LARA: Laparoscopy with Augmented Reality Adaptations

José Miguel Gomes
josemcgomes@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

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Abstract

One of the possible applications of Augmented Reality is surgery, especially laparoscopic surgery, which currently suffers from problems such as surgeon discomfort and fatigue caused by looking at a display positioned outside the surgeon's visual field, heightened by the length of the procedure. This fatigue is especially felt on the surgeon's neck, as it is strained from adopting an unnatural posture in order to visualise the laparoscopic video feed. Throughout this document we will present some works in the fields of Augmented Reality, as well as works in surgery and Augmented Reality applied to both surgery in general and laparoscopy in particular. Through a user and task analysis, we determined that users operate in a dimly lit environment, surrounded by monitors, and communicate through verbal commands and pointing gestures. We first performed a study on the effect of head-mounted displays on user posture, followed by the design and implementation of a multimodal interface that enhances the laparoscopic procedure, making the experience more comfortable for surgeons by allowing them to visualise the laparoscopic video regardless of neck posture, access patient imaging data without interrupting the operation and communicate with team members through the use of a pointing reticle.

Keywords: Laparoscopy; Augmented Reality; Head-mounted Display; Optical-see-through; Visual Field; Hand-eye Coordination

1. Introduction

There is great potential in applying optical-see-through Augmented Reality (AR) to laparoscopic surgery, as doctors will be able to visualise both the task being performed and patient data simultaneously, while improving posture and comfort as a result of eliminating the need to stare at a monitor placed at a distance [2]. This type of visualisation is accomplished by enhancing a real-world setting with computer-generated information overlaid onto a screen, through which both real and virtual objects can be simultaneously observed and interacted with. It is possible that this can have a greater impact on surgeries than robot assistance ever did, as despite its potential, this type of procedure currently makes up to less than five percent of total laparoscopies.

Laparoscopy is a type of minimally invasive procedure performed on the abdomen or pelvis, with the abdominal cavity being expanded with gas to permit the insertion and movement of laparoscopic instruments inside the body. Unlike open surgery, in laparoscopy there is a loss of direct visual contact with the organs, with the surgeons being required to use an endoscopic camera, which captures and feeds an image onto a display [2]. This results in a much more limited and restrictive experience compared to open surgery, as the surgeon's dexterity and ability to feel feedback from applying pressure on tissue is reduced by the laparoscopic instruments [8] [1]. The biggest problem with laparoscopic surgery, however, is hand-eye coordination, as surgeons have to look at screens placed outside the field of operation, which results in discomfort [1], affecting the surgeon's efficiency due to a disconnect between the visual and motor axis, because the surgeon cannot look at the instruments or hands and the field of surgery simultaneously. To be successful, more training is required to adapt to this condition, as extra mental effort must be applied [8]. In addition, almost all these display screens are limited in sense that they do not support techniques to improve visual collaboration with the rest of the surgical team [4].

In a first phase, we will perform a user and task analysis to gain a greater understanding of how users achieve their goals and how that can be improved. Next, we will perform a preliminary evaluation to assess whether using an Head-mounted display (HMD) impairs task performance in laparoscopic surgery. Finally, this work will aim to develop a multimodal interfaces prototype with surgical application for AR in order to mitigate some of laparoscopy's most serious problems. We will develop a user interface for an Augmented Reality headset, presenting endoscopic video stream directly to the surgeons, as well as preoperative data for them to browse and analyse. This interface has to ensure a mainly hands-free experience in order to be usable even when a surgeon is holding tools in both hands.

2. Related Work

In the last decade, there have been works on introducing new interaction techniques for Augmented Reality,attempts at incorporating the technology in the surgical field, including laparoscopy in particular. With respect to laparoscopy, studies have been performed to better understand how the procedure is conducted, what are its limitations, and how they can be overcome using AR. These works explore different types of image visualisation, like different monitor positioning or usage of HMDs, as well as different sources of input and ways to communicate.

Knight and Baber [7] conducted a study to determine whether the use of an HMD causes users to alter their head position to a posture that demands greater effort. To do this, seven paramedics performed a simulated treatment of a patient with cardiac problems with dummies in two different scenarios: in the first, the dummy represented a fully conscious middle-aged man complaining of chest problems, while in the second the dummy represented a patient that had gone into shock, requiring the performance of the CPR technique. The participants performed both exercises, first in the baseline condition, with no HMD, and afterwards using a 0.12 kg Seattle Sight monocular transparent display. The authors concluded that wearing an HMD can indeed force wearers to modify their neck posture, placing their head and neck under increased levels of stress. The main cause for posture modification is the centre of gravity in the head being shifted to the front of the wearer's face, but Knight and Baber also hypothesise that users may alter their head positioning to see the image against a more uniform background, like a wall or the ground. Other reasons include poor fit, requiring the wearer to reduce slippage by balancing the HMD, and poor image Field of View (FOV), as the HMD's casing blocks vision outside the viewing window.

Müller et al. [9] explored the use of feet as a source of input, experimenting with foot-tapping. Their work consisted in having a Hololens program instruct the users to tap a given target inside a semi-circular grid. This grid varied in number of rows, from one to three, as well as in number of columns, from two to six. Not only direct interaction was tested, indirect interaction was also a target of study. In direct interaction, the targets were presented on the ground, so users were required to look at the floor to interact with them. On the other hand, in indirect interaction, the semi-circular grid was displayed in front of them. The test measured both accuracy and efficiency, with direct interaction finding high accuracy results up to the highest condition, with three rows and six columns. Users commented that the HMD was easy to use and not tiring, compared to the default air-taps that HoloLens supports. However, they did complain about having to look down all the time. Indirect interaction was found to be not as accurate, even though it did not force users to look down. Accuracy suffered the most when using more than one row and tasks took more time to complete with each added row or column. However, this type of interaction found greater popularity among users, as they liked not having to look at the floor, and that the interaction felt easy to perform, especially if it were performed along with other tasks, due to not needing to use the hands. They also liked the radial placement of the targets. To best exploit this type of interaction the authors suggested favouring the target division into columns rather than rows as to prevent accuracy losses. They considered the use of direct interfaces to be best-suited to high accuracy interactions, with a large number of options, and proposed the use of indirect interfaces for longer-term interactions that need less accuracy, as well as in situations where a lower number of options is sufficient, or wherever there are constraints to the view, as in direct view the users have to look at the floor.

Figure 1: Müller et al. explored both direct and indirect interactions using foot taps.

Grinshpoon et al. [3] approached the subject of 3D content manipulation, trying to address the problem of hands-free visualisation during operation without resorting to the user's feet. Using the voice recognition and head-tracking features of Microsoft HoloLens, it is possible to rotate and scale 3D content. 3D models are selected with the gaze and activated through voice commands, while manipulations are performed with head movements such as up, down, left or right.

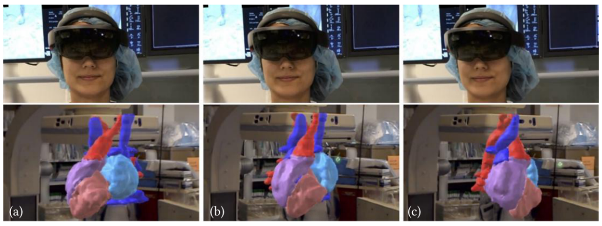

Figure 2: Grinshpoon et al. used head movements as a source of input for 3D image manipulation.

Prescher et al. [10] conducted a study to find out whether using a navigation grid or a navigation pointer could help instructors in directing assistants to specific targets. The navigation grid consisted of a 3x5 coordinate grid, with each quadrant being assigned a number and a letter, while the cursor consisted of a fluorescent green dot integrated into a laparoscope and projected onto a display. Using a laparoscopic box trainer with 240 pins, each of the 24 subjects executed 15 tests where they had to locate 5 random targets in each one. The tests with no navigation tool had the instructor merely convey four directional commands: up, down, left and right. In the tests with the grid, the instructor specified the quadrant, then gave the same four commands for further orientation, while in the tests with the pointer, the instructor pointed at the target with the camera. Results demonstrate, through faster completion times, that the pointer is a superior tool for navigation and guidance, compared with both the grid and no tool.

Walczak et al. [11] evaluated whether the positioning of the monitor has an impact on laparoscopic performance. They had 52 participants execute an exercise in a custom-made simulator, where they had to pass a thread through 9 holes of different sizes. This exercise was performed four times in two different monitor positions, the first at eye level, 1.6m from the ground and 1m away from the subject, and the second 0.6m away from the participant, at an angle of 20^o below eye level. Time to execute the task was measured and participants were asked at the end of the test which position they preferred. Results show the time taken to perform the task was shorter when the screen was placed downwards, which corresponded to the position participants most preferred. This position allows users to flex the head at 15 to 45 degrees below eye level, which is the most comfortable position, as looking down improves eye lens accommodation and reduces eye weariness and headaches.

Figure 3: Walczak et al.'s second condition in their experimental setup had the screen positioned 20^o below eye level, 60cm away from the participant.

Kihara et al. [6] developed a Virtual Reality (VR) system for use in real-world operation, combining a HMD with a 3D endoscope to provide the surgeon with high quality imaging right in front of him. The 3D HMD gives the feel of an open surgery and allows the visualisation of content regardless of head position, while direct vision is allowed by lowering the angle of sight.

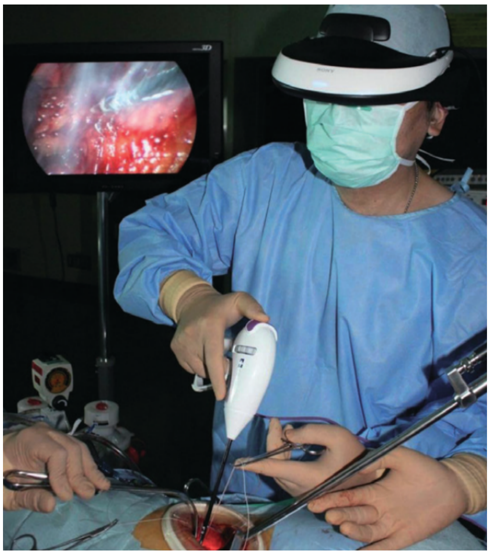

Figure 4: The HMD in Kihara et al.'s work allows visualisation of the hands and tools by looking down with the eyes.

Jayender et al. [5] worked on a mixed reality headset which integrates the image from the laparoscopic camera, a navigation system and diagnostic imaging, complemented by an audio feedback system. The system is implemented using a capture card to capture video from the laparoscope and the navigation system, a Unity application which renders the virtual environment into which the video is imported and a modified Oculus Rift DK2 headset to display the mixed reality environment. In it, each image is represented by a virtual monitor placed in front of the user, with the laparoscopic video being placed 15° below eye level, the navigation system placed lower, at an angle of 30° below eye level, and the diagnostic imaging placed to the side of the laparoscopic video feed. An audio navigation feedback system is also implemented, outputting sound based on the distance from the tool to the target. For interaction, pressing a foot pedal while placing a reticle on diagnostic images brings them closer, allowing them to be visualised in greater detail. To test this system, three different peg transfer exercises were employed, comparing it to a laparoscopic navigation with CT imaging approach. Time, accuracy, peg drops, incorrect peg selections and kinematic parameters such as velocity, acceleration and jerk were used to evaluate the tasks. While on the initial tests the results did not favour the system, the following tests demonstrated improved performance, reduced task time and reduced errors. A NASA Task Load Index questionnaire also demonstrated that the workload required from the user was significantly decreased.

3. Approach

Our approach is sectioned into three parts: first, we performed an analysis of users and their tasks to better understand the problem at hand, then we performed a preliminary evaluation to assess the effect of HMDs on users and lastly, we developed a prototype with the goal to mitigate the problems we observed and improve the laparoscopic experience for the surgeon.

3.1. User and Task Analysis

During surgery, there are at least six people involved in the procedure: A head surgeon, who coordinates the entire procedure, one to four auxiliary surgeons, who mostly observe but also participate in parts of the surgery, a nurse solely responsible for passing the surgeons tools they may require throughout the operation, an anaesthetist keeping track of the patient's vital signs, a nurse supporting the anaesthetist and a circulating nurse. Additionally, a senior surgeon may come in and serve as advisor, providing insight and making remarks about what is being seen on camera.

The surgery itself is divided into three phases: In the first phase, the surgical team is tasked with locating the target structure, which we observed to usually be a tumour. To achieve this, surgeons must navigate inside the patient's abdomen and clear a path using their tools until the target is reached. This part usually lasts at least thirty minutes and can go up to three hours, as the tissue must be carefully cut and cauterised to prevent bleeding and damage. Next, the target structure is extracted through a larger incision, being removed in a more conventional manner, taking at least half an hour as well. In this part, the surgeons are looking down at the patient like in an open surgery instead of using the screens. Finally, in the last part, the remaining structures are placed back in the patient and incisions must be sutured and closed. This final part takes from thirty to sixty minutes. Overall, laparoscopies can take 2 to 3 hours, but longer operations last for 4 to 5 hours. Surgeons also report that, in more extreme cases, they can take up to 11 hours, with shifts between personnel. Surgeries may also be aborted: in one of the surgeries we attended, for example, the procedure had to be cancelled because there was an unaccounted structure hindering access to the tumour.

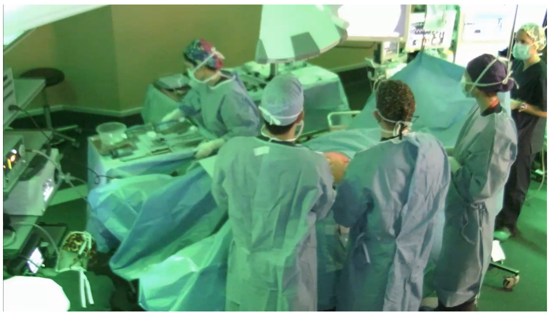
Figure 5: The operating room. From left to right: a roaming nurse, a nurse responsible for the tools, the head surgeon, two assistant surgeons and the anaesthetist.

Surgeons perform laparoscopy in an operating room with reduced lighting conditions. When the ceiling lights are turned off, green ambient lights help with visibility; this colour was chosen after multiple tests with different colours. When the surgery reaches the second stage and the laparoscope is not used, the room stays darkened, but auxiliary lights are used, as traditional ceiling lights are only used during preparation and turned on again when the surgery is finally over. In the operating room there is a perimeter delimited on the ground that separates two types of areas: the first is a restricted area, where the patient is located and only sterilised personnel, such as the people mentioned above, may enter. This area is also where the most critical medical equipment is located: A ceiling structure holds auxiliary lights, as well as six monitors which surround the patient, so surgeons can see the video feed from the laparoscope from all angles, although they usually all look at the same one in order to better communicate and understand each other. These monitors are adjustable, so they can be folded when the surgery is over to reduce clutter, or better positioned so the entire team can see it. Other equipment also includes the instrument tray, a column with auxiliary light controls and equipment where the laparoscope is plugged into, and monitoring equipment with four additional screens to keep track of the patient's vital signs. The heart rate monitor emits a periodic beep that is disturbed by the cutting tool, which causes interference by provoking a continuous sound akin to a lack of pulse. The outer area is where the nurses roam around and watch the operation; this is the area where non-sterilised personnel stay. The aforementioned senior surgeon stays here as well, making use of a larger screen that is embedded in the wall to give counsel to the operating team. This area also features some computers which are responsible for the room lighting and recording, as well as a whiteboard where data about the patient and the operation are included, such as age, gender, and tumour location. Lastly, there is a digital clock on the wall near the embedded screen, so surgeons can keep track of the procedure's duration.

3.2. Preliminary Evaluation

The preliminary evaluation sessions were conducted in an office inside the Champalimaud Foundation's building. To visualise the laparoscopic video, we used a Storz monitor display, positioned at a distance, for the first condition and the Meta 2 for the second condition. Start time and stop time were announced orally. For each condition, users performed five repetitions of a needle thread exercise. To help reduce possible bias associated with the order in which participants perform the task under which condition, the order users performed the tasks was dictated by a Latin square design: If the first user performed the tasks with the display monitor first, the second user would perform the tasks using first the Meta 2 headset.

We collected metrics on time taken (in milliseconds) and number of movements for each task. For each participant, we obtained the mean values for each of the two conditions, as we observed that task time decreased with each repetition. A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the time taken to perform the exercise when participants used the Meta 2 HMD compared to the monitor display. Data are mean ± standard deviation, unless otherwise stated. There were no outliers in the data, as assessed by inspection of a boxplot. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (p=.741). Participants took less time to perform the exercise when using the Meta 2 (115.113 ± 31.972 s) as opposed to the monitor display (118.096 ± 64.909 s), a statistically insignificant decrease of 2.982 (95% CI, -47.178 to 41.212) s, t(5) = -.173, p = .869, d = -.07. The mean difference was not statistically significantly different from zero. Therefore, we reject the alternative hypothesis and fail to reject the null hypothesis. Based on these results, we can conclude that using a HMD is neither better nor worse than the current procedure in laparoscopy.

3.3. Prototype

Our developed prototype aims to solve the problems that surgeons currently experience during laparoscopic surgery. Furthermore, we wanted the prototype to be as unobtrusive as possible in order to make the surgery as uninterrupted as it could be. To achieve this, in developing the prototype, we took a fully hands-free approach so that surgeons did not have to put down their tools at all, allowing for a continuous surgical experience.

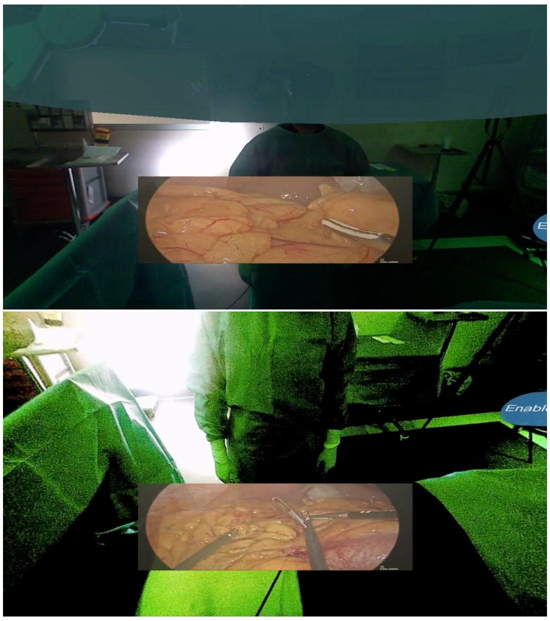

Figure 6: The user can change its head positioning and still be able to see the video.

Laparoscopy currently faces the glaring problem of monitor positioning. During surgery, screens are usually placed far away and at a uncomfortable angle, causing neck and eye strain over the course of a surgery, especially if it drags for longer periods of time. Given this, it was important to allow the surgeons some freedom in how they want to see the video, which led to a conclusion: The video, while visible, should follow user head movements so users would not have to reposition it in the augmented space, should they feel the need to assume another posture with the neck. We therefore implemented this in our prototype, centring the video in the HMD's display and making it as large as possible without it extending beyond the borders.

It was then hypothesised that the patient data could be accessed by looking to either side, while the laparoscopic video could be visualised by looking forwards. We still intended to have the video follow the user's head movements, so they could look wherever they wanted or felt most comfortable and still be able to see the video and, in particular, take advantage of the headset's transparent screen and look at their hands as well. We therefore proposed the following: the user could look around and move their head within a given amplitude that the video would continue to be displayed, but after crossing that amplitude the video would be hidden to allow the patient data to be visualised. In an attempt to mimic the software surgeons already use in preoperative planning, as well as evoke a feeling of familiarity, two planes would be displayed, while the third would be able to be accessed with a control underneath the images. The patient imaging was initially meant to follow user head movements as well, but the idea was scrapped in favour of having them placed in the augmented world, as surgeons usually consult two images at once, and presenting both images at the same time meant these had to assume a smaller scale in order to fit the Meta 2's narrow field of view. By fixing them on the world, they can assume a larger scale, which means they can be viewed in greater detail, but still somewhat simultaneously by placing them close together and allowing the user to look around.

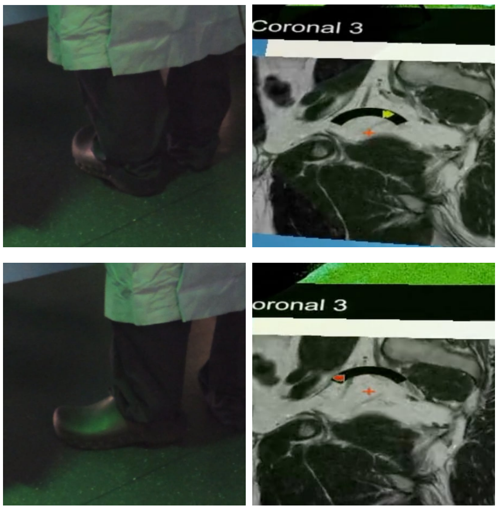

Figure 7: The curved bar helps users perceive the rotation their foot is assuming. Sensitivity was adjusted so users could reach both red icons without lifting the foot. To implement foot movement detection, a mouse was introduced below the rubber clogs used by the surgeons.

To implement image navigation, we drew inspiration from the work of Müller et al. [9]: this work revolved around tapping with the foot to activate controls, which we deemed not viable due to the risk of activating a pedal inadvertently, but gave us the idea to implement image scrolling simply through the use of foot movements. Several ideas were initially explored, involving vertical and horizontal movements akin to swipe gestures, but these were dismissed as user balance was put into question because it required lifting the foot from the ground. We eventually settled on heel rotation, as it enables users to keep their balance and does not require them to lift their feet and balance themselves. Using heel rotation, turning their foot like a dial, users can rotate the foot to the left to access previous images and to the right to access the next ones. The more the foot was rotated from the starting point, the faster the images would change. However, this would only happen when the user was looking at the image, to prevent errors or accidental triggers, as well as let users move their feet freely when not using the mechanism and not feel constrained. Furthermore, to prevent the same feeling of constraint when looking at an image without the intent to change it, a dead zone was implemented, allowing for a small amount of movement to be done with the foot without resulting in image change. After that dead zone, images can be changed in three different speeds, represented by three differently-coloured icons in the interface. We decided to complement this interaction method and made the progress bar interactive, allowing it to change images when intersected by the user's gaze, akin to an application window's scroll bar. This would let the user go through the whole image data set quickly, roughly obtaining the desired position and then fine-tuning it with the foot.

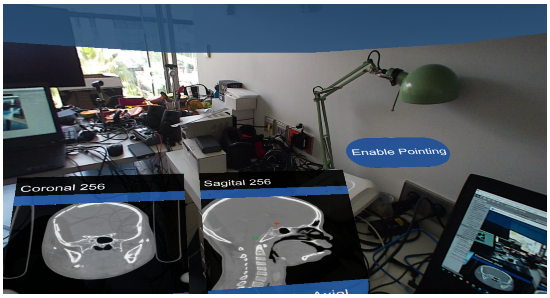

Figure 8: The button for pointer activation was positioned in a more upwards location to prevent being accidentally activated while the user transitions from the video to the images and vice-versa. The top of this picture contains the area which also activates pointing if the user gazes upon it. Additionally, the green pointer is present, indicating another user is pointing at the patient data.

Because the physical screen is removed in lieu of the HMD, users lose the ability to point at it. Therefore, a new mechanism for pointing was necessary as well. We opted to use the head gaze as means of pointing, as a similar type of interaction had already been experimented with in during the development of the patient data browsing functionalities, with a reticle used for interface navigation being stable enough to be used as a pointing reticle as well. When using the pointing reticle on the video, the video would be fixed in the augmented space so it could be properly pointed at, being placed at a centred position, instead of following the user's head movement. For the reticle's activation, we decided to explore the space above both the video and the patient data. Looking up past a threshold and holding the gaze there for a brief moment activates the pointing reticle, regardless of where the user is looking at, video or Magnetic Resonance (MR) images, and looking up again would disable it. After experimentation, we considered the amplitude of 20 degrees above eye level to be an adequate value for the threshold, as it was reachable without activating by accident or requiring too much effort. Despite the flexibility present in this interaction method, however, we considered the possibility that this movement could be too uncomfortable or just not practical for users to perform, and therefore we also implemented a small virtual button. This virtual button sits between the video and the patient data on both sides, so it would be easy to access, whether the user is looking at the video or the images.

4. Results & discussion

In order to evaluate how the users perceived the implemented features in the prototype, in terms of usefulness and usability, we used a think-aloud protocol to conduct qualitative evaluation sessions with users. We first began by explaining the goal of the sessions, which was to evaluate the prototype and not the users themselves. Users then filled out a user profile questionnaire and were explained and demonstrated the prototype's features. Afterwards, users put on the HMD and freely explored the prototype for ten minutes, with the session moderator encouraging them to try certain features they had not tried before. After the ten minute mark, users took off the HMD and answered to a user preferences questionnaire and had a semi-structured interview with the session moderator to discuss their impressions. To better emulate the prototype's usage in the context of a real operation, the prototype played a 720p video footage of a laparoscope, recorded in a previous surgery, while the displayed MR images are PNG files, converted from a set of anonymised DICOM images, pertaining to a rectum magnetic resonance, using IrfranView. While experimenting the prototype, users were asked to hold two laparoscopic instruments, which were partially inserted into a custom-made laparoscopic exercise training box.

Initial impressions regarding the laparoscopic video were positive: surgeons found the video following the user's head movements useful and easy to visualise, with some participants remarking how ergonomic it is, compared to the current way of looking at the video. Other participants found it to be the core benefit of the entire prototype. However, the main argument against the video is its display size: some other participants complained it looked too small and wished it took more of the user's visual field.

Figure 9: User in the exploration phase of the evaluation. Each hand holds a tool to confer a greater sense of authenticity and to prevent the user from rotating the torso as easily.

In terms of image navigation, users found the navigation bar and the foot to be complementary mechanisms, as they could make an approximation of what they wanted with the bar and make a fine adjustment with the foot. The foot itself was found to be comfortable, as surgeons were already used to using the pedals in the surgical room. In addition, a participant felt that the prototype could be improved if, when navigating on one plane, the other plane kept up. This participant also criticised the navigation bar, saying that when controlling it, the focus is on the bar and not the image, thus preferring the foot and complimenting how the foot rotation and scroll speed were being represented. Displaying two images as a means to mimic the imaging software used in the preoperative meeting was a generally accepted idea, although one recurring piece of feedback was the option to hide one of the images and enlarge the other one. In the end, users liked how easy it was to consult the images and how it is not necessary to call an assistant, which gives the surgeon a feeling of control, as an assistant might not know exactly what to look for.

Feelings regarding the pointing mechanism were positive as well. Regarding the two activation methods, using the button is majorly preferred, with only two users leaning towards looking up instead. The most common gripe regarding looking up entails having to make a more extreme movement, where the button is easier to reach. With respect to the reticle itself, users felt that it was easy to notice and to control, and that unlike the current procedure of pointing at the screen, it was unambiguous.

Some drawbacks about the prototype were noticed: There were many grievances about the weight of the Meta, especially how the weight was concentrated at the front instead of being evenly distributed. There were also problems in terms of calibration, as users sometimes observed the interface elements as if they were all tilted.

Overall, users were receptive to the idea of using the prototype in a surgical environment. One user noted that it was perfectly possible to observe the video and look at the tools, while another said “everything was quite easy to get, intuitive and natural”, praising the control activation times. Another participant also felt that the interaction was almost natural, that it could be learned in two or three minutes and that nothing activates by accident. It was also stated that, unlike some other devices the Champalimaud Foundation has, the prototype is easily usable by everyone.

5. Conclusions

Laparoscopy is a diagnostic procedure used to examine organs inside the abdomen. It’s minimally invasive in the sense that it requires small incisions. These small incisions are required to insert the laparoscope, a long and thin tube with high intensity light and high resolution camera. This camera sends video to a computer screen, allowing surgeons to see inside the patient’s body in real time, without needing open surgery. Laparoscopy is usually employed when non-invasive methods such as ultrasounds, CT scans and MRI scans don’t provide enough information in detecting abdominal problems. Compared to open surgery, laparoscopy creates smaller scars that result in smaller and fewer incisions, lesser tissue damage, lesser pain following the operation procedure, which in turn results in a lesser requirement for analgesics and shorter hospital stay due to a faster recovery time.

Despite these benefits, laparoscopy suffers from problems like discomfort and mental fatigue, caused by the monitor being placed outside the surgeon’s field of vision, forcing him to move his neck for an extended period of time. It also suffers from a lack of hand-eye coordination, as surgeons have to take the eyes off the tools they handle in order to visualise the laparoscopic video. There is also the problem of communication: surgeons point at the screen to get their point across, be an instruction or an explanation, but because the screens are placed far away the exact location they are pointing gets lost in ambiguity. Lastly, there is the issue of visualising preoperative data: currently, the procedure for visualising data such as an MRI is to call in an assistant, who will sit down with the surgeon to control the images, while the surgeon commands him to go back and forth until the desired image is found.

We have made a study on the conditions in which the laparoscopic surgeons perform their tasks, analysed areas of improvement and designed our prototype in an attempt to improve upon those aspects. Firstly, the developed prototype allows the user to visualise the laparoscopic video while looking at the tools by having it follow user head movements. Secondly, it allows patient data to be consulted during the operation, without needing to interrupt the procedure and call in an assistant, by merely requiring the surgeon to look to either side. Lastly, it allows surgeons to precisely point at the screen in a non-ambiguous and more viable fashion than using the finger or the laparoscopic tools.

In our evaluation, we found that users were receptive to the innovations brought forth by our work, showing excitement about the fact that their issues are being mitigated. The capability to observe the laparoscopic video has the potential to reduce the physical effort required by surgeons, the displaying of MR images cuts time losses whenever the need to consult an image arises and the ability to accurately target anatomic structures on the screen improves understanding between team members.

Finally, we believe that, by streamlining the visualisation of important data, as well as team communication, our work has the potential to change the laparoscopic procedure to one that does not require as much mental and physical effort as it requires now.

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AR	Augmented Reality
FOV	Field of View
HMD	Head-mounted display
MR	Magnetic Resonance
VR	Virtual Reality