The multi modality might distract the therapist during a critical moment, increasing the number of errors

Table 3.1.5: Requirement 5

Requirement 6	The information presentation of the system has to enable the operator to easily retrieve the information that is necessary for succesfully completing the procedure	
Rationale	The amount of information that becomes available with the creation of this system can result in a cognitive overload of the therapist. Cognitive overload consists of the number of decisions that need to be made, number of interruptions, time pressure and the drive to be efficient (Kirsch, 2000). The cognitive overload will be especially present if all of the information is presented visually (Brewster, 1997). Developing the system to prevent this is thus a necessary requirement	
Actor(s)	Therapist	
Objective	The information presentation is created in such a way that cognitive overload is lowered, enabling the therapist to quickly retrieve important information	
Effects	+	The system will enable the therapist to have a better performance by making it easy to access important information and implementing the use of additional information
	-	The system might overload the therapist with information, resulting in a lower level of performance

Table 3.1.6: Requirement 6

Requirement 7	The system needs to give feedback about the current status of all of the parts within the system
Rationale	Therapists and medical staff are responsible for the well-being of a patient. This means that the therapists would like to have total control of the system, as was mentioned in the interviews with the therapists. To know when to intervene, the therapist has to know what the system is doing and if the system is suffering any problems

Requirement 7 continued from last page		
Actor(s)	Therapist; Additional medical staff (optional)	
Objective	Inform the therapist about the status of the complete system	
Effects	+	Since the system gives the therapist all of the information about its status the therapist can decide when to intervene, increasing the satisfaction for the system
	-	The additional information being presented to the therapist might result in a higher workload

Table 3.1.7: Requirement 7

3.2 Situation dependent requirements

Requirement 8	The operator should be capable of making a photo of the endoscopic output without having to remove his gaze from this output	
Rationale	Making a photo for later referencing is something that is done during a procedure as can be seen in scenario and in the task analysis (task 39)	
Actor(s)	Therapist	
Objective	Enabling the therapist to make a photo without the therapist having to remove his gaze from the endoscopic video output	
Effects	+	The therapist can make a photo without looking away from the video output, making it possible for the therapist to more quickly do the procedure
	-	To be able to make a photo without removing the gaze of the therapist from the endoscopic output might result in the necessity of obstructing the output partially with a button for making a photo, possibly resulting in errors

Table 3.2.8: Requirement 8

Requirement 9	The system will need to represent information that is specific to the different instruments that are embedded in the endoscope and that can be added through the working channel(s) of the endoscope

Requirement 9 continued from last page	
Rationale	The instruments available to the therapist, as can be found in the task analysis in the appendix tables A.2.2 and A.2.3 and as mentioned in the scenario description, all have different capabilities and associated information. This information should be presented to the therapist so he is capable of making informed decisions regarding the procedure
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Granting the therapist the necessary information about the inserted instruments
Effects	+ The therapist can make informed decisions, improving the quality of the procedure
	+ The system relays the status of the instruments to the therapist, giving him the capability of intervening if deemed necessary, improving the satisfaction for the system
	- Changing between the information sources from the instruments might increase the cognitive workload of the therapist, lowering the performance and increasing the amount of errors

Table 3.2.9: Requirement 9

Requirement 10	The settings of the system should be changeable for all of the different parts of the system
Rationale	The addition of functionality to the current endoscope results in additional settings to the system. Changing the current settings is already a possibility (table 2.5.1), so this system should also incorporate it to be able to be adjusted to the operators specifications
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Make it possible for the medical staff to change all of the possible settings
Effects	+ The system can be changed to the desire of the medical staff, improving the satisfaction of the system
	- The amount of settings can induce an increase in workload if the settings have to be changed for every usage by a different therapist

Table 3.2.10: Requirement 10

3.3 Additional requirements

Requirement 11	The operator should be capable of making a video of the endoscopic output without having to remove his gaze from this output

Requirement 11 continued from last page	
Rationale	Making a video of the endoscopic output will make later referencing of larger parts of the procedure possible.
Actor(s)	Therapist
Objective	Enabling the therapist to make a video without the therapist having to remove his gaze from the endoscopic video output
Effects	+ The therapist can make a video without looking away from the video output, making it possible for the therapist to more quickly do the procedure
	- The additional option might distract the therapist, resulting in errors

Table 3.3.11: Requirement 11

Requirement 12	The system has the capability of having profiles with the desired settings
Rationale	Being able to change the system settings might result in additional work (see requirement 10) if the settings need to be changed for every user. Simplifying this proces is desired
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Implementing profiles which contain the desired settings of a therapist
Effects	+ By simplifying the proces of changing settings, the satisfaction for the system will increase

Table 3.3.12: Requirement 12

Requirement 13	The system should be capable of giving the operator help about the systems functionality at any time
Rationale	It is possible for the medical staff to forget certain commands or actions when using a system, or forgetting what some information represents. To prevent this is to incorporate a way for the operator to access information that is focused on helping the operator to use the system (Zhang et al., 2008)
Actor(s)	Therapist; Additional medical staff (optional)
Objective	Granting the medical staff the possibility to request the system for help using the system itself
Effects	+ Always having the possibility to look up how to operate the system will increase the satisfaction of the system

Requirement 13 continued from last page		
	-	The presentation of any information for helping will take the attention away from the procedure at hand, resulting in lower performance

Table 3.3.13: Requirement 13

Requirement 14	The operator should have the capability to look into the patient file using the system as well as change the file	
Rationale	During a procedure, the need might arise for the therapist to look in the patient file (as mentioned in one of the interviews with the experts)	
Actor(s)	Therapist	
Objective	Giving the therapist access to open and possibly alter a patient file during a procedure	
Effects	+	In case of doubt about possible interventions, the therapist will be able to use the patient file for additional information to the current issue, increasing the effectiveness of the procedure
	+	The file can be changed, making entries more accurate in comparison to postprocedure entries, resulting in a higher quality patient file
	-	The introduction of this additional information can remove the attention from the patient, possibly resulting in negative consequences for the patient

Table 3.3.14: Requirement 14

4   Iterative design

The procedural tasks and end user's wishes will be fully facilitated by iteratively developing the system. As a result of the iterative development, a prototype is created that will be tested on performance and user friendliness with an experiment. Each iteration starts with designs that are created based on gathered information from different sources, including literature, evaluations and feedback by end users, the task analysis and the requirements. These designs will be evaluated by employees within the TeleFLEX project, therapists and/or other experts in other fields that are relevant to the development of the system. The last design will be considered ready for testing if it is concluded from the evaluation that the design adheres to the set requirements, and will be used as the prototype.

4.1   First iteration

In the first iteration, two designs have been created. The first design is based solely on the requirements and the second design is based on both the requirements and design elements as can be found in the DaVinci surgical system that was used during the attendance at the Meander hospital.

4.1.1   First design

The first design consists of two separate screens, which would be presented on two different monitors, with the first screen (figure 4.1.1) consisting of passive interface elements and the second screen (figure 4.1.2) of interactive interface elements. Segmentation between two screens will reduce the cognitive overload of the therapist in using the system (Mayer and Moreno, 2003), which is in accord to requirement 6. Using two monitors will also lower the amount of interface elements per screen, letting the therapist maintain his cognitive resources (Albers, 1997; Adams, 2007). Using more than two monitors would demand too much space to be used in an outpatient room. The segmentation of active and passive elements will also reduce the cognitive overload (Mayer and Moreno, 2003).

First screen   During the attendance of the endoscopic procedure at the hospital, it became apparent that the therapist relies most heavily on the endoscopic video output (requirement 1). The choice was made to let it occupy the largest portion of the screen, making it the most prominent element on the screen. The vital signs are also an important part during any procedure (requirement 4). They are placed underneath the endoscopic video output, indicating its importance compared to the endoscopic output. The audio feedback will be an important part of this element (requirement 5). The remaining space on the screen is reserved for the endoscope shaft location and tip orientation (requirement 2 and 3). Although both the location and orientation of the endoscope cannot be determined with the equipment that was present at the Meander hospital, determining them is possible with current technology (for example ScopeGuide (Olympus)) and should thus be taken into account. Since these elements will increase the situation awareness of the therapist, in turn increasing the performance, they are placed next to the endoscopic video output and the vital signs. The reason behind the placement in the first screen is that these elements are passive.

Figure 4.1.1: Impression of composed first screen
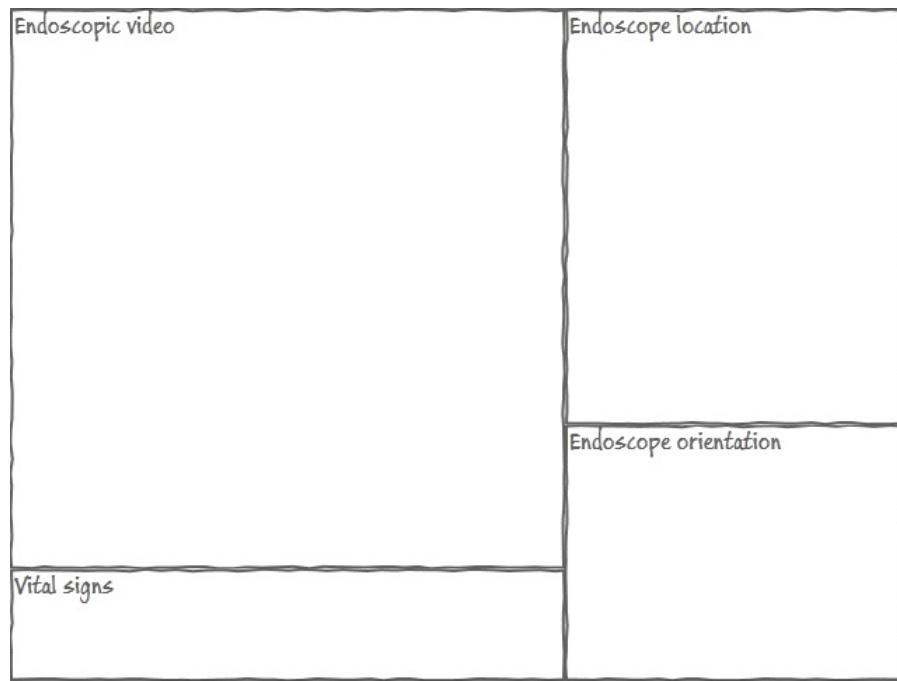
Second screen   The second screen (figure 4.1.2) will incorporate elements with which the therapist can interact. It will be a touchscreen because this makes the interaction more intuitive. Additional functionalities that have the need for textual input (adding information to the patient file, searching for profiles) result in the need for a keyboard. The preference for this input is a touchscreen keyboard, since it is easier to make it sterile and it can be changed to make it easier to use with gloved hands (slightly bigger keys) and with the interface (make interface specific buttons). To make the usage treshold as low as possible, the basic layout of a keyboard will be used and will be placed underneath the monitor with the second screen.

One interaction which is needed by the therapist is the photo and video button (requirement 8and 11). This will enable the therapist to record the endoscopic video output. The requirements state that the therapist should be capable of doing so without having to remove his gaze from the video output. That is why the button was given a large size and was placed in the lower left corner. The therapist will be capable of quickly pushing the button without having to look away. To differentiate between making a photo and recording a video, the necessary input should be different. The other important active interaction elements are the settings of the system, the setting profiles, the patient file and the help file (requirements 10, 12, 14and 13). All of these elements need to have input from the therapist, although the therapist will not need to use all of these elements at the same time. That is why the choice was made to use tabs for each element. Using these tabs will decrease the amount of information that is presented to the therapist when compared to presenting all of the elements at the same time. Presenting the elements at the same time would also result in a problem of space, since all of the elements will need sufficient space to be properly presented. The use of tabs solves this problem. Two elements that remain are the

instrument information (requirement 9) and the system status (requirement 7). Although it is of yet uncertain if these elements will need any input, they are located on the second screen because they are of less importance than the elements that are located on the first screen. The instrument element has a higher importance than the system status, since this information is directly related to the procedure. That is why the element is located on the left of the screen, giving it a location close to the endoscopic video ouput. The system status takes up the remaining space.

Figure 4.1.2: Impression of the composed second screen
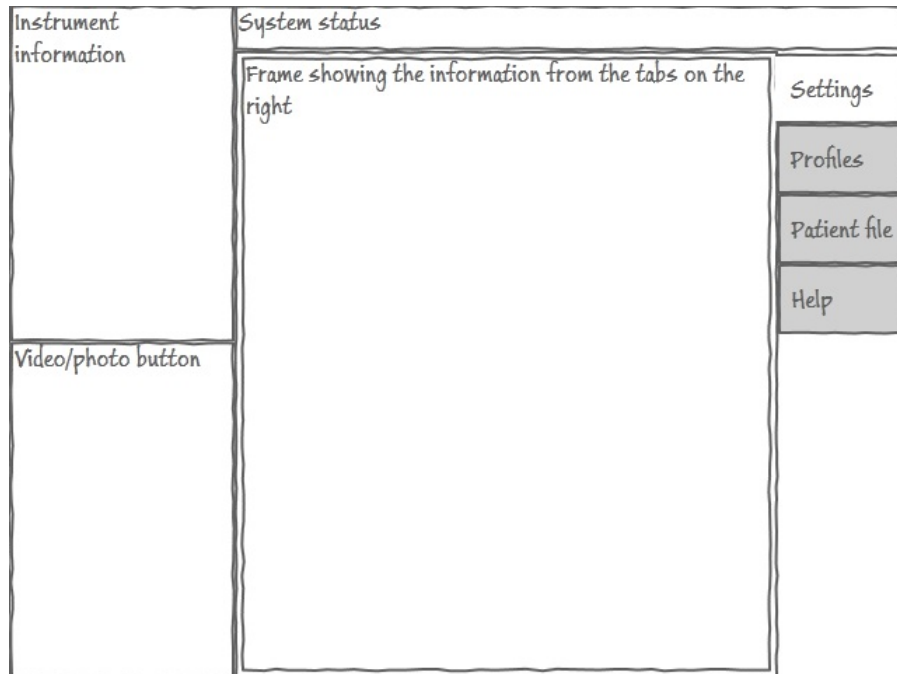
Screen location   Since text input might be necessary in the second screen (entering information in the patient file, commenting on photos or videos in the patient file), a keyboard is needed underneath the screen. The interaction needed with the second screen demands that the monitor is put close to the therapist. To make sure that the therapists attention is not drawn to this monitor due to its close vicinity, the first monitor will also have to be put close to the therapist (figure 4.1.3) as opposed to the location as used in the attended procedure (figure 4.1.4).

Figure 4.1.3: Setup using two monitors

Patient

First screen

Second screen
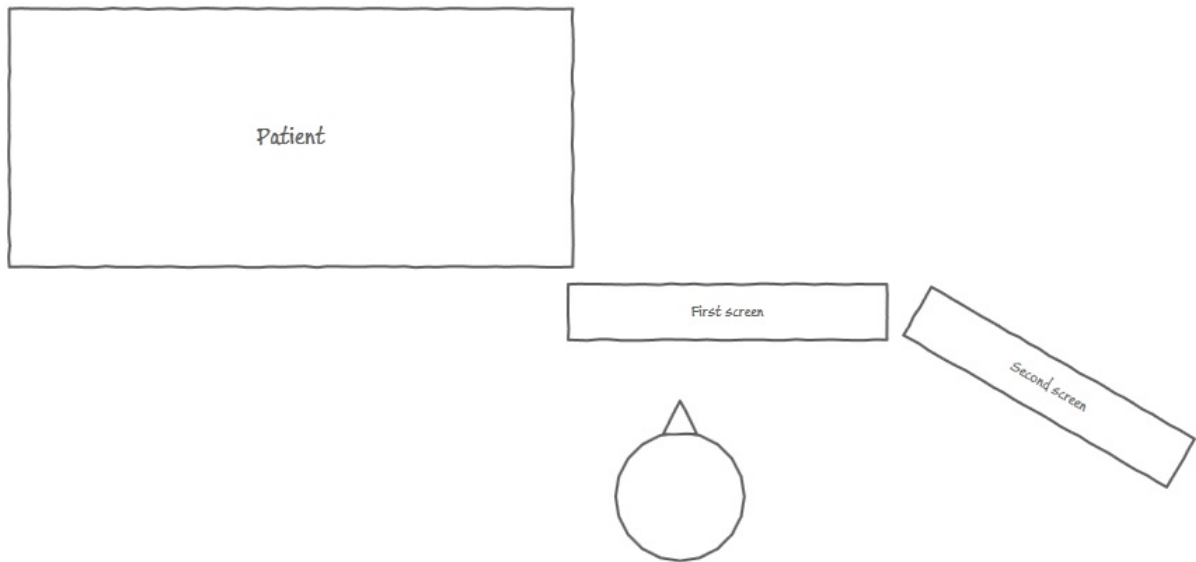
Figure 4.1.4: Setup of monitors during attended procedure
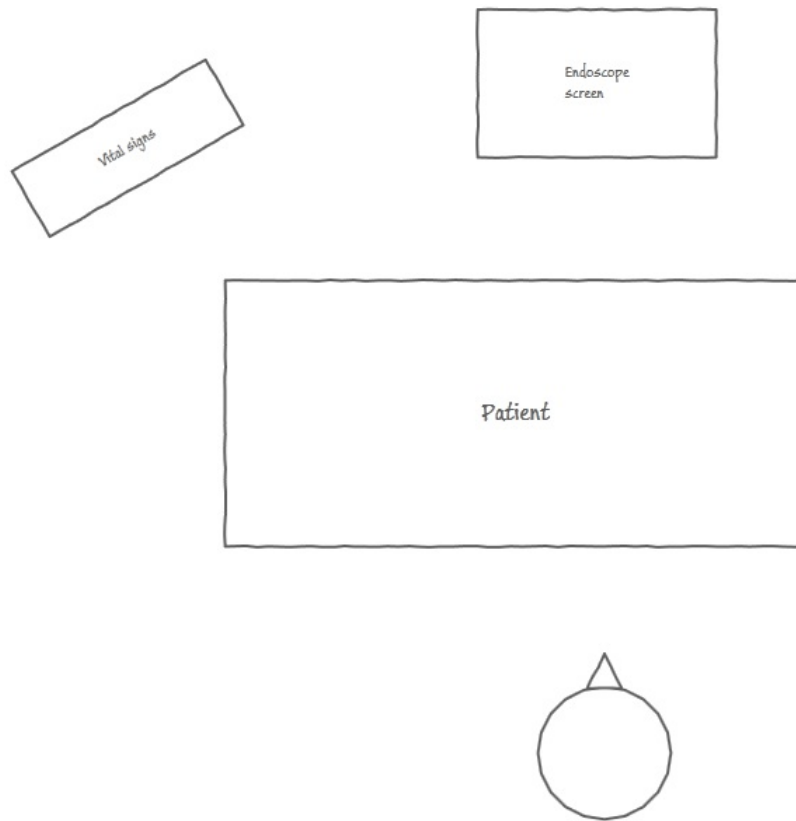
4.1.2 Second design

The design described in the previous section has been based purely on the requirements that were set up. The different elements did not take into account the information that would be presented in each element. The information that is presented heavily influences the design. That is why the next design is based on design concepts as can be found in the DaVinci surgical system (figure 4.1.5), since this system is based more on the information already present, although it uses laparoscopy instead of flexible endoscopy.

Figure 4.1.5: Image of the DaVinci interface as developed by Intuitive Surgical and used in the Meander Lichtenberg hospital

The implementation of the DaVinci system has taken the laparoscopic output as its main feature, giving all of the other elements (system feedback, orientation compass, instrument information) limited spacing. This results in a low cognitive overload (requirement 6) because of the small intrusion of these elements in the visual work area of the therapist. This is the reason that the endoscopic video output is receiving a large amount of space on the screen. The vital signs need less space than assumed in the first design, if the same information is used as the vital sign measurement in the Meander hospital. It used letters to depict the measurement, making it suited for overlapping the endoscope output, in turn making it easily accessible to the therapist. The overlap of the letters might obscure small anomalies, but it is expected that due to the continuous movements of the endoscope these anomalies will quickly fall outside of the overlap (as opposed to a complete overlap). The instrument information also has a small amount of necessary information, making the representation comparible to the DaVinci by only giving the name of the inserted instrument. The photo and video buttons have been relocated to the left screen. The reason behind this is that they are more easily accessible to the therapist, leaving his gaze near the endoscopic output (as per requirements 8 and 11). Above these buttons there is some space to depict the system status information. On the right of the endoscopic output, the orientation and location of the endoscope will be depicted, combined in one frame because it is expected that the information can easily be combined. Depending on the availability of this information, they can be hidden from the output, creating more room for the already discussed elements of the first design.

As a result of making most of the elements smaller, it is possible to use one screen. The above described parts will take up three fourth of the screen. The remaining quarter is used for the additional functions (settings, profiles, patient file and help). These functions are sharing their space, since these functions are expected to not be used all of the time during a procedure. The

resulting one screen can be seen in figure 4.1.6.

Figure 4.1.6: Impression of the second design of the second screen
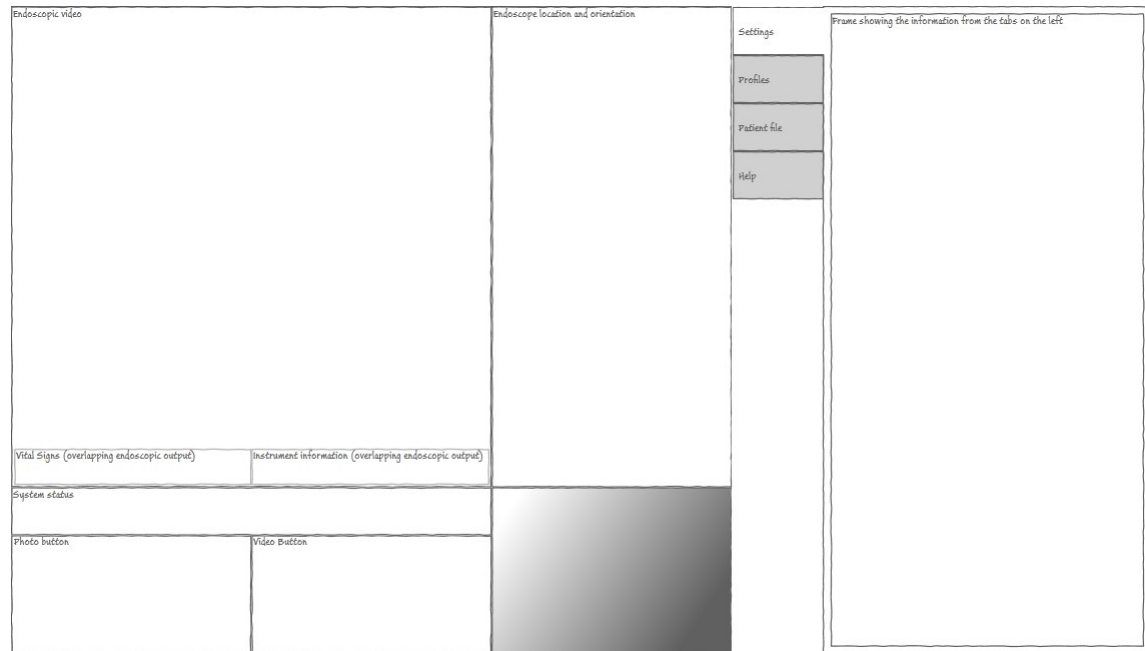
4.1.3 Evaluation first iteration designs

The first iteration evaluation will start with an overview of the questions that arose during the development of the above described designs. This is followed by a description of the interviewees and the setting in which they were interviewed. Conclusions based on the comments given by the interviewees will be drawn. These conclusions are used to create new designs. Questions that arise during the evaluation or the conclusions will be listed last.

Questions   After the creation of the first two designs, the questions that need to be answered are:

- Which first impressions and comments do the interviewees have in regard to the first design?

- Which first impressions and comments do the interviewees have in regard to the second design?

Since the two designs are in the first iteration, there are a lot of uncertainties about the designs. Testing specific questions might result in a too narrow view on the complete interface. That is reason why these global questions will be answered.

Interviewees and interview setup and setting   The interviews were conducted with two employees within the TeleFLEX project, since these could more easily participate on short notice compared to therapists. The first interviewee has had multiple conversations with therapists about

their work and how they would like to see their work improved with the addition of a robotized flexible endoscope. The second interviewee has experience in designing interfaces for both medical and non-medical applications.

The interview took place at Demcon, Oldenzaal. It was done in the office of one of the interviewees. During the presentation of the designs, both interviewees were present. They were prompted to freely comment on the interface during the presentation of the designs. The presentation consisted of showing the designs to the interviewees and explaining the different elements of the design and explaining the choices that were made in regard to the elements and the design as a whole. After the presentation, a dialogue was done in which more specific questions were asked and the two designs were compared. All comments were noted down by the interviewer.

Conclusions   Most of the comments by the interviewees were in regard to both designs, focussing on the shared elements across the designs. Some design specific comments were given. Both the general and the specific comments will be discussed.

General comments

1. The buttons for making a photo and video can be removed from the screens. They will be incorporated into the joysticks (phantom omni's, Sensable) to control the endoscope, which is not a part in the further iterative design phase. Placing these options on the joysticks does result in design choices which will be mentioned where necessary. The output from these interactions still be presented in the interface and will be implemented in the new designs.

2. In regard to the endoscopic output, it was remarked that it should take up a larger part of the screen. This would result in an even more prominent place in the interface, because the presentation of this information will be the main focus of the therapist. This was followed by an idea of switching from a landscape oriented screen to a portrait oriented screen. This idea will be incorporated in the next designs.

3. It was unclear if some of the elements should be implemented due to unaccessibility of the necessary information or uncertainty about the information presentation. For example, it is uncertain if the location and orientation of the endoscope will be accessible, or if the presentation of the patient file information is clear to the therapist. If this information is inaccessible but technologically available, or the presentation is unclear, these elements will still be implemented in following designs and will be evaluated again.

4. There are two ways to implement the patient file element in the designs. The first way is to embed the currently used patient file system into the interface. The reason to embed the current system is because therapists are already familiar with that system, decreasing the amount of learning that is required and having all of the existing functionality in place. The second way is to implement a new depiction of the information in the patient file which uses data from the currently used patient file system. The reason to implement this is that the therapist will be presented with only the information that is relevant for this procedure (for example, brain scans will not be relevant for a colonoscopy). Which method is preferred will be verified with therapists after the second iteration. Within the future designs, a simple implementation of an alternate patient file will be created.

5. To both interviewees, it was uncertain what kind of information the system status would depict. That is why for now this elements has been removed from the interface, but might be implemented later on.

Comments on first design   In regard to the first design, the main comment was that the elements took up too much space in the interface. It was hard to distinguish between important and less important elements based purely on the size of the element. In line of the general remarks, the video and photo button should be removed. There was uncertainty in the depiction of the endoscope location and orientation, both about if they should be implemented and if so, how they should be implemented. There was also uncertainty about the need and specific implementation of the system status, settings, profiles, patient file and help elements. Albeit this uncertainty, the elements will still be incorporated in the next designs, unless considered to be obsolete.

Comments on second design   The second design received less comments compared to the first design. The endoscopic video output was regarded as being more prominent compared to the first design due to its size, although the size itself was still regarded as being too small. The smaller depiction of the vital signs and instrument information and the location of these elements nearer to the endoscopic video output were remarked as being a positive design choice and should be maintained.

Additions to the prototype   After the feedback phase, it became clear that additional information and functionality needs to be implemented. These are:

1. The newer endoscopes have the possibility for entering up to three different instruments. The interface should thus have the possibility to depict the information for up to three instruments.

2. The video output from the endoscope is in high definition and therapists have already remarked within the TeleFLEX project that the addition of high definition imaging is important for performance during a flexible endoscope procedure. The interface should thus incorporate the ability to present the high definition information.

3. Although the system will be created for a situation in which the nurses and therapist are needed for safely using the flexible endoscope, there will be elements which are designed based on a situation in which the system is capable of performing the same actions autonomously.

Remaining questions   As a result of the interview, the following questions for the therapists have arisen and will be answered in the next interview:

- Is the endoscopic video output considered to be large enough?

- Should the location and orientation of the endoscope be implemented in the system? If so, how would the therapists prefer the implementation?

- Should the patient file be created from the start, or should the existing patient file system of a hospital be embedded?

4.2 Second iteration

In the last interview it was apparent that the employees preferred the second design, due to its limited amount of information and clear layout. This is the reason why the second design is taken as the basis for the designs in this iteration.

4.2.1 Third design

For the third design (see figure 4.2.7 and 4.2.8), the endoscopic output has been enlarged due to the comments as given in the feedback phase. It will need to take up a larger part of a screen and should be free of (too much) obstructions. This choice dictates that additional information should be presented around the sides of the endoscopic output (top, bottom, left or right).

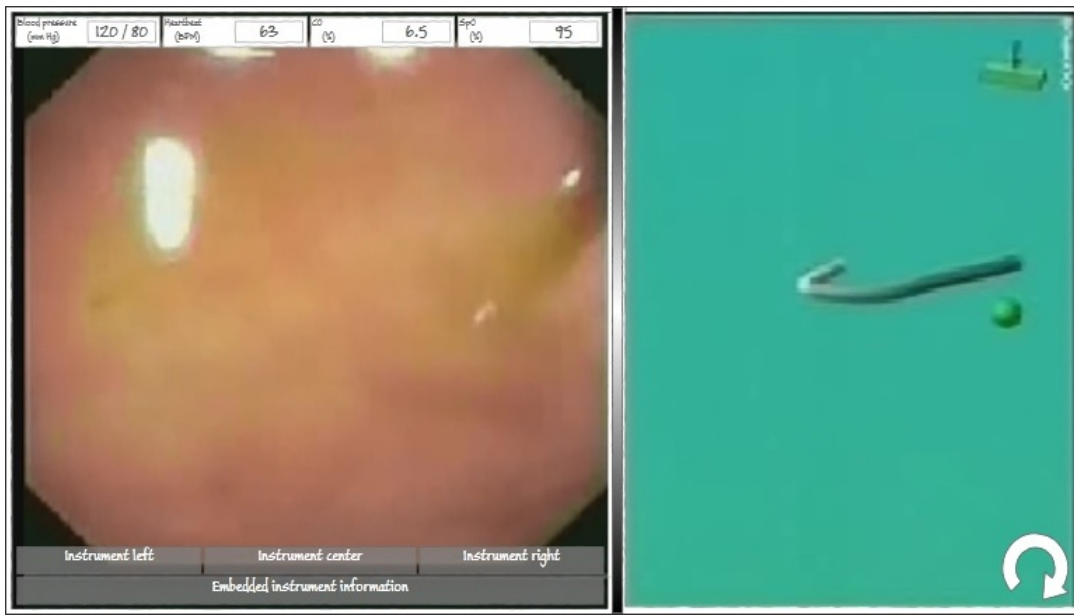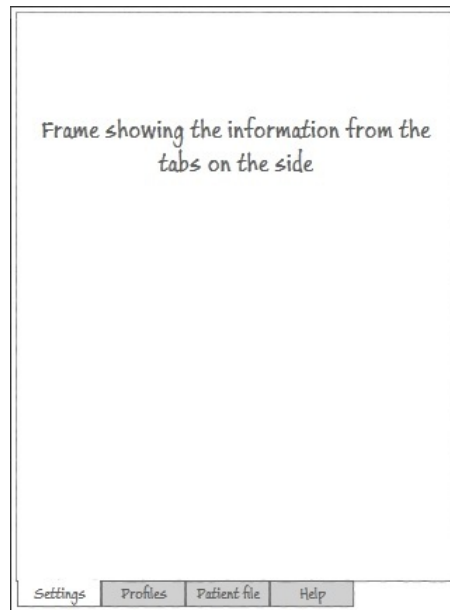Figure 4.2.7: Impression of the first screen of the third design

Figure 4.2.8: Impression of the second screen of the third design

Frame showing the information from the
tabs on the side

Settings | Profiles | Patient file | Help

Endoscopic output, instruments and vital signs   An element showing the name of the inserted instrument is needed because with the new system, the therapist is not responsible for entering the instrument anymore which will be performed by a nurse. The element will help the therapist in distinguishing which instrument is entered. If no instrument is entered, no information is given. In the case of an older endoscope with the possibility of entering just one instrument, the reference to the left and right instruments can be hidden. The embedded instrument information is needed to show which actions the therapist is doing with the embedded instruments, making it unneccesary for the therapist to remove his gaze from the information. These elements are placed at the bottom of the endoscopic output so as to correspond with instruments visible in the endoscopic output. The information can either overlap the endoscopic output, but using an transparent background, or can be presented in an individual frame.

The vital signs are still an important part of the necessary elements. The above choice to place the instrument information at the bottom dictates that the vital signs should be put on the topside of the endoscopic output, since this will create an information symmetry in the overlap of the endoscopic output. This results in a more aestheticly pleasing design (Bauerly and Liu, 2008) and a better usable interface (Thimbleby, 2002). As with the instrument information elements, they can overlap the endoscopic output, again using a transparent background, or can be presented in an individual frame.

Endoscope location and orientation   The location and orientation of the endoscope constantly change based on the control of the endoscope. That is why an element presenting that information should be visible at all times, just like the endoscopic ouput. It is unclear in which orientation (portrait or landscape) the location and orientation of the endoscope should be represented. Current spatial orientation devices present the location and orientation as seen from the front of the patient,

31

with the patient standing. However, it is unclear if another orientation might increase the situation awareness of the therapist, since another orientation might be in accord with how the patient is lying resulting in less needed mental rotations of the information. This rotation might lead to annoyance with the interface, since having an upright orientation might be more natural or might be a learned skill. This difference will be presented to the therapists to gain expert information about this topic. The influence it has on the situation awareness does not fall within the scope of this thesis. At this point, the choice is made to make it possible to rotate the view.

Additional functionalities   In regard to the additional functionalities (settings, profiles, patient file and help), it is unclear if there would be a preference for placing the functionalities on a separate monitor. The reason to place it on a second monitor is that these functionalities are mostly used pre- en postprocedure. The settings are expected to be set before the procedure starts and will probably not be changed during the procedure. During the attendence of the endoscopic procedure in the Meander Lichtenberg hospital, the patient file was used after the procedure, updating the file with the procedure information. The file was probably also used to prepare for the procedure, but this was not done during the attendance. Since these functionalities are all secondary in regard to the endoscopic procedure itself, they are preferred to be put on a separate monitor (Grudin, 2001). A reason to use one monitor for the complete interface is that all the functionality that comes with the system is combined in one screen, possibly increasing usability (Robertson et al., 2005). This will make the workflow of the therapist more continuous and will also enable him/her to more easily access the information if he would prefer some information (for example from the patient file). The latter will result in a smaller distance the therapist will have to gaze away. The assumptions about one or two monitors will have to be verified with therapists, possibly using an experimental setting to see the usage of either one.

Within the additional functionalities, the user can make two choices in regard to profiles: the therapist settings profile and the patient file. These can be implemented in two different ways, namely either using a dialogbox (figure 4.2.9) or taking up the complete screen (figure 4.2.10). A reason to use the former is that the dialogbox can be manipulated to show the information underneath the box and that the box is now the only focusable and usable object. The reason for the latter is that a full screen can present more information, increasing the visibility of all relevant elements within a search. A choice for either one will be made after verifying them with therapists. Choosing these profiles will be done by either searching for a name, identification number or a date of birth. After a profile has been chosen, it needs to be explicitly loaded, preventing simple errors by opening the incorrect profile. The profile can be altered, saved and closed, or another profile can be opened.

Figure 4.2.9: Example of using dialog box to open a profile

Figure 4.2.10: Example of using full screen to open a profile

Choose patient		
Search patient:	Fill in name, ID or date of birth	🔍

Name	ID	Date of birth
Aaberg, Jesper	1027742657	November 5, 2003
Adams, Ellen	1071641366	December 29, 2006
Adams, Terry	1290327759	January 19, 2004
Adams, Terry	1350114690	December 22, 2007
Penor, Lori	1111465503	February 2, 2006
Pfeiffer, Michael	1351072419	August 23, 2003
Philips, Carol	1162634792	May 27, 2007
Poe, Toni	1084950949	May 24, 2006
Hicks, Cassie	1364462757	September 19, 2004
Argentiero, Luca	1084382762	August 10, 2003
Aaberg, Jesper	1236416145	September 20, 2007
Adams, Ellen	1321435113	August 9, 2006
Adams, Terry	1372505168	February 25, 2008
Adams, Terry	1074311680	July 20, 2008
Penor, Lori	1271062424	September 10, 2006
Pfeiffer, Michael	1018682623	September 5, 2005

Load patient file

| Settings | Patient File | Help |

Therapist profile   The therapist profile will consist of the settings that the therapist has set on an earlier time and has saved for his convenience. A new profile with settings can be created and the settings can be set without using a profile. The settings values as set in the settings screen will be used by the system to adjust the associated system setting. If the choice is made to use a dialog box to choose the profile, the profile tab will be removed (as in figure 4.2.9).

Patient file   The patient file will contain the most basic information that the therapist will need during a procedure (figure 4.2.11). The basic information is based on conversations that were conducted with therapists earlier on in the TeleFLEX project, but will be verified after having discussed the preference for incorporating existing software. The information presented consists of demographical and medical records, combined with information from previous interventions that are relevant to the procedure as indicated by the therapists in the interviews, with text and image associated with a selected intervention.

Figure 4.2.11: Impression of patient file depiction

Help function The information that is presented in the help functionality will be limited to information on how to enter the endoscope and the instruments into the system. It will also contain information about how to use the other additional functionalities (settings and patient file). For first time users, the help function will also contain a walkthrough tutorial to make the user familiar with the system.

4.2.2 Fourth design

The fourth design is similar to the third design. The difference is that instead of locating the additional functionalities on the right of the screen, or on a separate monitor, it is presented at the bottom. The monitor will be put into a portrait position for this.

Again, this will result in the user being able to access the information with limited gaze straying because all of the information is on one screen. This easy accessibility will possibly result in the therapist using the information more often than if presented in a separate monitor. The easy access to the information might improve the execution of the procedure (Williams et al., 2007).

4.2.3 Evaluation second iteration designs

The second iteration evaluation will start with questions that still need to be answered after the last iteration. These are followed by questions that arose during the development of the above described designs. This if followed by a description of the interviewees and the setting in which they were interviewed. Conclusions based on the comments given by the interviewees will be drawn. These conclusions are used to create new designs. Questions that arise during the evaluation or the conclusions will be listed last.

Questions Questions for the therapists from the last iteration that need to be answered in this iteration:

- Is the endoscopic video output considered to be large enough?

- Should the location and orientation of the endoscope be implemented in the system?

- Should the patient file be created from the start, or should the existing patient file system of a hospital be embedded?

Questions for the therapsists that have risen after creating the designs in this iteration:

- Is there a clear preference for the usage of one or two monitors? If so, what is the reason behind this preference?

- In what orientation should the depiction of location and orientation of the endoscope be implemented?

- Which elements of the third and fourth design are an improvement compared to the first and second design, and why?

Interviewees and interview setup and setting In this evaluation, five people were interviewed. The two employees already interviewed in the first iteration were willing to evaluate the designs again. In addition to the employees, two therapists and one Technical Medicine graduation student familiar with flexible endoscopic procedures were interviewed. From the therapists, the first is specialized in laparascopy and is experienced in using the DaVinci system. He is also closely involved in the TeleFLEX project and is associated with the Experimental Centre for Technical Medicine (ECTM) located at the University of Twente. The second therapist is a colonoscopist and is specialized in flexible endoscopy and works at the Meander hospital in Amersfoort. The graduation student also works in the ECTM and is familiar with the use of flexible endoscope

simulators as well as actual flexible endoscope usage. Her knowledge in ergonomical and interface design in the field of medicine are benificial to (the evaluation of) the designs.

The interview with the employees was again done at Demcon, Oldenzaal, in one of the offices of employees. The therapist specialized in laparoscopy was interviewed at his office on the university of Twente. The colonoscopist was interviewd in a room at the Meander Lichtenberg Hospital in Amersfoort. The graduation student was interviewed in a room at the university of twente.

The employees were again interviewed with both of them present in the room. The therapists and graduation student were all interviewed individually. The interviewees were interviewed in the same way as in the first iteration evaluation: they are free to comment during the presentation, which consisted of showing the designs to the interviewees and explaining the different elements of the design and explaining the choices that were made. After the presentation, a dialogue was done in which more specific questions were asked and the two designs were compared. All comments were noted down by the interviewer. In the case of the therapists and graduation student, some procedure specific information was gained.

Conclusions Some comments of the interviewees were in regard to both designs. These general comments are to be expected since the third and fourth design share elements. No design specific comments were given. The general comments will be discussed.

General comments

1. Independently from each other, the therapists commented that they would prefer to have the endoscopic output clear of information and have all of the information on a separate (part of the) screen. They agreed with our notion that the vital signs and instrument information are important and should always be visible, but should also be moved to the separate (part of the) screen. Both of the therapists remarked that this information could ideally be combined with the location and orientation of the endoscope depiction.

2. The therapists, again independently, came up with the idea to use the separate (part of the) screen to switch between different information sources. The first source would be a view consisting of the information that is necessary at the time of the procedure. This view would consist of the vital signs, instrument information, the location and orientation of the endoscope and the patient information. Additional elements to this source were proposed by the colonoscopist and the graduation student and will be discussed in the paragraph *Additions to the prototype* below.

3. The second source in the separate (part of) the screen would be the patient file. The therapists remarked that they would prefer to use an embedded version of the patient file system that the hospital has in use. Therapists would prefer this since they are already familiar with the software and they would have access to all the preferred information that is available in the hospital or even across hospitals. During the procedure, the source would be used for referencing only and would not need any textual input. The colonoscopist remarked that doing this would take up too much time and would result in discomfort for the patient. Before and after the procedure, the software should be accessible and changeable.

4. The third source is the settings of the system. Both therapists agreed that having a therapist profile is desirable since it will take away the need for a therapist or nurse to set the preferred

37

settings of the therapist with every usage of the system. Loading the therapist profile might be (more) easily done by incorporating the ID login system already in use in some hospitals. The colonoscopist also mentioned that the accessibility of the settings should be varied. The settings that do not result in severe consequences during the procedure (e.g. white balance, contrast, brightness) should be easily accessible and changeable. Settings that might result in more severe consequences should be hard to access and change.

5. The fourth source is the help information. No comments were given on this element and remains incorporated into the interface.

6. In the first source as described above, the depiction of the orientation and location of the endoscope has to be in the upright orientation as depicted in figure 4.2.12. This was remarked by both therapists. They also commented that this element should most definitely be implemented, since it will improve the performance during a procedure.

7. The employees commented that the depiction of instruments in the location and orientation of the endoscope might work counter productive, due to mental rotations that the therapists might have to make. As an alternative, the instrument depiction should be removed from the location and orientation depiction and should be given its own place inside the first source.

Figure 4.2.12: ScopeGuide image shown in an upright position

8. It has been decided in regard to the setup of the system that a touchscreen keyboard will be incorporated into the system. The use of the patient file system outside the procedure will have the need for a keyboard. The same goes for any other program that might be embedded

into the system, for example EndoBase (Olympus) to process all of the endoscopic output. Adding the keyboard will enable the therapist to perform all of his tasks from one console. The keyboard will be located underneath a monitor.

9. The choice has been made to use two monitors. This choice was made because the information separation will be easier and because there exists uncertainty about the positioning of some information. The colonoscopist mentioned that he would like the endoscopic output to be the most prominent part in an interface, but should not envelop his complete view. He should not have to turn around his head or gaze away too much to be able to see the endoscopic ouput. This would, according to the colonoscopist, leave him without an overview of his working area. Since the endoscopic output is high definition and it will be presented on a monitor that is capable of presenting that amount of information, it will have to be located about 1,5 meters from the therapist, as was mentioned by one of the interviewed therapists as being an often used distance. The touchscreen and keyboard part of the interface need to be reachable by the therapist, dictating that this monitor is located closely to the therapist. The result is a design which uses two monitors (see figure 4.2.13). The distance might have a negative impact on how (much) the therapists uses the additional information. To make sure that the therapist will use the additional information, the setup with two monitors adjacent to each other might be preferable (see figure 4.1.3). This would result in the need to downscale the endoscopic output on the first screen for the therapist to be able to perceive the output without having to move his/her head. At this time, the choice is made to use the latter setup, but will be reviewed in the first experiment.

Figure 4.2.13: Setup using two monitors at different locations
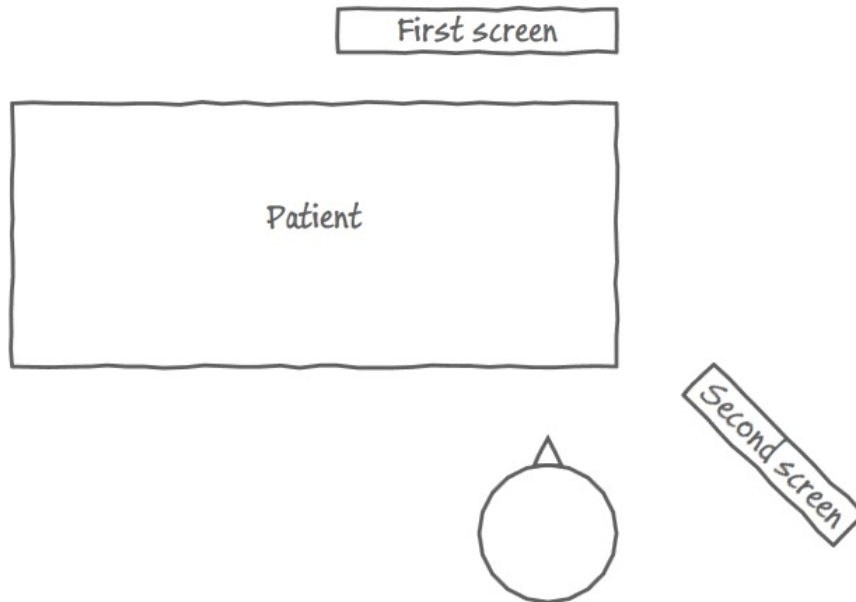
Additions to the prototype   After the comments given by the colonoscopist and the graduation student, it became clear that additional information and functionality needs to be implemented. This additional information and functionality are:

1. The first additional element inside the first view is the depiction of patient information in this view, possibly on top of the location and orientation of the endoscope. Normally, this information would be presented on top of the endoscopic output, but the colonoscopist experiences this as annoying and removes this information from the endoscopic output. Placing this information in the separate (part of the) monitor would make him use the information more often. Additions to the standard information would be references to important issues that might arise during a procedure (e.g. patient allergies, specific colon issues, lower heartrate threshold) and performance measures. These issues should be set by a therapist before a procedure, either using the patient file to contain this information or letting the therapist manually enter the information.

2. The second additional element inside the first view is the lower or higher threshold for vital signs example given with the patient information. This element was mentioned by the graduation student. The reason to set the threshold might be necessary in case of patients with a lower or higher threshold on some vital signs (for example the heart of a heart patient will not be able to take the amount of stress as compared to a relative healthy patient). The therapist should be capable of setting these thresholds before the procedure, either using the values on those found in the patient file or letting the therapist manually enter the thresholds.

3. The third element inside the first view is the performance measures, also already mentioned with the additional patient information. These measures were mentioned by the colonoscopist and consist of measuring the time taken to withdraw the endoscope and a total polyp count. The former is already being used, but lacks certain nuances. The colonoscopist would prefer a way to easily start and stop a timer, with stopping being necessary in the case of actions that need to be performed which are not related to withdrawing the endoscope itself and might take considerable time (e.g. removing a polyp, solving technical problems, determining possible colon problems). The polyp count can be done with a simple counter which the therapist would use to add or subtract to the total number of polyps.

Remaining questions   As a result of the interview, the following questions have arisen and will be answered in the next interview. It is possible that questions remain from the previous iteration.

- In which monitor setup will the therapist be able to more easily gather the necessary information?

4.3   Third iteration

This third iteration will be the last iteration before a first experiment will take place. No evaluation was done in this iteration. Any changes on the design will be made after the experiment, based on the results and drawn conclusions from the experiment.

4.3.1 Fifth design

The fifth design consists of two different monitors with different screens. The first screen will present the therapist with only the endoscopic output (figure 4.3.14). The endoscopic output can use the whole screen or just a part of the screen, dependent on what the therapist would prefer. He can change this in the settings screen, which is located on the second monitor.

Figure 4.3.14: First screen with only endoscopic video output

Persistent elements   The second screen will have persistent (figure 4.3.15) and dynamic elements (examples in figures 4.3.16 and 4.3.17). The persistent elements can be found at the left side of the screen, consisting of patient and procedural information (e.g. name, date of birth, start time, important patient information), vital signs, procedure time and polyp count. These elements are persistent because they are relevant throughout the complete procedure. Switching the dynamic elements will have no effect on the persistent elements.

Figure 4.3.15: Persistent elements in the second screen

Patient name:	Adams, Terry
Date of birth:	January 19, 2004
Date:	31-1-2011
Therapist:	Pfeiffer, Michael
Start time:	15:31:20
Procedure time:	00:00:00
Number of polyps:	0
Important information:	Allergies: citric acid & propylene glycol

Blood pressure (mm Hg) — 120 / 80

Heartbeat (BPM) — 63

O2 (%) — 6.5

Procedure Timer
Reset
Start — 00:00:00

Polyp counter
- — 0 — +

Dynamic elements   The dynamic elements consist of several possible views. The first view is an actual view which depicts the current location and orientation of the endoscope as well as the orientation of the instrument and instrument information. This view can be shared with an image from the patient file (see figure 4.3.16).

Figure 4.3.16: Actual view with location and orientation of endoscope and patient file image
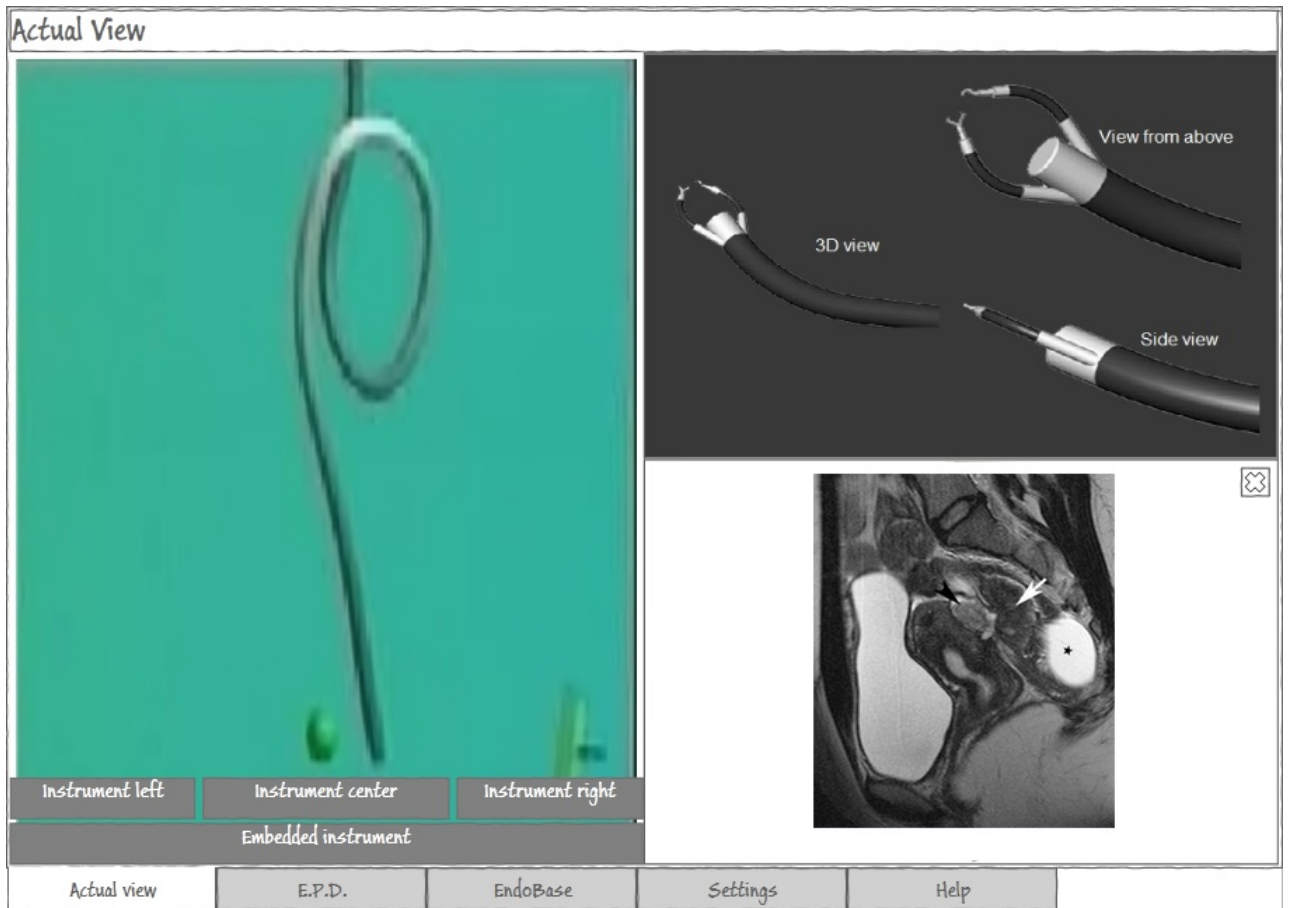
The second and third views are used for the hospital software to access the patient file database (in the Netherlands called the Elektronisch Patienten Dossier, E.P.D.) and software for processing the endoscopic output and other information from the procedure (most often used in the Netherlands is EndoBase, Olympus). Both of these views can be used before, during and after the procedure. The E.P.D. can provide images that can be moved to the actual view (figure 4.3.16).

The fourth view is the settings of the system. In comparison to earlier designs, the possible setting options are directly accessible as soon as the view is opened. This will enable the therapist to quickly change the settings, preventing considerable slow down of the procedure. More advanced settings, with possible negative consequences to the procedure, will be added to this view, but will be harder to access due to additional steps (first opening the advanced settings) and using validation of entered values (using notifications). The option to manually choose a therapist profile is possible, but can be done by scanning, for example, the therapist's ID.

Figure 4.3.17: Settings view

The fifth view is the help view, which will depict the same information as mentioned in the third and fourth design. Added information will be about the EndoBase view.

Monitor setup As has already been discussed in the previous iteration, the location of the monitors is not yet fully known. We are going to compare the setup as can be seen in figure 4.1.3 with the setup as in figure 4.2.13. The position of the second monitor in the latter case will be at that position. In all of these setups, a keyboard will be added because of the already discussed needed textual input and the combining of all functionalities in one console.

4.3.2 Multimodality

A system can be developed with the use of one or several modalities, with the main modalities being vision, hearing, touch, smell, taste. Once two or more modalities are combined, an interface can be said to be a multimodal system. A multimodal system makes it possible for the system to

present the user with different kinds of input, facilitating the output of the system by a combination of modalities or granting additional output by using different modalities.

The multimodality of the interface has not been discussed in the earlier iterations because the layout of the information was a priority. With the last iteration, multimodality was introduced. The multimodality in the system will be created by using audio in combination with visual stimuli. Using haptic feedback does not grant the therapist additional information when combined with one of the monitors, because the therapist will not be constantly having his hands on the monitor. Haptic feedback is preferred with the touchscreen keyboard, giving the therapist feedback about his presses.

The most critical information in the prototype is the vital signs. The vital signs are directly related to patient health and in case of dangerous values, the prototype will alert the user with both visual and audio signals. The signals will consist of a blinking red square and an on and off bleeping sound, for as long as the vital signs remain on dangerous levels. These options are commonly used in interfaces, with the red color indicating an error or warning and the accompanying sound being a pressing sound. The combination often prompts the user for action, or at the least makes him aware of negative or dangerous problems that might occur or are going to occur with the interface (or in this case with the patient).

The second most critical information is the instrument information. Problems that occur with the instruments or the endoscope might result in negative consequences for the patient. The prototype will inform the therapist of the problems that the instruments or endoscope are experiencing and give possible advice on how to proceed. Since the instrument information is located in the dynamic part of the interface, there are two design choices: the instrumental errors will have audio associated with them and an error occuring will force the screen to move to the actual view tab which will present the instrument information. These choices will make sure that the therapist will be aware of occurring errors.

The effects of the two elements using multimodality will be tested during the experiments. The main question we would like to see answered is if the user is indeed made aware of the problems with either the vital signs or the instruments.

The only other audio signals that will be present are the standard button presses. These are commonly used in all interfaces and will not be discussed further. Graphical aids in using the prototype will be the graying out of control elements when they are not available and changing the presentation of a button when pressed.

5 First experimental evaluation

For us to be able to draw conclusions about the performance of the prototype created in the iterations and to test its user friendliness, an experimental setting in which these elements are measured was necessary. First a theoretical background about these measurements is given, along with the research questions following from that background as well as from the iterative design phase. This background is followed with an experimental setting which will describe the setup and materials, which will be followed by the results of the experimental setting. Conclusions were drawn based on the results.

5.1 Background

The eventual product will have to be user friendly to make sure the therapists will use the system and that the performance of the therapists will increase with using the system. This can be obtained by increasing the usability of the system. Usability is defined by the International Standardisation Organisation (ISO) 9241, Part 11 ISO 13407 (1998), as being the "effectiveness, efficiency and satisfaction with which a specified set of users can achieve a specified set of tasks in a particular environment". This definition is opposed by Frøkjær et al. (2000) and Hornbæk and Law (2007), who found that these factors are not correlated and should not be used to measure usability as one aspect of the interface. The three factors will be measured in this thesis and will be regarded as individual factors of the system. It is still necessary to achieve satisfactory levels of these factors, so the effectiveness, efficiency and satisfaction will have to be optimized. To determine how high the current prototype scores on the factors, an experiment was conducted.

In this experiment, the different factors needed to be measured. An overview of the used measurements for these factors in earlier research has been created by Hornbæk (2006). With each research question, the measurements chosen to answer the research question will be detailed. The reason some of the measurements were not chosen is because the measurements are too complex to implement due to the expert group that is going to participate or because the prototype is missing some input methods that fall outside of the prototype (e.g. controlling the endoscope, controlling the instruments).

It is important to note that stress is an important factor that determines the performance during a laparoscopic procedure (Arora et al., 2010a). It is expected that this will also hold for an endoscopic procedure, especially since the patient is semi-conscious during the procedure. This stress is induced by the high mental workload that is placed on a therapist when conducting a procedure (Berguer et al., 2001). Since workload might have a large influence on the performance with a system, it will be incorporated in the setting of the experiment and also within the research questions.

Questions from iterative design phase There are two remaining questions from the iterative design phase. The last question arose during the addition of the multimodality to the system.

- In which monitor setup will the therapist be able to more easily gather the necessary information?

- Does the addition of audio warnings to visual warnings increase the perception of dangerous levels for the vital signs and of problems with the instruments?

These questions will be combined with the factors, resulting in research questions that will be answered after the experiment.

Effectiveness The effectiveness of an endoscopic procedure can be seen as the quality of the procedure as it is performed as well as the resulting (lack of) patient trauma. With two possible monitor setups for the prototype (as can be read in *Third iteration* section) is is unclear which setup has the highest effectiveness. This leads to the following research question:

> **Research question 1:** In a high workload setting, which of the two monitor setups results in the highest effectiveness?

The multimodality of the system can increase the quality of the procedure by preventing serious problems form occurring. It is uncertain if the addition of audio will increase the quality, so the next question would be:

> **Research question 2:** In a high workload setting, does the addition of audio to visual warnings increase the effectiveness?

Efficiency The efficiency of an endoscopic procedure can be seen as the amount of resources that the therapist needs to spend on completing the procedure. These resources can be drawn from different sources, for example physical, psychological or time resources. The less cognitive resources the therapist has to spend on the procedure, the higher the efficiency will be. With the unclear monitor setup, the question which setup results in the highest efficiency arises:

> **Research question 3:** In a high workload setting, which of the two monitor setups results in the least resources used/the highest efficiency?

Satisfaction There have been several theories about the acceptance of technology in ones work, one of them being the Technology Acceptance Model (TAM) (Davis, 1989; Davis et al., 1989). This model has been tested and proven to be applicable in the health care domain (Holden and Karsh, 2010). In short, the model states that a more positive feeling about an IT product by employees results in easier and quicker incorporation of the product into the work of the employees. This positive feeling is based on perceived usefulness, perceived ease of use, attitude and behavioral intention. In this thesis, only satisfaction is measured because of the ISO directive. The satisfaction of a person is the attitude he/she has towards a product. That is why the product should be as satisfactory as possible. The monitor setup will possibly influence the satisfaction that a user experiences, which leads to the following research question:

> **Research question 4:** In a high workload setting, which of the two monitor setups results in the highest satisfaction?

5.2 Method

5.2.1 Participants

Since the experiment will test the usage of the interface and not the medical knowledge and insight of the participant, there was no restriction of medical knowledge for participants. In total there were

eight participants in the experiment, four male and four female. Two participants are associated with the Radboud University of Nijmegen, one with the University of Twente, four with Demcon and one is associated with Océ. The age range lies between 21 to 32. The participants did the experiment in a room that was located at their associated location.

5.2.2 Design

The experiment used a within-subjects design with two monitor setups as the independent variable. In the first setup, the monitors are separated from each other bij 1,5 meter, henceforth known as the separation setup. In the other setup, the monitors are located next to each other, henceforth known as the console setup. Conditions of the indepent variable were counterbalanced per participant. The participants all received presentation sets with events happening in the interface. The order of these presentation sets was the same for every participant. The dependent variables were the number of correctly completed given assignments, the total number of errors during these assignments, time needed to complete the assignments, number of differences between the drawing of the interface and the actual interface. To measure the human factors of the system, the scores on two workload questionnaires were used (NASA-TLX, STAI) and the satisfaction scales of the QUIS satisfaction questionnaire (overall and subscales). Also asked was to rank the monitor setups and rate them by using a number between the 0 and 10.

5.2.3 Setup, materials and measurements

Prototype and tasks The prototype as developed during the three iterations was used in the experiment. Some additions to the prototype were implemented, making it possible to perform the workload inducing task during the experiment. The workload inducing task consisted of the participant having to count the blue circle that appeared at random locations on top of the endoscopic video output and with random time intervals (between 1 and 3 seconds). The endoscopic video output and Scopeguide videos were taken from one of the videos available with Waye et al. (2009).

Before the actual experiment started, two assignments were given to the participant to make him/her familiarize with the interface. To be able to do these tasks, one patient profile under the name of Mr. Janssen was created with relevant information about previous interventions, including images of these interventions. A therapist profile with the name of Dr. Barends was also created. The assignments that were given to the participant were:

1. **Opening patient file** - "Open the patient file of Mr. Janssen."

2. **Opening therapist profile** - "Open the therapist profile of Dr. Barends."

The assignments that needed to be completed during the execution of the workload inducing task were told by the experimenter to the participant during the execution of the experiment. The assignments were, in given order:

1. **Changing polyp count** - "Could you change the polyp count to 4?"

2. **Starting procedure timer** - "Could you start the procedure timer?"

3. **Opening MRI scan** - "Could you open the MRI scan made of patient Janssen?"

4. **Pauzing procedure timer** - "Could you pauze the procedure timer?"

5. **Changing the settings** - "Could you change the white balance value of the therapist profile to 20?"

6. **Closing MRI scan** - "Could you close the MRI scan made of patient Janssen?"

7. **Opening endoscopic image** - "Could you open the endoscopic image in which a polyp is located on the colon wall?"

Since the participants had to be triggered for the effectiveness and efficiency measurements after using the interface, two presentation sets were created inside the prototype. A presentation set consisted of warnings and errors for respectively the vital signs and the instruments. A vital sign warning consisted of a flashing red background and a buzz sound. The presentation set also depicted the entry of instruments in one of the three possible channels (left, center, right). The instrument element has been created for the use in the experiment and was thus not discussed in the iterative design phase. The entry of an instrument was represented by presenting a green dot under the associated channel. If no entered instrument was present, the dot was white. An instrument error showed a red dot beneath the channel of entry and an explanation of the error beneath the channels (see figure 5.2.1). All participants were presented with the sets in the same order, regardless of the counterbalancing of the monitor setups. An overview of the presentation sets can be found in table 5.2.1 and table 5.2.2. Also incorporated in these sets are the given assignments as described above.

Figure 5.2.1: Depiction of instrument entry and errors

Presentation set for first monitor setup	
Presentation	*Onset (ms)*
Changing polyp count assignment	160000
Left instrument is entered, visual cue is given	191000
Starting procedure timer assignment	205000
Center instrument is entered, visual cue is given	245000
Visual and audio heartbeat warning	270000
Center instrument presents visual error: "Left instrument is stuck. Remove instrument and re-enter instrument."	280000
Opening MRI scan assignment	290000
Center instrument error is removed, visual cue is given	301000
Right instrument is entered, visual cue is given	330000
Visual heartbeat warning	373200
Center instrument is removed, visual cue is given	392000
Pauzing procedure timer assignment	400000

Table 5.2.1: Presentation set for first monitor setup as used in the experiment.
Onsets are relative to the start of a monitor setup and listed as milliseconds

Presentation set for second monitor setup	
Presentation	*Onset (ms)*
Changing settings assignment	95000
Right instrument entered, visual cue is given	130000
Right instrument presents visual error: "Right instrument is stuck. Try moving the instrument up and down."	156000
Closing MRI scan assignment	180000
Visual and audio bloodpressure warning	201600
Center instrument entered, visual cue is given	213000
Center instrument presents visual error: "Instrument has lost contact to system. Reattach the instrument."	220000
Center instrument error is removed, visual cue is given	252000
Visual oxygen saturation warning	275400
Opening endoscopic image assignment	340000
Right instrument error is removed, visual cue is given	359000
Right instrument is removed, visual cue is given	373000
Left instrument entered, visual cue is given	374000
Visual and audio bloodpressure warning	390600

Table 5.2.2: Presentation set for second monitor setup as used in the experiment.
Onsets are relative to the start of a monitor setup and listed as milliseconds

Setup There were two room setups, namely the separation setup and the console setup. In the separation setup, the additional functionalities monitor was located near the participant. The endoscopic video output monitor was located behind a table, at approximately 1,5 meter from

the participant. In the console setup, both monitors are located in front of the participant and before the table. In both setups, the participant sat in a chair before the monitors. For a graphical representation see figure 5.2.2. Although the additional functionalities monitor will be a touchscreen in the eventual system, in this experiment a normal monitor with a keyboard and mouse were used. Since the assignments that needed to be completed were unimanual and only needed single-point interaction, it is expected that there was no added value by using a touchscreen (Forlines et al., 2007).

Figure 5.2.2: Experimental monitor setups, with (1) endoscopic video monitor, (2) additional functionalities monitor, (3) participant and (4) table

(a) Separation setup   (b) Console setup
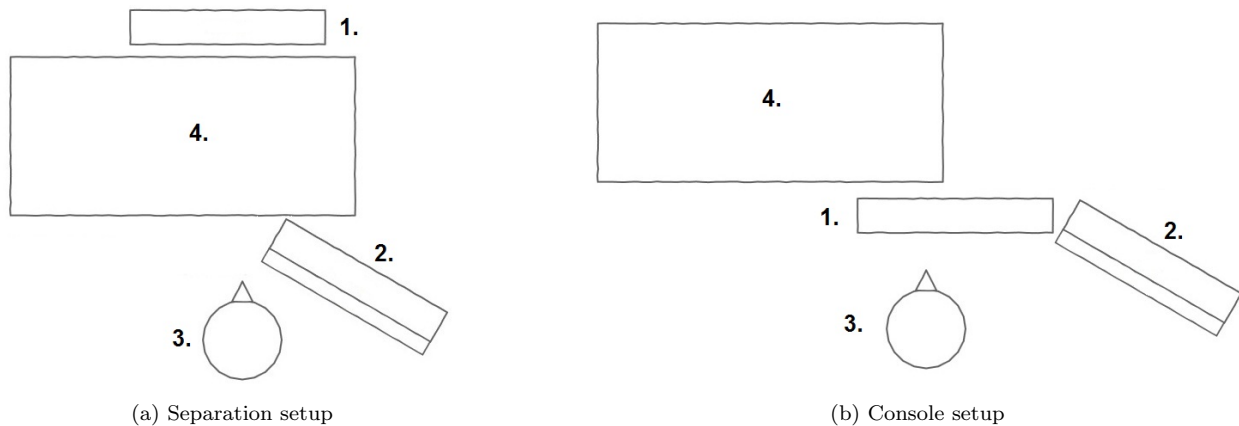
Measurements

Effectiveness measurement   The effectiveness was measured using several of the options that are listed in Hornbæk (2006). The most obvious choices were the *binary task completion* and the *accuracy* measurements. These are commonly used and are easy to implement. A less used measure is the *recall* in which a user has to recall information from the interface. Although not used as much, it is easy to use as a measurement and thus will be used.

The binary task completion measurement consisted of the total number of correctly completed assignments. The accuracy was measured by counting the errors the participant made during the execution of the assignments. Recall of the interface was done by letting the participant draw a general overview of the main view of the interface, with the main focus of the drawing being the information location and important interaction elements. This measurement was done after the first monitor setup, since the participant might haved paid more attention to the interface during the second monitor setup, negatively influencing the outcome of this measurement. In total, there were eight elements the participant could identify. Every correctly named information source was considered correct, even if location and size were not drawn correctly. If an element was missing, this was counted as missing and incorrectly drawn elements were counted as being incorrect.

After each monitor setup, the participant was asked effectiveness questions in regard to the presention of the vital signs and instrument information. These specific questions were:

1. How many times did the vital signs enter dangerous levels?

2. Which vital signs entered dangerous levels and how many times?

3. How many instruments were entered in the system?

4. In which channel were instruments entered (left, center, right)?

5. How many instrument errors occured?

6. In which channel(s) did the errors occur?

To answer the question if the addition of audio increases the effectiveness, a comparison was made between the correct count of the vital signs warnings, comparing two warnings with an audio signal (bloodpressure), two warnings with the audio both being present and absent (heartbeat) and one warning without audio feedback (oxygen saturation).

Efficiency measurement The efficiency was measured with the use of the *time*, i.e. the duration of tasks or parts of tasks, and *mental workload*, i.e. the users' mental effort when using the interface. More specific inside the time domain was the measurement of *task completion time*, i.e. the time users take to complete a task.

The task completion time measured the time it took the participant to complete an assignment given to him/her. The time was started as soon as the participant received the assignment and was stopped as soon as the assignment was regarded as completed by the experimenter.

The mental workload was measured after both the separation and console setup using two questionnaires: the NASA-TLX (Hart and Staveland, 1988; Hart, 2006) and a 6 item version of the State Trait Anxiety Inventory (STAI) (Chlan et al., 2003) as used in (Arora et al., 2010b) and as translated and validated by van der Bij et al. (2003). Both questionnaires have been validated and are short, preventing the participant to think too much about the given answers influencing the measurement.

Satisfaction measurement To measure the satisfaction, the validated and standardized Questionnaire for User Interaction Satisfaction (QUIS) (Chin et al., 1988) was used. The *preference* measure consisted of the participants having to rate the two monitor setups on a scale from 1 to 10 and indicating which monitor setup they preferred by giving them the rank of first or second.

Materials For the monitor setups, one computer monitor, a laptop with mouse, one cable to attach the monitor to the laptop, two tables and a chair were required.

The NASA-TLX consists of 6 items, measuring mental, physical and temporal demand, the performance, effort and frustration. Each item has a 20 point scale. After having completed the NASA-TLX two times, the participant is presented with 15 combinations of 2 items. With each combination, the participant had to indicate which item is more important in their experience of measuring the workload. The order of the combinations are created randomly for each participant with only unique combinations. The NASA-TLX can be found in appendix C.

The STAI as used by (van der Bij et al., 2003) was used. It consists of 6 items which measure calmness, tenseness, how upset a person is, relaxation level, how content a person is and how worried somebody is. The question have to be rated on a 4 point scale, ranging from 'totally not' to 'very

much'. The STAI can be found in appendix D. The first, fourth and fifth items were inverted to concur with a workload measure.

The QUIS consists of 5 subcategories with a total of 27 items. The subcategories consist of the overall reaction to the software, the screen, the terminology and system information, learning and system capabilities. The items inside the subcategories range from 0 to 9, with 0 being a negative appraisal and 9 being a positive appraisal. After the participant completed the items, he/she had to list the 3 most negative aspects and the 3 most positive aspects. The QUIS can be found in appendix E.

At the end of the experiment, the participant had to rank and rate the monitor setups. After that, the participant had to fill in a demographics questionnaire, also containing questions about former interface experience. The questions can be found in appendix F

5.2.4 Procedure

Introduction and instruction The participant was welcomed and let into the room by the experimenter. First, the experimenter described to the participant that he/she is going to perform some tasks with the system as it is set up in the room. If the participant agrees to participate, he/she was asked to fill in a consent form (appendix B), agreeing with the anonymous usage of their gathered data.

To become a more familiar with the system, the participant was instructed to open the patient file of Mr. Janssen and the therapist profile of Dr. Barends. After having done this, they could start with the first monitor setup.

First monitor setup Before starting this part of the experiment, the participant received the instruction to count the blue circles that appear in the endoscopic video screen. He/she was also made aware that certain assignments will be given by the experimenter during the experiment and that these should be completed while at the same time as doing the workload inducing task. These assignments should be completed as fast as possible, trying to prevent any incorrect steps. As soon as they fulfilled the given assignment, they can focus on the workload inducing task again. This part of the experiment took 7 minutes and 50 seconds.

First questionnaire set After the first monitor setup, the participant was asked to complete the NASA-TLX, STAI and QUIS questionnaires. Having completed these, they were given a piece of paper and were given the instruction to recall and draw the interface as they remembered it. They were prompted to focus on the location of necessary information in the interface, but if possible should draw specific elements.

Second monitor setup The participant received the same instruction as with the last monitor setup. The difference with the first monitor setup were the remaining assignments that were given to the participant, and the changed setup. This part of the experiment took 7 minutes and 50 seconds.

Second questionnaire set After the second monitor setup, the participant was asked to complete the NASA-TLX, STAI and QUIS questionnaires again. As an addition to the NASA-TLX, the participant had to choose between two alternatives in the 15 sets given. After having completed

the questionnaires, the participant filled in the rank and rate and completed the demographics questionnaire.

Open discussion and debriefing   After having completed all the questionnaires, the participant was asked to partake in an open discussion about the experiment and the system. He/she was asked to tell the experimenter about the experience with the system and the different setups and if they think anything can or should be improved of the system. After this discussion, the participant was thanked and shown the exit of the room. If they were interested in the results of the experiment, they could leave their email address with the experimenter.

5.3   Results

The small sample of participants is not ideally suited for sound statistical analyses. These results should thus be regarded as suggestive. In some cases, comparisons across variables are done between the monitor setups (separation and console) but also between order of monitor setups (first and second). This was done due to the observation that participants were better capable of controlling the interface in the second task, possibly influencing the results.

Effectiveness   The *binary task completion* measurement of correctly completed assignments was higher for the separation setup ($M = 3.3$, $SD = 0.9$, with a range from 0 to 7 correctly completed assignements) as compared to the console setup ($M = 3.13$, $SD = 0.83$). Comparing the console and separation setups subdivided in first and second task, the console setup as the first task had more correctly completed assignments ($M = 4.00$, $SD = 0.00$) compared to the separation setup ($M = 3.75$, $SD = 0.5$). With the console and separation tasks as second tasks, there was no difference ($M = 2.50$, $SD = 0.58$).

The *accuracy* measurement of the amount of errors made in completing the assignments was higher for the console setup ($M = 2.87$, $SD = 5.36$) compared to the separation setup ($M = 2.63$, $SD = 2.45$). Comparing the console and separation setups subdivided in first and second task, the separation setup as the first task had less errors in completing the assignments ($M = 1.75$, $SD = 2.36$) than the console setup as the first task ($M = 4.75$, $SD = 7.54$). The console setup as second task had less errors ($M = 1.00$, $SD = 0.82$) than the separation setup as second task ($M = 3.50$, $SD = 2.52$).

It is important to note that the results from the *recall* measurements are based on four participants since each setup only had one recall measurement per participant. The amount of recalled interface elements of the *recall* measurement was higher in the separation setup ($M = 7.00$, $SD = 0.82$, with a range from 0 to 8) compared to the console setup ($M = 5.00$, $SD = 2.16$). The amount of incorrect and missed elements was lower for the separation setup ($M = 1.00$, $SD = 0.82$ and $M = 0.00$, $SD = 0.00$ respectively) than the console setup ($M = 3.00$, $SD = 2.16$ and $M = 1.50$, $SD = 3.00$ respectively). An overview of the results from all three measurements can be found in table 5.3.3.

	Console setup		Separation setup	
	Mean	SD	Mean	SD
Binary task completion				
First setup	4.00	0.00	3.75	0.50
Second setup	2.50	0.58	2.50	0.58
Accuracy				
First setup	4.75	7.54	1.75	2.36
Second setup	1.00	0.82	3.50	2.52
Recall				
Correctly recalled elements	5.00	2.16	7.00	0.82
Missed elements	3.00	2.16	1.00	0.82
Incorrect recalled elements	1.50	3.00	0.00	0.00

Table 5.3.3: The binary task completion, accuracy and recall measurements per monitor setup, subdivided in the setup used in first or second task. Gray cells indicate the most positive value. Binary task completion measures range from 0 to 7, accuracy is measured in amount of errors (higher is worse), correctly recalled elements ranges from 0 to 8 elements

In regard to the effectiveness questions, less errors were made in the separation setup (4 out of 6) compared to the console setup (0 out of 6). In two cases, the same amount of errors were made. See table 5.3.4 for an overview of all the questions. Looking at the chronical order of the setup, the first setup questions were answered worse in all respects compared to the questions after the second setup (see table 5.3.5). When subdividing the questions in both the monitor setups and the first or second setup, the separation resulted in less errors (7 out of 12) compared to the console setup (4 out of 12). An overview of all the combinations between the monitor setups and chronological order can be found in table 5.3.6.

	Console		Separation	
	Mean	SD	Mean	SD
How many dangerous vital signs[1]	1.13	1.64	0.75	1.49
Which vital signs became dangerous[2]	0.63	0.52	0.88	0.35
How many instruments entered[1]	1.00	1.07	0.88	1.13
In which channels were the entries[2]	0.50	0.53	0.50	0.53
How many instrument errors occured[1]	0.63	0.92	0.50	0.53
In which channels were the errors[2]	0.38	0.52	0.38	0.52

[1] errors made by participant, a low value is preferred
[2] correct amount as given by participant, with 0 indicating all incorrect amounts and 1 indicating all correct amounts

Table 5.3.4: Means and standard deviations of the effectiveness questions subdivided into console and separation setup. Gray cells indicate the most positive values.

	First setup		Second setup	
	Mean	SD	Mean	SD
How many dangerous vital signs[1]	1.13	1.64	0.75	1.49
Which vital signs became dangerous[2]	0.63	0.52	0.88	0.35
How many instruments entered[1]	1.75	0.89	0.13	0.35
In which channels were the entries[2]	0.13	0.35	0.88	0.35
How many instrument errors occured[1]	0.63	0.74	0.50	0.76
In which channels were the errors[2]	0.13	0.35	0.63	0.52

[1] errors made by participant, a low value is preferred

[2] correct amount as given by participant, with 0 indicating all incorrect amounts and 1 indicating all correct amounts

Table 5.3.5: Means and standard deviations of the effectiveness questions subdivided into first and second setup. Gray cells indicate the most positive values.

	Console setup		Separation setup	
	Mean	SD	Mean	SD
How many dangerous vital signs[1]				
First setup	2.25	1.70	0.00	0.00
Second setup	0.00	0.00	1.50	1.91
Which vital signs became dangerous[2]				
First setup	0.25	0.50	1.00	0.00
Second setup	1.00	0.00	0.75	0.50
How many instruments entered[1]				
First setup	1.75	0.96	1.75	0.96
Second setup	0.25	0.50	0.00	0.00
In which channels were the entries[2]				
First setup	2.25	1.70	0.00	0.00
Second setup	0.00	0.00	1.50	1.91
How many instrument errors occured[1]				
First setup	0.75	0.96	0.50	0.58
Second setup	0.50	1.00	0.50	0.58
In which channels were the errors[2]				
First setup	0.00	0.00	0.25	0.50
Second setup	0.75	0.50	0.50	0.58

[1] errors made by participant, a low value is preferred

[2] correct amount as given by participant, with 0 indicating all incorrect amounts and 1 indicating all correct amounts

Table 5.3.6: Means and standard deviations of the effectiveness questions divided into console and separation setup and subdivided into first and second setup. Gray cells indicate the most positive values

The use of an audio signal in association with a visual warning with the vital signs results in less errors in perceiving the warnings ($M = 0.25$, $SD = 0.47$). Inconsistency in presenting an audio signal with a visual warning (first presenting the warning with the audio, the second time without the audio), there are more errors in perceiving the warnings ($M = 0.63$, $SD = 0.92$). No audio also had a low level of errors in perceived warnings ($M = 0.25$, $SD = 0.47$).

Efficiency Each monitor setup had four measurements for each task completion time. Comparing the mean completion times is not meaningful with such a small sample. Instead, a comparison was made which tasks were completed faster in each setup. In the console setup, the second, fourth and seventh assignment were completed faster, in the separation setup the first, third, fifth and sixth were faster. This results in the separation setup having the assignments completed faster.

On the overall scores of the NASA-TLX, there was no difference between the separation setup and the console setup since the mean score for the console setup ($M = 10.31$, $SD = 2.04$, compared to a range from 0 to 20) is almost the same as that of the separation setup ($M = 10.28$, $SD = 2.43$) with high standard deviations. When subdividing the console and separation setup with first and second setup, the separation setup has a lower workload as the first task ($M = 9.92$, $SD = 1.39$) than the console setup ($M = 11.55$, $SD = 1.90$). In the second task, the console setup had a lower workload value ($M = 9.00$, $SD = 2.38$) than the separation setup ($M = 10.69$, $SD = 1.22$). In itself, the values fall around a normal workload experience, with no diversion to completely relaxed or stressed out.

On the overall scores of the STAI, the console setup had a lower workload level than the separation setup ($M = 2.88$, $SD = 0.28$ and $M = 2.94$, $SD = 0.22$ respectively, with a range from 1 to 4, with 1 being no workload and 4 experiencing a lot of workload). Subdividing the monitor setups in first and second task, the separation setup scores lower on workload in the first task ($M = 1.76$, $SD = 0.08$) compared to the console setup ($M = 1.96$, $SD = 0.35$), with the console setup having a lower score when done in the second task ($M = 1.38$, $SD = 0.25$) compared with the separation setup ($M = 1.83$, $SD = 0.51$). For an overview of both the NASA-TLX and STAI means divided between monitor and chronical setups see table 5.3.7.

	Console setup		Separation setup	
	Mean	SD	Mean	SD
NASA-TLX				
First setup	11.55	1.90	9.92	1.39
Second setup	9.00	2.38	10.69	1.22
STAI				
First setup	1.96	0.35	1.46	0.08
Second setup	1.38	0.25	1.83	0.51

Table 5.3.7: The NASA-TLX (range from 0 to 20) and STAI (4 point scale) means per monitor setup, subdivided in the setup used in first or second task. Gray cells indicate the most positive value

Satisfaction There was no difference on the overall QUIS mean rating between the console and separation setup ($M = 5.49$, $SD = 1.25$ and $M = 5.49$, $SD = 1.15$ respectively). All of the subscales were rated as being better in the console setup. Interestingly, comparing the setups in chronical order, the second setup was rated higher on all scales (overall and subscales) compared to the first

setup. For an overview see table 5.3.8. When comparing each possibility of both monitor and chronological setup, in all cases the separation setup was rated as more positive on all subscales than the console setup when done in the first task, whereas the console setup was rated as more positive on all subscales in the second task (see table 5.3.9).

	Console		Separation		First setup		Second setup	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Overall	5.49	1.25	5.49	1.15	4.78	1.35	5.88	1.30
Screen	6.21	0.94	6.09	0.96	6.21	1.13	6.29	0.73
System Information	5.73	0.88	5.68	0.96	5.42	0.79	6.02	1.07
Learning	5.97	0.75	5.91	0.64	5.78	0.86	6.28	0.91
System capabilities	6.92	0.71	6.65	0.80	6.65	0.86	6.98	0.82

Table 5.3.8: Means and standard deviations of the QUIS subdivided into console, separation first and second setup. Scales range from 1 to 9. Gray cells indicate the most positive values

	Console setup		Separation setup	
	Mean	SD	Mean	SD
Overall				
First setup	4.17	0.96	5.79	1.26
Second setup	5.98	1.89	5.78	0.60
Screen				
First setup	5.85	1.16	6.56	1.14
Second setup	6.63	0.92	5.96	0.28
System information				
First setup	5.00	0.49	5.83	0.87
Second setup	6.21	1.09	5.83	1.19
Learning				
First setup	5.38	1.14	6.17	0.14
Second setup	6.50	0.79	6.05	1.08
System capabilities				
First setup	6.42	0.94	6.89	0.84
Second setup	7.15	0.50	6.80	1.12

Table 5.3.9: Means and standard deviations of the QUIS divided into console and separation and subdivided in first and second setup. Scales range from 1 to 9. Gray cells indicate the most positive values

The *preference* measure, rating the monitor setups, resulted in a preference for the separation setup ($M = 6.75$, $SD = 1.13$) above the console setup ($M = 6.25$, $SD = 1.28$). In the ranking, 5 out of 8 participants chose the separation setup, with 3 out of 8 chosing the console setup.

5.3.1 Observations

Apart from the above results, there have been several observations in regard to (the usage of) the interface. These observations are an important base for the last changes that will be made to the interface and will thus be listed here.

Although no satisfaction measurement of the addition of audio to warnings was taken, it was important to note that five of the eight participants indicated that they preferred the audio warning, as it drew their attention to the dangerous levels of the vital signs. If they compared the vital signs warnings with the instrument errors, it was apparent that they missed a larger amount of instrument errors.

Several participants mentioned that there were three problems with the instrument input. First, they found that changing the color of the circles did not draw their attention to the instrument. Only when an error appeared did it draw their attention. Second, the instrument information disappeared when one of the tabs was opened. Third, the warnings missed audio signals that would draw their attention towards the instrument errors.

Three of the eight participants mentioned that placing the therapist profile with the settings tab was strange. They would have preferred the therapist profile in another location.

Participants started to switch their attention between monitors to be able to see any warnings or errors. Two of those participants mentioned that they missed error warnings in the endoscopic video output, which would trigger them to change their attention to the other monitor.

5.4 Discussion and conclusions

5.4.1 Factors

Effectiveness The *binary task completion* measurement did not give a clear preference for the console or the separation setup. Although the console setup resulted in more correctly completed assignments, it's difference with the separation setup is small, so no real preference can be chosen here. In itself, the assignments were completed correctly half of the time. This might be explained due to the unexpected assignements which the participants had to plan at the time of receiving the assignement. The combination of this unexpectancy and the workload inducing task might lead to a too high demand on cognitive resources, resulting in less correctly completed assignments.

The *accuracy* measurement presents a learning effect for each group of users, but the amount of errors made were smaller when a user starts with the separation setup, followed by the console setup. The differences between the monitors setups are larger compared to the binary task completion results, but they could be explained due to the small group sizes. Larger groups should be tested to be able to draw any strong conclusions. The overall amount of errors made can be considered small, which is a promising result and will be tried to retained in the next design.

The *recall* measurements clearly points in the direction of the separation setup, which the users apparently could remember more easily. This might also explain the results obtained with the accuracy measurement, since participants had a better idea on where different elements were located, resulting in less errors.

The effectiveness questions clearly indicate a learning effect with the interface, since all questions were answered better in the second task than in the first. Even subdividing the monitor setups in first and second task shows this pattern, with almost every second task having a lower value than the first task (taking the counterbalancing of the monitor setup into account), indicating a

preferable pattern. For effectiveness, a small preference exists for the separation setup, since this setup had less errors in the questions.

Only visual as well as audio and visual presentation result in less errors in the usage of the system, indicating a higher effectiveness than an inconsistent presentation of audio and visual or only a visual warning. It should be noted that the level of errors in itself were small, making the previous conclusion less strong. Albeit the small difference, it is still preferable to use the combination of an audio and visual warning, since this will increase the chance of a therapist being made aware of possible complications with the system or the patient.

Efficiency   The assignments were completed faster in the separation setup. Some participants noted that the separation setup enabled them to use their peripheral view to see the interface, possibly making it possible for them to more easily navigate through the interface. The low completion times in themselves present a preferable usage of the interface and will be tried and maintained in the next design.

The values found with the NASA-TLX indicate a learning effect with the interface since the second task workload values were lower than those in the first task, taking into account the counterbalancing. These values do not indicate a clear preference for either monitor setup. The values themselves should be as indicating a normal level of workload, with participants not being either relaxed or extremely stressed. It is expected that therapists will have this level of workload since every task increases the workload and therapists have a number of tasks that need to be performed during a colonoscopy. It might be desirable to measure the workload during peak moments, but will not be done in this thesis to make sure a natural flow exists in the usage of the interface.

The STAI values also indicate a learning effect. When considering each score seperately (with a division and subdivision between console and seperation setup and first and second setup), it is apparent that the participants scored lower on this scale, indicating a more relaxed experience than those found with the NASA-TLX.

The efficiency of the system is considered to be higher in the separation setup. The quicker completion of the assignments is the only reason to conclude this, since the effects of the NASA-TLX and STAI do no result in a preference.

Satisfaction   The QUIS questionnaire resulted in a preference for the console setup, but looking at the differences between the console and separation setup compared to the chronical order of the tasks, it became apparent that learning to use the interface already had a positive effect on the complete interface. Since this learning effect is stronger, which can also be seen when subdividing the monitor setups in chronological order, the QUIS remains indecisive in regard to the satisfaction and a choice for the setup. The scores overall indicate a positive experience with the interface, with the highest subscale values ranging from 5.79 to 7.15. These values are quite high, considering they are on a 9 point scale. The next design will try and retain these high values.

What remains is the *preference* measure. The rating of the monitor setups did not provide a strong preference for either setup, since the difference was small with a high standard deviation. This small difference is also visible with the ranking, where the difference is dependent on one person. No preference for a monitor setup can be concluded based on the results from the satisfaction measurements.

5.4.2 Overall

The experiment resulted in slightly positive results. The participants were capable of quickly learning to use the interface, which can be seen in the increase in effectiveness on the questions used to measure the effectiveness, the lowering scores on the NASA-TLX and the STAI, and the higher scores on the QUIS. Participants were also capable of almost completing all of the assignments with a small amount of errors.

Although differences are small for all factors, the separation setup has a small preference, mostly for the effectiveness factor. This dictates the choice to develop the system for two separate monitors, although the possibility of putting those monitors in a console setup should not be totally dismissed. The addition of audio to visual warnings and errors is an important improvement, seeing as it results in the attention of the user being directed to important events. With this addition, the instrument information will also be changed. The depiction of the entered instruments and the orientation will remain, but individual instrument information and the errors will be moved to the persistent part of the interface. The addition of an audio signal to the errors will be done with a different audio signal than that from the vital signs warnings, making identifying the kind of error easier for the therapist.

Next to the addition of audio signals to errors and warnings, and making instruments errors visible in the persistent part of the interface, the endoscopic video output will receive elements that will indicate that an increase or change in attention by the therapist is needed. These elements will alert the users that any errors or warnings occur and will trigger the therapist to move his/her attention to the other monitor for error or warning information.

Although not mentioned in the *observation* part of the results, when drawing the interface, six out of eight people did not know what the name of the first tab was. This lead us to belief that they considered this tab to be the main screen, since they did not remember the name. That is why the interface will be changed to represent the elements in this tab as being the main part of the interface and having all of the other tabs as additional functionalities. This might also result in users closing one of the open tabs to show the main screen again, since ScopeGuide information is expected to be of a higher importance than the settings of the system.

A small change to the system will consist of the possibility to double click on certain features, as is common in main stream software and was shown by the behavior of the participants. It will also be possible for the therapist to click on more items, making the interaction more natural (for example clicking on the patient name will open the patient file).

6 Final design

The experiment resulted in a slight preference for the separation setup. The next design will thus focus on this setup and will have a higher fidelity than the former design. After this section, the design will be referred to as the system.

6.1 Endoscopic video output window

This window presents the user with the endoscopic video output. Alongside or above of this output, warning icons (figure 6.1.1) will be presented in case of dangerous levels of the vital signs and/or errors with the instruments. The icon is used to divert the attention of the user from the endoscopic video to either the vital signs or instruments, both located in the other window. The icon presentation will be done in combination with an audio signal, with a different signal for vital sign warnings and instrument errors.

Figure 6.1.1: Warning icon used in the system to attract the attention of the user to an important event in the additional functionalities window with textual output to indicate the origin of the warning or error

Vital signs / Instrument

Vital signs / Instrument

6.2 Additional functionalities window

The additional functionalities window has received a dark gray color scheme to make each individual element more prominent, highlighting the information.

6.2.1 Persistent elements

The persistent elements panel (figure 6.2.2) has been given a shadow effect, distantiating this panel from the initial dynamic elements (ScopeGuide, orientation of the tip of the endoscope, patient file image area). The panel itself has been subdivided in three groups, with the groups having larger distances between them than the elements in those groups. The first group is the patient information. Added to the patient information is the possibility of clicking on the patient name or the therapist name to load their respective files. The second group is the vital signs and the instruments. These were grouped because of their importance and their presentation of warnings/errors. The third group is the performance measures, in this case a procedure stopwatch and a polyp counter.

As was concluded after the first experiment, the actual information tab has been implemented as the basic level of the dynamic elements, making it a persistent element. ScopeGuide, the orientation of the tip of the endoscope and the possibility for a E.P.D. image are part of the actual information (figure 6.2.3).

Figure 6.2.2: The panel with the persistent elements and the subgroups of these elements

6.2.2 Dynamic elements

The remaining dynamic elements are the patient file system (E.P.D.), settings, EndoBase and help functionalities. All of these elements have been clustered into a tab. This tab can be opened by

pressing one of the buttons for one element. The tab will slide open and will reveal the associated element. The embedded programs within these elements (E.P.D. and EndoBase) have images depicting the programs. The settings and help elements will be fully functional. Closing the tab can be done by pressing the close button, or pressing the element button a second time. The choice of having a moving tab was made to make it clear to the user that it is a dynamic element and is not the most important information presented. It is expected that users will more often close this tab, revealing ScopeGuide, the orientation of the tip and the E.P.D. image.

Figure 6.2.3: The panel with the dynamic elements and the sliding tab
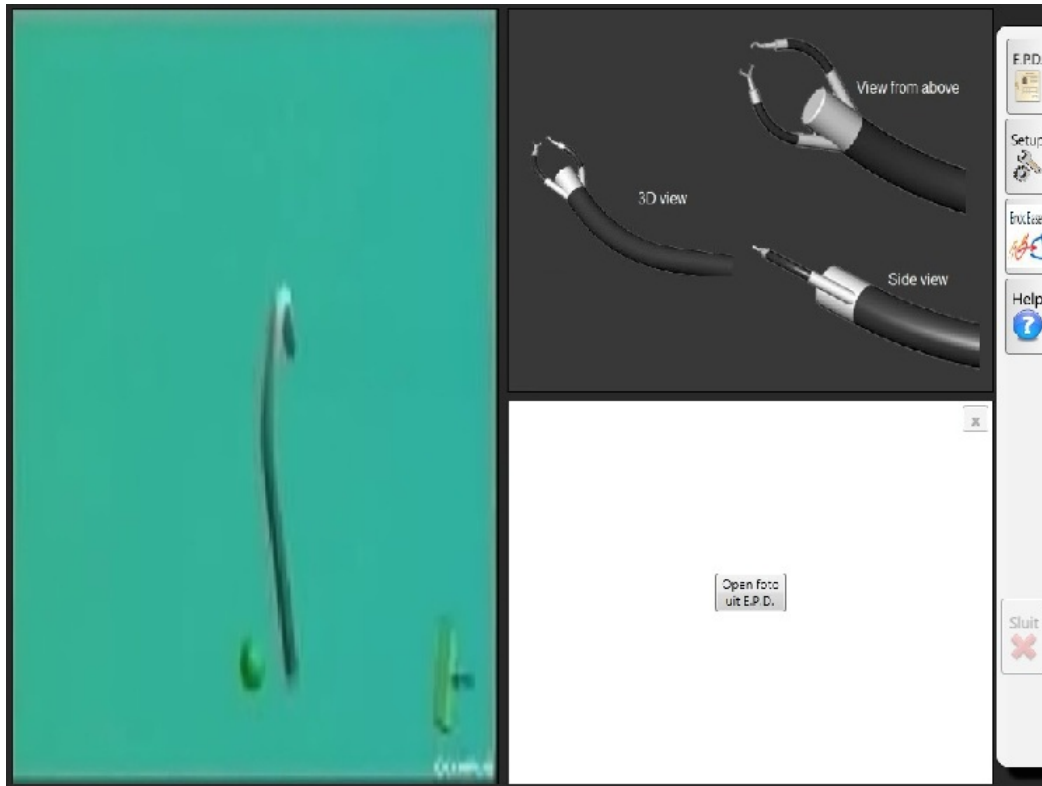
The settings and help tab are the only elements with which the user is able to interact. The help tab has not changed compared to the earlier designs, so will not be discussed. The settings tab (figure 6.2.4) has been reduced in size and one advanced setting has been added for illustrative purposes. All of the other functionality has been preserved. Opening a therapist profile will open a dialog window on top of the current window (figure 6.2.5).

Figure 6.2.4: Tab with the additional information elements

Figure 6.2.5: Window used for chosing therapist profile

7 Second experimental evaluation

The system discussed in section 6 was followed by an experimental evaluation of that system. This experimental evaluation had almost the same research questions as the experimental evaluation as conducted in section 5, with the difference being that no longer will there be any different setups, nor difference in audio and visual sets. We measured the effectiveness, efficiency and satisfaction in a high workload setting. Using the results from the first task separation setup from the previous experimental evaluation as the baseline, the ratings on the factors (effectiveness, efficiency and satisfaction) in this evaluation were compared with this baseline. Changes to the method are discussed.

7.1 Research questions

The research questions that will be answered in this experimental evaluation are:

Research question 5: In a high workload setting, does the newest system result in a higher effectiveness rating compared to the previous experimental evaluation?

Research question 6: In a high workload setting, does the newest system result in a higher efficiency rating compared to the previous experimental evaluation?

Research question 7: In a high workload setting, does the newest system result in a higher satisfaction rating compared to the previous experimental evaluation?

7.2 Method

7.2.1 Participants

Although it is not imperative that participants have medical knowledge about endoscopic procedures, the choice was made to perform the experiment with medical professionals or students that possess experience closely related to the endoscopic field. All of the participants were new to the interface and the experiment. In total there were four participants in the experiment, three male and one female. Three participants are therapists associated with the Meander Hospital in Amersfoort and one participant is a Technical Medicine student at the University of Twente and has theoretical experience in performing endoscopic procedures. The respective ages are 44, 27, 40, 25. The participants did the experiment in a room that was located at their associated location.

7.2.2 Design

There was only one condition in the experiment, the high workload condition, because we were only interested in a high workload setting and since the comparison can be made with the previous experiment. The dependent variables were the number of correctly completed given assignments, the total number of errors during these assignments, time needed to complete the assignments, mean score on the NASA-TLX, mean score on the STAI and the satisfaction scales of the QUIS (overall and subscales).

7.2.3 Setup, materials and measures

System and tasks The system as described in section 6 was used in the experiment. Some additions to the system were implemented, making it possible to perform the workload inducing task during the experiment. The workload increasing task consisted of the participant having to count the blue circle that appeared at random locations on the endoscopic output window and with a random time interval, randomly chosen from three possible time intervals (0.5 - 1.5 seconds, 1.5 - 2.5 seconds and 2.5 - 3.5 seconds). The choice for the three time intervals was made to prevent the participant from counting the blue circles by having a pattern in the appearance of the circles, which two of the participants mentioned in the previous experiment.

Before the actual experiment started, an instruction and demonstration of the system were given. The participant was free to use the interface to get familiar with its functions. As soon as the participant thought he understood and could use the interface, the workload inducing task was started.

The assignments that needed to be completed during the execution of the workload inducing task were told by the experimenter to the participant during the execution of the experiment. The assignments were, in given order:

1. **Starting procedure timer** - "Could you start the procedure timer?"

2. **Opening E.P.D. image** - "Could you open a photo from the E.P.D.?"

3. **Opening therapist profile** - "Could you open a random therapist profile?"

4. **Pauzing procedure timer** - "Could you pauze the procedure timer?"

5. **Changing the settings** - "Could you change the white balance value of the therapist profile to 20?"

6. **Setting polyp count** - "Could you set the polyp count to two?"

Since the participants had to be triggered for the efficiency and effectiveness measurements after using the interface, one presentation set was created inside the system. The presentation set consisted of warnings and errors for respectively the vital signs and the instruments. All participants were presented with this set. An overview of the presentation sets can be found in table 7.2.1. Also incorporated in these sets are the given assignments as described above.

Presentation set		
Presentation	*Onset (ms)*	*Duration*
Visual and audio blood pressure warning	60000	16000
Visual and audio blood pressure warning	136000	14000
Right instrument is entered, visual and audio cue are given	153000	
Starting procedure timer assignment	160000	
Opening E.P.D. image assignment	181000	
Left instrument is entered, visual and audio cue are given	257000	
Open therapist profile assignment	290000	
Visual and audio oxygen saturation	330000	20000
Center instrument is entered, visual and audio cue are given	340000	
Pauzing procedure timer assignment	342000	
Visual and audio heartbeat	359000	14000
Changing the settings assignment	358200	
Right instrument gives visual and audio feedback about error	415000	
Setting polyp count assignment	421000	
Center instrument gives visual and audio feedback about error	430000	

Table 7.2.1: Presentation set as used in the second experiment. Onsets are relative to the start of a monitor setup and listed as milliseconds. Durations are given only for the vital signs warnings, because continuous presentation in combination with the audio signal would result in annoyance with the system

Setup, materials and measurements   Since the results of the last experiment resulted in the choice for a setting with the monitors separated, the separation setup from the previous experiment was used. A monitor with a laptop and mouse were still used. The measurements and measurement materials are identical to the first experiment apart from four measurements. The recall task was removed due to the intuitiveness that was apparent in the previous experiment. The ranking and rating measurements were removed because there were no different setups. The completion times were not used because the assignments differed from the first experiment and could thus not be compared.

7.2.4   Procedure

The procedure of the second experimental setup is the same as the first, apart from the second monitor setup and second questionnaire set which were removed.

7.3   Results

As in the first experiment, results are based on a small participant group. The means of the values given here are to be considered suggestive.

Effectiveness   The *binary task completion* measurement resulted in a large number of correctly completed tasks ($M = 5.75$, $SD = 0.50$ out of a total of 6 tasks), with a high *accuracy* level (small amount of errors) ($M = 0.50$, $SD = 1.00$).

The effectiveness questions resulted in varied results compared to the first experiment. In this experiment, the participant were better at indicating which vital signs had dangerous levels ($M = 0.50$, $SD = 0.58$), how many instruments were entered ($M = 0.50$, $SD = 0.58$) and how many instrument errors occured ($M = 0.00$, $SD = 0.00$). The comparison of this and the first experiment can be found in table 7.3.2.

	First experiment		Second experiment	
	Mean	SD	Mean	SD
How many dangerous vital signs[1]	0.00	0.00	1.75	1.71
Which vital signs became dangerous[2]	1.00	0.00	0.50	0.58
How many instruments entered[1]	1.75	0.96	0.50	0.58
In which channels were the entries[2]	0.00	0.00	0.75	0.50
How many instrument errors occured[1]	0.50	0.58	0.00	0.00
In which channels were the errors[2]	0.25	0.50	0.75	0.50

[1] errors made by participant, a low value is preferred

[2] correct amount as given by participant, with 0 indicating all incorrect amounts and 1 indicating all

Table 7.3.2: Means and standard deviations of the effectiveness questions of the second experimental setup, compared to the effectiveness questions of the separation setup which was done first of the first experiment. Gray cells indicate the most positive values

Efficiency   The mean overall score on the NASA-TLX ($M = 9.75$, $SD = 2.87$, compared to a range from 0 to 20) was slightly lower than in the first experiment ($M = 9.92$, $SD = 1.39$), but is not regarded as a significant difference due to the high standard deviations. The mean STAI score was higher in this experiment ($M = 2.08$, $SD = 0.32$, with a range from 1 to 4, with 1 being no workload and 4 experiencing significant workload) than in the previous one ($M = 1.46$, $SD = 0.08$).

Satisfaction   The overall score on the QUIS was higher than the previous experiment ($M = 6.93$, $SD = 1.23$, on a 9 point scale). All of the subscales were rated as being better than the previous experiment. For an overview see table 7.3.3.

	First experiment		Second experiment	
	Mean	SD	Mean	SD
Overall	5.79	1.26	6.93	1.23
Screen	6.56	1.14	6.88	2.02
System information	5.83	0.87	6.67	1.27
Learning	6.17	0.14	6.55	1.41
System capabilities	6.89	0.84	6.98	1.42

Table 7.3.3: Means and standard deviations of the QUIS (9 point scales) in the second experiment compared to the first experiment. Gray cells indicate the most positive value

7.3.1 Observations

As in the first experiment, some observations in regard to (the usage of) the interface were made. These observations will most likely be used for future system enhancements and will be elaborated on in the *Discussion* section of this thesis.

Three out of the four participants mentioned that, at the presentation of a warning or error, the therapist would stop the endoscope and first try to remove the source of the error or warning before resuming the procedure.

In regard to the separation of the monitors, two participants mentioned that they preferred this setup. Another participant mentioned that he would like to see the endoscopic video smaller and possibly integrated in the complete interface, closely resembling the earlier considered console setup. Upon further questioning, the participant said he would like to have a clear overview of the video and all of the relevant information output.

After completing assignments that made use of the tab, the participants closed the tab in almost all cases. This resulted in the desired effect that users return to the main screen.

One of the therapists recommended to increase the size of the buttons, to make sure that they can easily be pressed, even with gloves on.

7.4 Discussion and conclusions

An important note should be made about the conclusions drawn here. There were some differences in the setups of the previous experiment and this one. So the results are based on different designs, making it hard to draw conclusions about the differences in the results. Where deemed necessary, the differences that might influence the results are discussed. And as was mentioned at the beginning of the *Results* section, the small number of participants is a reason to doubt the conclusions drawn from the results.

The system enabled the user to complete his/her tasks, since the number of correctly completed tasks and their accuracy were quite high. The effectiveness questions gave more diverse results, with no clear pattern. Considering the results on the questions in a whole, it is apparent that in both experiments the values were positive in regard to the effectiveness. The small differences might be explained due to the memory of the participants or a misinterpretation by the participant of the instructions given by the experimenter.

The efficiency as measured by the NASA-TLX did not result in a significant difference. On the other hand, the STAI did result in a higher value, with the workload being higher with the new system. In the second experiment, the workload inducing task was made more complex to ensure a higher workload. The difference on the STAI might indicate that the task induced a higher workload due to the changes made to the task.

The system was rated more positive on the QUIS than in the previous experiment, indicating a preference for the current system. The largest differences can be found in the overall score and the system information. The latter was the main focus of the changes for the current system. The higher satisfaction ratings of the system will make the acceptance of the system more probable (Holden and Karsh, 2010) and will generally leave either a pleasant or non-negative experience with the therapists.

From the observations, several conclusions can be drawn. Based on the first observation, it is expected that the user will be capable of having a lower workload when using the system, since no other tasks will have to be performed when an error or warning occurs. The second observation is about the choice of a separation versus a console setup. There seems to be no clear preference with

71

therapists for a console or separation setup. Important to note is the desire to have overview, which appears as the most important factor, with some having overview on a separated screen and others having overview on a smaller video output located in a console setup. A more elaborate discussion about this issue as well as solutions are given in the *General discussion*. The last observation shows that the desired behavior of users closing the tab to return to the main screen was achieved.

8 General discussion and conclusions

In this section, conclusions about the system as it now stands are drawn, and changes to the system and future research are discussed.

8.1 Effectiveness, efficiency and satisfaction

The effectiveness, efficiency and satisfaction have all been researched for the current system. Changes to the system can still be made (and will be discussed later on), but overall the results from both the first and the second experiment are promising. The users were capable of completing tasks correctly (effective) and with the use of few resources (efficient). They also indicated to be satisfied with the system as it now stands, favoring the ease of use compared to a possible complex interface.

The three factors might be subjective to change once the first three modules are introduced. The therapists will receive more (complex) tasks, which might influence the effectiveness and efficiency of the system. The modules will also influence the satisfaction of the complete system, since their usage will affect the complete experience of the system. Keeping track of these changes is an important task that will need to be done during the complete development of the system within the TeleFLEX project.

8.2 System setup

The experiments have mostly focused on the monitor location and the access to the information, but the goal of this thesis was also to make a setup choice to be used in the TeleFLEX project. During the execution of the experiments, observations and remarks of the therapists have made it possible to make some choices in regard to the setup. These choices will be discussed here. An overview of the complete setup can be seen in figure 8.2.1.

Figure 8.2.1: Final system setup
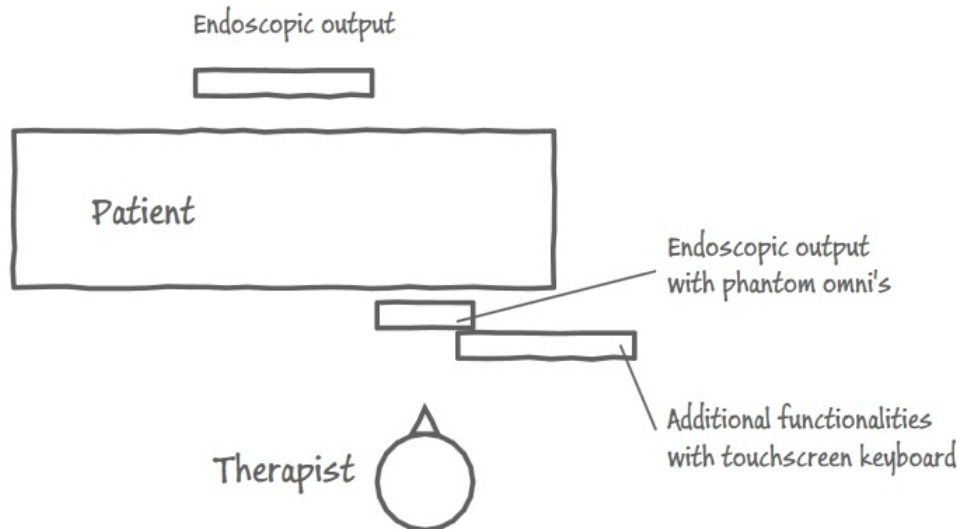
Monitors   The results from the first experiment slightly point in the direction of using two monitors in a separated setup. The results from the second experiment show that the effectiveness, efficiency and satisfaction of the created system with the separated monitor setup are acceptable. Based on these results, the choice would be made for a separated setup, but there are some other factors that influence this choice.

The first factor is that in the second experiment one of the participants, a therapist, mentioned that he would prefer to have the endoscopic output smaller and closer to the other information, possibly integrating it. He mentioned that this would give him overview of the endoscopic output. The choice for a separate setup was also based on giving the therapist an overview of the endoscopic output. Apparently, the overview of the endoscopic output is important for the therapists and can be incorporated in both monitor setups.

The second factor is the placement of the controls (phantom omni's) for the endoscope and instruments. Preferably, these controls would be placed underneath the endoscopic output monitor, since this creates a direct mental mapping between the controls and the visual output from the instruments. Placing the controls in this way and getting the mapping is most easily achieved in a console setup because the controls are located directly under the corresponding instruments.

The third factor is the space available in the outpatient room. Placing a monitor on two sides of the bed decreases the space personnel have to move around. And in case of an emergency, the monitor might be in the way of quickly moving the patient. Having the monitors on one side of the bed would be preferable.

These factors as well as the small differences in the results of the first experiment do not present a clear choice for either setup. This indifference results in two possibilities: further research, preferably after the introduction of the other modules, or giving the therapists an integrated setup of the console and separation setup. In the second case, the integrated setup would preferably consist of two monitors positioned next to each other. The reason for using two monitors opposed to one large monitor is that several participants in the experiments mentioned that the two monitors made it possible for them to more easily distinguish between the information presented in the monitors. To ensure that the therapists have an overview of the endoscopic output, it should be made resizable as desired by the therapist. A general overview might be necessary in colonoscopy, resulting in a small size of the endoscopic output. But a more specific, detailed view might be necessary with more advanced procedures like NOTES, demanding a larger size of the endoscopic output. A way to resize the screen size without losing the monitor space can be done by placing one of the monitors behind the other. By sliding the occluded monitor from behind the monitor in the front, the size of the endoscopic output is increased. This kind of setup is easy to combine with a monitor that is positioned some distance from the therapist, making it possible for other medical personnel present in the room to see the endoscopic output.

The first and second monitor resolutions should be high enough to present the high definition video output of the endoscope and the monitor size should be large enough to facilitate all the information in the system. The buttons that are present on the screen should also be large enough for the therapist to press without accidentally pressing another button. That is why it is recommended to use monitor sizes of at least 20 inch.

Keyboard   As already discussed earlier in this thesis, the keyboard that the therapists should have access to should be a touchscreen because it can be more easily sterilized. The buttons presented on the touchscreen should be large enough for the therapists to easily type, decreasing the amount of errors made. The keyboard should be placed underneath the additional information monitor, since

overlaying it will take up too much space and will place the hands of the therapist in a straining position. No exact setup for the keyboard can be chosen here based on the results, so it should be researched further along in the TeleFLEX project. Possible options of keyboard placement can be found in figure 8.2.2.

Figure 8.2.2: Possible keyboard placements
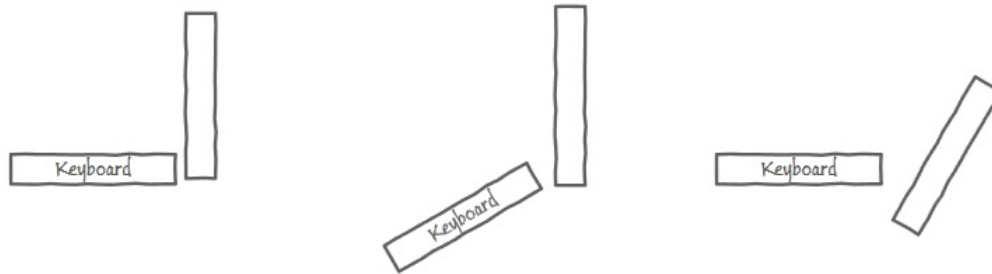
Multimodality   The use of audio is imperative in the system. As can be seen in the first experiment, the audio that is presented with visual warnings resulted in more recognized warnings. It was also preferred by the participants as was mentioned by them in the open discussions.

The haptic modality will not be used in the main information screens, as the therapist will have no added value when he is presented with haptic feedback since he might not be touching the screen. The touchscreen keyboard would profit from haptic feedback, since the therapist will be confirmed in his keypresses.

8.3   Software improvements

During conversations after the experiments, several ideas about software implementations were given by the therapists. These ideas do not directly fall within this thesis or the TeleFLEX project, but are important to mention since this knowledge was obtained during the creation of the system and might influence future design choices.

The first idea, which was mentioned by several therapists, was the placing of waypoints or landmarks in the ScopeGuide (or a similar system) data. Placing a landmark can be done automatically, depending on event triggers, or can be done by the therapist. The therapists would like this option because it would improve the quality of their work, since they do not need to remember the location of the photo. The information can also be used in following procedures, since a specific location of an event is known, increasing the quality of those procedures and decreasing the cognitive resources needed by the therapist.

The second idea was that of a similar system to ScopeGuide, only more advanced. ScopeGuide is not widely used in the Netherlands, although it does have positive effects on the endoscopic procedure and more specifically NOTES (Fowler et al., 2011). The therapists indicated that they would prefer a more specific computer model of the colon instead of just the position of the endoscope. This model should be specific enough to incorporate small anomalies like polyps. It should also be combined with the waypoint and landmark design discussed above.

The third idea was that of software being capable of automatically recognizing a polyp and calculating it's size and presenting this within the interface, possibly along the discussed landmarks.

8.4 Future research

As with every system, it should be tested several times during it's creation. The system created here is the fourth module of the TeleFLEX project. As the other modules near completion, their evaluation can and should be combined with the evaluation of the here created system. The introduction of the first three modules will heavily influence the usage of this system. Future research should thus focus on the usage of the four modules combined and change the system where needed based on this research.

The experiments conducted within this thesis can be used as the basis for future research. With the development and completion of the other modules, tasks in the experiments can be replaced. The workload inducing task should be replaced by a simulation of an actual endoscopic procedure. Such a simulation would revolve around a specific case. The case description should incorporate several tasks that need to be performed with the fourth module, testing it's effectiveness, efficiency and satisfaction in a near real-life situation. A case should be done for different kinds of procedures (colonoscopy, gastroendoscopy, NOTES) so as to test the system for each kind of procedure.

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A   Task analysis

The tables that follow will list the tasks in the chronological order in which they would be conducted during the complete procedure, although some tasks can be performed at all times. It is possible that a task is present that does not necessarily have to be performed (at all or in the listed chronological order). Tasks that cannot benefit from the system (for example getting the patient and introducing therapist and nurse) are left out of the task lists.

When a difference between the current and the future procedure is present, this will be represented in the tables by a gray row, indicating a replacement of a current task (light gray) or the addition of a task to the current tasks (dark gray).

Six columns can be found in the tables. The first column gives the task number. The second column lists the (possible) actors that partake in the task, with the tasks listed in the third column. The fourth column lists the triggers and prerequisites for the task that is to be done. The fifth column summarizes the needed actions to perform the task, followed by the result of the task once completed in the sixth column.

A.1   Preprocedure

In this section, the tasks that are done before the actual procedure are listed. This includes every task that is done until the endoscope is entered into the patient.

Table A.1.1: Task list of the task performed before starting the procedure. Gray rows indicate tasks done when prototypical system would be implemented in the future system, with dark gray indicated added tasks and light gray indicated replaced tasks

Preprocedure tasks

#	Actor	Task	Triggers and prerequisites	Actions	Result
1	Assistant	Start the different electronical units	Polyclinic room is being prepared	Attaching units to electrical network and pressing the start button	All of the needed electronical units are running
2	Assistant	Retrieve endoscope from dry room	Polyclinic room is being prepared	Carrying it from the dry-room storage	Endoscope is ready to be attached to master console
3	Assistant	Attach endoscopic output to master console	Endoscope has been taken from the dry room	Connect the plug in the receiver	Master console is retrieving video output from the endoscope
4	Assistant	Place endoscope in slave unit	Endoscope is attached to the master console	Open the slave unit and enter the endoscope in the correct manner. Close the slave unit	Slave unit can control the endoscope
5	Assistant	Change settings (e.g. height of console, brightness, contrast) of master console	Master console is running	By pushing the necessary buttons on the main information unit	Master console has the desired settings for the therapist
6	Assistant	Change settings of master console and slave unit	Master console and slave unit are running	By changing the necessary values on the master console	Master control and slave unit have the desired settings for the therapist
7	Assistant	Change settings of master console and slave unit to those in a therapist profile	Master console and slave unit are running	By opening a therapist profile on the master console	Master control and slave unit have the desired settings for the therapist
8	Therapist	Reading through patient file	Preparing procedure	Getting the file and reading it	Therapist can make decisions that are important for the procedure

Preprocedure tasks

#	Actor	Task	Trigger	Actions	Result
9	dito	dito	dito	Getting the patient file on the master console	dito
10	Assistant	Attaching instruments for vital signs measurement	Patient is located on operation table and master console is running	Attach the instruments to the master console	Vital signs are shown on master console
11	Assistant	Putting needle into the vein of the patient	Patient is located on the operation table	Sticking needle in vein of the patient	Needle can be used to insert any necessary drug or medication
12	Nurse	Sedating patient	Patient needs to be sedated	Putting sedative into the syringe and injecting the patient with the sedative	Patient is sedated, vital signs change in accord to sedation
13	Therapist	Lubricating anus with finger	Therapist is wearing gloves and has lubrication	By putting lubrication on his gloved finger and then administiring it in and around the anus	Endoscope can be more easily entered through the anus
14	Therapist	Start the procedure	He has taken the endoscope and is standing next to the patient	By entering the tip of the endoscope in the anus of the patient	Procedure starts
15	dito	dito	The endoscope is located in the slave unit. The therapist is holding a part of the endoscope that is not located in the slave unit and is standing next to the patient	dito	dito

A.2 Procedure

In the following tables, tasks in regard to colonoscopy and/or endoscopic surgery are listed. The three tables have been subdivided into tasks that involve the maneuvering of the endoscope, tasks that can be done with the embedded instruments of the endoscope and tasks that can be performed using additional instruments. The latter has been subdivided based on the different instruments that can be entered and used.

Table A.2.1: Task list of maneuvering the endoscope. Gray rows indicate tasks done when prototypical system would be implemented in the future system, with dark gray indicated added tasks and light gray indicated replaced tasks

Endoscopic movement					
#	**Actor**	**Task**	**Triggers and prerequisites**	**Actions**	**Result**
16	Therapist	Entering the endoscope into the intestines of the patient	During complete procedure (mostly at beginning)	Using dominant hand to gently push the endoscope through the anus and into of the intestines	Endoscope moves further into the intestines
17	Therapist	Retracting the endoscope out of the intestines of the patient	During complete procedure (mostly at end)	Using dominant hand to gently pull the endoscope through the anus out of the intestines	Endoscope is moved back towards the anus
18	dito	dito	dito	Using master console to retract the endoscope	dito
19	Therapist	Maneuvering the endoscope through the intestines	During complete procedure	The tip of the endoscope is controlled up/down and left/right using the two biggest gears on the endoscope with the non-dominant. In combination with the forward/backward movement of the endoscope, maneuvering becomes possible	Endoscope is put in the desired location and orientation in the intestines of the patient

Endoscopic movement

#	Actor	Task	Trigger	Actions	Result
20	dito	dito	dito	The tip of the endoscope is controlled up/down and left/right using the touchpad (when inserting endoscope) or the master console (when extracting endoscope). In combination with the forward/backward movement of the endoscope, maneuvering becomes possible	dito
21	Therapist	Getting information of the environment of the endoscope	During complete procedure	Looking at the endoscopic video output	Therapist has information about the intestines of the patient
22	Therapist	Knowing the position of the endoscope	During complete procedure	Looking at the spatial orientation device output	The therapist has information on how the endoscope is located in the intestines of the patient
23	dito	dito	dito	Looking at the master console containing the spatial orientation device output	dito
24	Therapist	Removing a loop that is present in the large intestine	When the therapist confirms a loop, either using his honed experience with the endoscope or from the output of the spatial orientation device	Pulling back the endoscope using dominant hand, maneuvering the tip of the endoscope using the non-dominant hand	The patient will feel relieved and the working environment will be easier for the therapist
25	Assistant	Making endoscopic maneuvering easier	When the therapist can not easily continue on through the large intestine	Pushing on the stomach of the patient, thereby bending the intestine inward, resulting in easier access for the therapist	The therapist is better capable of moving the endoscope through the intestines

Endoscopic movement

#	Actor	Task	Trigger	Actions	Result
26	Staff	Turning patient on his/her back or other side	If the endoscope cannot easily move forward and pressure on the stomach did not help, turning the patient around might open up some space in the intestines	Lifting the patient and turning him/her around	The therapist is better capable of moving the endoscope through the intestines
27	Therapist	(Un)stiffening of the endoscope	When the therapist would like a different flexibility of the endoscope	By turning the smallest gear on the endoscope	The endoscope is either stiff or flexible, making the work easier for the therapist
28	Assistant	Keeping scope stable	Helping maneuvering the endoscope or making it possible for the therapist to make a photo	Holding the endoscope near the anus	Therapist will be able to make a clear photo
29	Slave unit	dito	dito	Keeping the endoscope stable near the anus	dito

Table A.2.2: Task list for embedded instruments in endoscope. Gray rows indicate tasks done when prototypical system would be implemented in the future system, with dark gray indicated added tasks and light gray indicated replaced tasks

Embedded instruments

#	Actor	Task	Triggers and prerequisites	Actions	Result
30	Therapist	Suctioning away large quantities of fluids and/or other waste	Mostly during the complete procedure, but most certainly if the fluids and waste obstruct the view of the therapist	By pressing the suction valve on the endoscope	The fluids and waste are removed from the intestine
31	dito	dito	dito	By pressing the necessary button on the master console	dito
32	Therapist	Blowing gas into the intestine	If some additional space is needed for the maneuvering of the endoscope	By pressing the air valve on the endoscope	The intestine is bigger, giving the endoscope more maneuverability
33	dito	dito	dito	By pressing the necessary button on the master console	dito
34	Therapist	Cleaning the lens of the endoscope	When the lens is dirty due to fluids and wastes	By pressing the water valve on the endoscope	Lens is clean, giving the therapist a better view
35	dito	dito	dito	By pressing the necessary button on the master console	dito
36	Therapist	Rinsing water into the intestine	When there is a large amount of waste in the way that can not be removed by means of suctioning	By pressing a pedal located on the floor	Waste is either removed or relocated

Embedded instruments

#	Actor	Task	Trigger	Actions	Result
37	dito	dito	dito	By pressing the necessary button on the master console	dito
38	Therapist	Making photo of endoscopic output	The therapist decides he needs a photo for the patient file	Pressing the pedal to make a photo	A photo with the endoscopic output is located on the main information unit
39	dito	dito	dito	By pressing the necessary button on the master console	dito
40	Therapist	Making video of endoscopic output	The therapist decides he needs a video for the digital patient file	Pressing the pedal to make a video, with the first press starting the video and the second to stop it	A video with the endoscopic output is located on the main information unit
41	dito	dito	dito	By pressing the necessary button on the master console, with the first press starting the video and the second to stop it	dito
42	Therapist	Switching to and from narrow band imaging	The therapist decides he would like to increase the visibility of the tissue structure of the colon wall	Pressing a button on the endoscopic control box	The endoscopic video output switches to and from the narrow band imaging
43	dito	dito	dito	By pressing the necessary button on the master console	dito

Table A.2.3: Task list for additional instruments in endoscope, with subdivision based on instruments. Gray rows indicate tasks done when prototypical system would be implemented in the future system, with dark gray indicated added tasks and light gray indicated replaced tasks

Additional instruments

#	Actor	Task	Triggers and prerequisites	Actions	Result
Biopsy instrument					
44	Therapist or assistant	Inserting biopsy instrument into the endoscope	During an examination where a tissue sample of a polyp needs to be taken	The therapist or assistant enters the biopsy instrument through the insertion tube	Biopsy instrument is ready for usage
45	dito	Inserting biopsy instrument into the slave unit	dito	The therapist or assistant enters the biopsy instrument through an opening in the slave unit	dito
46	Therapist or assistant	Opening biopsy instrument	After the biopsy instrument has been entered into the endoscope	By simply entering the biopsy instrument through the insertion tube of the endoscope	Biopsy instrument is ready to be pressed into tissue
47	Therapist	Pressing the biopsy instrument into the tissue that is to be extracted	When the biopsy instrument is present and opened	Either pushing the endoscope or the biopsy instrument forward	The biopsy instrument can collect the tissue it is located on
48	dito	dito	dito	Either pushing the endoscope using the master console or the biopsy instrument forward	dito
49	Therapist or assistant	Closing biopsy instrument	The needle of the biopsy instrument is located in the desired tissue	By pressing the instrument further into the insertion tube	The biopsy instrument is closed around the desired tissue sample

89

Additional instruments

#	Actor	Task	Trigger	Actions	Result
50	Therapist or assistant	Burning through the tissue around the instrument	When the biopsy instrument is clipped around the tissue and has the ability to burn through tissue	Pressing the necessary button	The biopsy instrument contains the dissected tissue sample
51	Therapist or assistant	Retrieving tissue sample	The biopsy instrument has been closed on the desired tissue	Pull back biopsy instrument through the insertion tube	Tissue sample has been acquired and can be brought to the laboratory for examination
Injection needle					
52	Therapist or assistant	Inserting injection needle into the endoscope	During surgery when the injection of a solution is needed	Inserting the injection needle into the insertion tube of the endoscope	Injection needle is ready for usage
53	dito	Inserting injection needle into the slave unit	dito	Inserting the injection needle through the insertion tube, by pushing it into an opening in the slave unit	dito
54	Therapist	Injecting needle into tissue	Before injection can start, the needle has to perforate the tissue	Moving the endoscope forward	The needle is located in the colon tissue
55	dito	dito	dito	Moving the endoscope forward using the master console	dito
56	Therapist or assistant	Placing/switching solution	A new or different solution to be injected is needed	Inserting a syringe with the necessary solution into the end of the injection needle	The needed solution is ready to be injected into the tissue
57	Therapist or assistant	Injecting solution into tissue	A polyp has to be elevated from the colon wall or ink has to be inserted to indicate a location	Inserting the solution into the injection needle by depressing a syringe filled with the solution	Tissue is injected with the solution, resulting in the necessary effect of the solution

Additional instruments

#	Actor	Task	Trigger	Actions	Result
58	Therapist or assistant	Spray area for better detection of polyps	The therapist is uncertain if he is able to detect a polyp or any other abnormalities. The injection needle is not inserted into any tissue and is hovering over the area of interest	Inserting vital stains or contrast agents into the injection needle by depressing the syringe filled with these fluids	Elements of the area can more easily be ascertained
59	Therapist or assistant	Retracting injection needle from insertion tube	Injection of solution has been made or instrument is not necessary anymore	Retracting injection needle from insertion tube	Needle is removed from endoscope

Polypectomy snares

#	Actor	Task	Trigger	Actions	Result
60	Therapist or assistant	Inserting snare into endoscope	During an procedure in which a polyp has to removed from the colon wall	Pushing the snare through the insertion tube of the endoscope	Snare is ready for usage
61	dito	dito	dito	Pushing the snare through the insertion tube of the endoscope, using an opening in the slave unit	Snare is ready for usage
62	Therapist or assistant	Enlarging the snare	The snare is located at the endoscopic tip	By increasing the entered length of the snare	Snare is larger, making it easier to move it around a polyp
63	Therapist	Maneuvering the snare around the polyp	The snare is located at the endoscopic tip	By moving the endoscope forward/backward and maneuvering the tip, the snare is pushed around the polyp and against the colon wall	Snare is around the polyp
64	dito	dito	dito	By moving the endoscope forward/backward and maneuvering the tip using the master console, the snare is pushed around the polyp and against the colon wall	dito

Additional instruments

#	Actor	Task	Trigger	Actions	Result
65	Therapist or assistant	Rotating the snare	The snare is located at the endoscopic tip and snare has ability to rotate	Making the necessary adjustments to the snare	Snare is rotated, possibly making it easier to move it around a polyp
66	Therapist or assistant	Closing snare	The snare is located at the endoscopic tip	By decreasing the entered length of the snare	Snare is closed around the polyp
67	Therapist	Checking to see if only polyp is captured in the snare	The snare is located at the base of the polyp and closed around it	Moving the endoscope forward and backward alternatively, looking for any movement of the back wall of the colon	Snare is closed around the base of the polyp
68	dito	dito	dito	Moving the endoscope forward and backward alternatively, using the master console, looking for any movement of the back wall of the colon	dito
69	Therapist or assistant	Surgically burning through the base of the polyp	The snare is located at the base of the polyp and does not have any other tissue ensnared	Pressing the button to send an electric current through the snare at the meantime closing the snare	The polyp is removed from the wall of the colon
70	Therapist or assistant	Retracting snare from insertion tube	Polyp has been dissected or instrument is not necessary any more	Retracting the snare from the insertion tube	Snare is removed from endoscope

Endoscopic clips

#	Actor	Task	Trigger	Actions	Result
71	Therapist or assistant	Entering endoscopic clip into endoscope	The therapist has a need to stop a bleeding source	Attach a clip to a special insertion tube that is entered into the insertion tube of the endoscope	Endoscopic clip is ready for usage
72	dito	dito	dito	Attach a clip to a special insertion tube that is entered into the insertion tube of the endoscope, through an opening in the slave unit	dito

Additional instruments

#	Actor	Task	Trigger	Actions	Result
73	Therapist or assistant	Opening clip	To be able to attach the clip to the tissue, it has to be open	Moving the insertion tube of clip further through the endoscope	Clip is open
74	Therapist or assistant	Rotating clip	The clip is in the wrong position to successfully clip the tissue	If rotation disk is available, clip can be rotated by itself. If not, endoscope has to be repositioned	Clip is in the right position for the therapist to more easily target it
75	dito	dito	dito	If rotation disk is available, clip can be rotated by itself. If not, endoscope has to be repositioned using the master console	dito
76	Therapist or assistant	Closing clip	The clip needs to close of the blood moving to a bleeding source	The clip needs to be moved further through the insertion tube, closing the clip	Clip is closed on the source, cutting of the bleeding
77	Therapist or assistant	Retracting clipping from insertion tube	Clip is attached and instrument is not necessary any more, or a new clip needs to be attached	Retracting the insertion tube from the endoscope's insertion tube	Clip is replaced or the instrument if removed
Argon plasma coagulation probe					
78	Therapist or assistant	Entering argon plasma coagulation probe into endoscope	The probe is necessary to stop bleeding or make sure any remaining polyp tissue is removed	Pushing the probe through the insertion tube of the endoscope	The probe is ready for usage
79	dito	dito	dito	Pushing the probe through the insertion tube of the endoscope, using an opening in the slave unit	dito
80	Therapist or assistant	Starting coagulation at the tip of the probe	Probe is located above the area that needs coagulation	The pedal is depressed to start the coagulation	The tissue is burned, stopping the bleeding and/or removing any remaining polyp tissue

Additional instruments

#	Actor	Task	Trigger	Actions	Result
81	dito	dito	dito	The master console is used to engage the coagulation	dito
82	Therapist	Moving the probe over the area	The coagulation is in process, but a larger area needs to be covered	Maneuvering the endoscope over the area	A larger area is burned
83	dito	dito	dito	Maneuvering the endoscope over the area using the master console	dito
84	Therapist or assistant	Stopping coagulation	The necessary area has been coagulated	Releasing the pedal	The burning stops
85	dito	dito	dito	Using master console to stop coagulation	dito
86	Therapist or assistant	Retracting probe from insertion tube	Coagulation is ready and instrument is not needed anymore	Probe is taken out of the insertion tube of the endoscope	Probe is removed from the endoscope

Mesh basket

#	Actor	Task	Trigger	Actions	Result
87	Therapist or assistant	Entering mesh basket into endoscope	A polyp has been removed and has to be removed from the intestines	The mesh basket is pushed through the insertion tube of the endoscope	Mesh basket is ready for usage
88	dito	dito	dito	The mesh basket is pushed through the insertion tube of the endoscope, using an opening in the slave unit	dito
89	Therapist	Maneuvering mesh basket over removed polyp	The polyp has been removed and the mesh basket is located at the endoscopic tip	Maneuvering the endoscope, putting the mesh basket over the polyp	The mesh basket is located around the dissected polyp
90	dito	dito	dito	Maneuvering the endoscope using the master console, putting the mesh basket over the polyp	dito

Additional instruments

#	Actor	Task	Trigger	Actions	Result
91	Therapist or assistant	Closing the mesh basket	The mesh basket is located over the polyp	Pull the mesh basket back, closing the basket under the polyp	The mesh basket is closed around the polyp
92	Therapist or assistant	Retrieving removed polyp	The surgery is done and the polyp is located in the closed mesh basket	Extracting endoscope from intestines and releasing the polyp from the mesh basket	The mesh basket is removed from the endoscope, making it possible to collect the polyp
93	dito	dito	dito	Extracting endoscope using master console from intestines and releasing the polyp from the mesh basket	dito

A.3 Postprocedure

In this section, the tasks that are done after the procedure are listed. This includes every task that is done after the endoscope leaves the body of the patient.

Table A.3.1: Task list of the task performed after completing the procedure. Gray rows indicate tasks done when prototypical system would be implemented in the future system, with dark gray indicated added tasks and light gray indicated replaced tasks

Postprocedure					
#	Actor	Task	Triggers and prerequisites	Actions	Result
94	Assistant	Collecting polyp	Endoscope is retracted from patient and polyp is released from mesh basket	Gather polyp using containment unit and let the unit be brought to the laboratory for analysis	Polyp can be analysed
95	Assistant	Detaching the measurement instrument for the vital signs from the patient	Procedure is ready	Removing each instrument	No sensors remain on the body of the patient
96	Assistant	Removing needle from vein	Procedure is ready and measurement instruments have been removed	Removing the needle from the vein, stopping any blood loss	Patient is ready to be brought to the recovery room
97	Assistant	Endoscope is disconnected from master console	Procedure is ready	Disconnect the plug from the receiver	Master console loses video output
98	Assistant	Endoscope is removed from slave unit	Procedure is ready	Opening slave unit and removing the endoscope. Closing slave unit	Endoscope is free to be moved
99	Asisstant	Endoscope and instruments are brought to dry room	Procedure is ready and endoscope is disconnected from master console	Endoscope and instruments are carried into the dry room	Endoscope and instruments can be cleaned

Postprocedure					
#	Actor	Task	Trigger	Actions	Result
100	Therapist	Adding photographs to patient file and the other procedures performed that day	Procedure is ready and photographs have been made during the procedure	Printing out the necessary photos and adding them to the file and the other procedures performed that day	Patient file and hospital have photos of the procedure for later referencing
101	Therapist	Writing report about procedure and adding it to the patient file and the other procedures performed that day	Procedure is ready	The therapist enters the details of the procedure in a template report and prints the report. The report is added to the patient file and to the other procedures that day	Patient file has report of the procedure for later referencing and the hospital has an overview of the procedure
102	Therapist	Writing report about procedure and adding it to the patient file and the other procedures performed that day, using the master console to do so	Procedure is ready	The therapist enters the details of the procedure in a template report and prints the report using the master console. The report is added to the patient file and to the other procedures that day	Patient file containts a report of the procedure for later referencing and the hospital has an overview of the procedure

B Consent form

The information about the experiment given by the experiment was satisfactory. I was given the possibility to ask questions about the experiment. I was satisfied with the answers given to my questions about the experiment. I was capable of thoroughly thinking about my participation of the experiment. I have the right to quit the experiment at any time, without a given reason. I agree to the usage of my data for the thesis of the experimenter. I agree to the recording of the monitor display.

I agree with participating in the experiment:

Name: Birthday:
Date :   Signature:

C   NASA-TLX

C.1   NASA-TLX items

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand   How mentally demanding was the task?

Very Low   Very High

Physical Demand   How physically demanding was the task?

Very Low   Very High

Temporal Demand   How hurried or rushed was the pace of the task?

Very Low   Very High

Performance   How successful were you in accomplishing what you were asked to do?

Perfect   Failure

Effort   How hard did you have to work to accomplish your level of performance?

Very Low   Very High

Frustration   How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low   Very High

C.2 Example of NASA-TLX pair comparison

Geef bij onderstaande 15 paren aan welke van de twee schalen van de NASA TLX u het belangrijkste vind als bijdrage aan de werklading van het tellen en de opgaves (omcirkel de schaal die het meest bepalend is voor de werklading)

Effort   Frustration

Mental demand   Frustration

Temporal demand   Frustration

Mental demand   Effort

Mental demand   Temporal demand

Physical demand   Effort

Mental demand   Physical demand

Temporal demand   Effort

Physical demand   Frustration

Performance   Effort

Physical demand   Performance

Temporal demand   Performance

Mental demand   Performance

Performance   Frustration

Physical demand   Temporal demand

D STAI

Recreated and translated version of the STAI (van der Bij et al., 2003).

Please rate the following 6 items on a 4 points scale on how you feel at this time. Try to do this as quick as possible.

I feel calm

Totally not	A little bit	A reasonable bit	Very much

I feel tense

Totally not	A little bit	A reasonable bit	Very much

I feel upset

Totally not	A little bit	A reasonable bit	Very much

I feel relaxed

Totally not	A little bit	A reasonable bit	Very much

I feel content

Totally not	A little bit	A reasonable bit	Very much

I feel worried

Totally not	A little bit	A reasonable bit	Very much

E   Questionnaire for User Interaction Satisfaction

OVERALL REACTION TO THE SOFTWARE		0 1 2 3 4 5 6 7 8 9		NA
1.	terrible		wonderful	
2.	difficult		easy	
3.	frustrating		satisfying	
4.	inadequate power		adequate power	
5.	dull		stimulating	
6.	rigid		flexible	
SCREEN		**0 1 2 3 4 5 6 7 8 9**		**NA**
7. Reading characters on the screen	hard		easy	
8. Highlighting simplifies task	not at all		very much	
9. Organization of information	confusing		very clear	
10. Sequence of screens	confusing		very clear	
TERMINOLOGY AND SYSTEM INFORMATION		**0 1 2 3 4 5 6 7 8 9**		**NA**
11. Use of terms throughout system	inconsistent		consistent	
12. Terminology related to task	never		always	
13. Position of messages on screen	inconsistent		consistent	
14. Prompts for input	confusing		clear	
15. Computer informs about its progress	never		always	
16. Error messages	unhelpful		helpful	
LEARNING		**0 1 2 3 4 5 6 7 8 9**		**NA**
17. Learning to operate the system	difficult		easy	
18. Exploring new features by trial and error	difficult		easy	
19. Remembering names and use of commands	difficult		easy	
20. Performing tasks is straightforward	never		always	
21. Help messages on the screen	unhelpful		helpful	
22. Supplemental reference materials	confusing		clear	
SYSTEM CAPABILITIES		**0 1 2 3 4 5 6 7 8 9**		**NA**
23. System speed	too slow		fast enough	
24. System reliability	unreliable		reliable	
25. System tends to be	noisy		quiet	
26. Correcting your mistakes	difficult		easy	
27. Designed for all levels of users	never		always	
		0 1 2 3 4 5 6 7 8 9		**NA**

List the most **negative** aspect(s):

1.

2.

3.

List the most **positive** aspect(s):

1.

2.

3.

F Demographics questionnaire

Participants were given a dutch version of these questions.

Demographics and computer experience

Age: ____

Gender: Male / Female

Level and kind of education: _____

_____

Hours spent on a computer per week on average: ____ hours

Do you ever play games (mostly First Person Shooters) on the desktop pc? Yes / No

    If so, what is the average of hours spent playing games per week: ____ hours

Do you have any experience with medical software systems?
If so, could you list what (kind of) systems?

_____

_____

_____

_____

Do you have any remarks in regard to the experiment?

_____

_____

_____

_____