Shared Control Approaches for Hybrid Multidisciplinary Team Meetings

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Abstract

Successful cancer treatment depends on individual and group contributions of numerous healthcare professionals who discuss the best course of treatment over Multidisciplinary Team Meetings (MDTMs), aided by 2D medical imagery. Recently, MDTMs held over video conference platforms have become a regular feature in many hospital settings, offering high standard services to geographically distributed locations and favouring a more efficient and economical hybrid setup. In addition, the recent pandemic has further incentivized the need for smaller groups to collaborate remotely to curb in-person limitations. Still, communication issues exist between peers of different medical specialties when analysing imagery, which hampers the MDTMs workflow and limits decision-making processes. To address this, we developed an interactive system to visualize and manipulate visual content for hybrid MDTM settings. We aim to investigate how collaborative interactive displays, including individual and shared work-spaces, impact collaboration and potentially enhance peer communication.

Keywords: Medical Imagery, Multidisciplinary Team Meetings, Collaboration, Cancer Treatment

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Glossary

MDTM	Multidisciplinary team meetings, widely adopted in cancer care for effective decision-making.
MRI	Magnetic resonance imaging, an image modality used for medical examination.
PET	Positron Emission Tomography, an image modality used for medical examination.
CT	Computed tomography, an image modality used for medical examination.
CAD	Computer-aided detection, system that supports healthcare specialists interpreting medical imagery.
PACS	Picture archiving and communication system, image sharing and storage technology used in healthcare.
UI	User interface, the medium where computer-human interaction occurs.
SUS	System usability scale, a 10 item Likert scale to evaluate system usability.
PDA	Personal digital assistants, handheld devices which functions as a personal information manager.

1. Introduction

1.1 Motivation

Over the last years, cancer survival rates have significantly increased, not only because of healthier lifestyles, but more importantly due to the early detection and more effective treatments of the disease [1]. Oncologic pathologies are patient-specific, their treatment is lengthy and requires coordination of multiple medical specialties following a pipeline that allows them to handle great numbers of patients effectively. Cancer treatment workflow thus follows the ideology of initial diagnosis, followed by a discussion of the best treatment options over a meeting, in an effort to streamline the decision-making process and discuss as many patients as possible.

Multidisciplinary Team Meetings (MDTMs) gather a group of professionals from one or more clinical disciplines, such as surgeons, radiologists, oncologists, pathologists, psychologists, and nurses, who together make decisions regarding the recommended treatment of individual patients (Figure 1). These meetings usually occur weekly, and several patients are discussed in 1 to 2-hour meetings relying on the visualization of medical images, namely Magnetic Resonance Imaging. Even though images are the backbone of this deliberation by enabling the effective discussion of multiple patients in an acceptable timeframe, these meetings have revealed a pattern of decision-making issues linked to suboptimal imaging quality, hardware, teamwork, and communication habits [2-4].

Radiologists and pathologists produce the 2D images used in the MDTMs, contributing to up to 8 meetings daily, spending on average 2 to 2.4 hours on preparation for every 1 hour of meeting time. The workload on them is substantial, and as image quality may suffer due to this, so do the meetings. Furthermore, there usually is no supporting application for the Picture Archiving and Communication System (PACS) used in medical institutions to segment, share and demonstrate these images of interest effectively to a group of people [3].

The intricate 2D content has to be understood by all meeting attendees in a 3D context in order to fully capture what a speaker is pointing out, such as, for example, a tumour's structure. Techniques like the use of the cursor or hand pointing onto 2D slices are not going to be clearly understood by everyone. Differently specialized professionals interpret information according to their knowledge and beliefs, further distancing themselves from the speaker's perspective [3].

Figure 1. Example of a face-to-face MDTM with video conference on the upper-left screen. Adapted from [5].

Reliable communication and interaction between the meeting members are essential to enhance the quality of this collaboration aspect. Attendees argue that a high presence of team members, readily available data, and adequate time for case discussion are critical for a successful meeting. Additionally, recognizing the complex and informal dynamics between members, and organizational processes that impact workflow are valuable factors to consider when developing systems to improve these meetings [6].

In 2009 Kane et al. [7] analysed the collaborative workflow at MDTMs. They provide insight into what technology is used to support the meeting and its missing features, as well as how diagnostic work is included in the decision-making process. The process of achieving diagnosis is a collaborative effort and not an individual task. They also point out the level of visual and individual difficulties that the wide range of specialists encounter. From surgeons to nurses, radiologists to pathologists, the level of expertise varies greatly between all of them, as well as their social bonds. This complex nature of the meeting setting brings forth a difficult challenge when seeking to provide adequate and novel support to it.

The MDTM took place at a schoolroom type setup, as seen in the image below, where participants face a plasma screen instead of facing each other. In addition, to support the remote capabilities needed, a camera and speaker, as well as a screen with a video stream of remote participants are available.

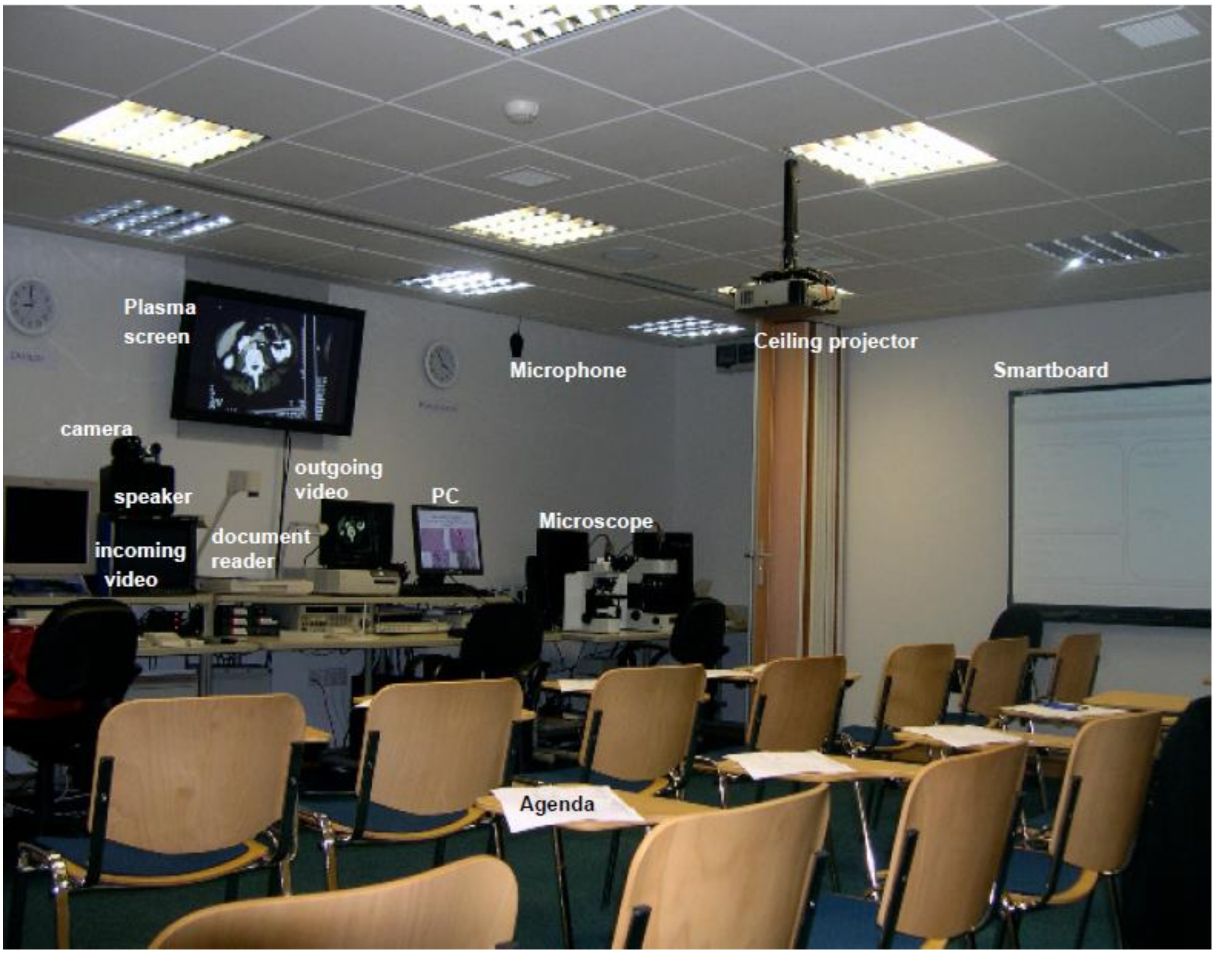


Figure 2. MDTM room setup. Adapted from [7].

As seen in Figure 2, the computer and microscope are in the front of the room, used by the radiologist and pathologist, respectively. These individuals tend to sit sideways if they are not presenting images to see the audience in the room. The collaborative task is introduced by a lead clinician who announces the case, while a designated member displays patient details on the PC, which appears on the plasma screen for the audience to see. After this, clinicians pay attention to a member who summarises clinical findings via speech, supported by images and pointing gestures. Next, a radiologist offers a specialist's opinion, followed by the pathologist doing the same. Both also use speech and medical imagery to support their explanation, using pointing gestures to grasp people's attention. During these demonstrations, other clinicians may issue questions to the speaker, which are supported by the imagery presented and their physical gesticulations. By the end of the presentations and exchange of ideas, all clinicians try to come to a consensus, a diagnosis and treatment decision is made.

The researchers identified the clear interest for policymakers to pursue an ever-growing teleconferencing approach to the MDTM. It enables concentrating specialist groups in small centres and providing medical services to large geographical areas at a reduced cost. Nonetheless, they consider that the technology at the time of this study suggested that the extensive practice of teleconference MDTMs is unsustainable.

In another work Kane et al. [6] proposed a framework to evaluate technology used in the collaborative setting of MDTMs, taking into account variables such as work practices and individual healthcare worker's perspectives. The researchers point out the delicate environment of an MDTM and the importance to not obstruct ongoing work practices when doing research such as this. For example, patients should not be put at increased risks, and video recordings of meetings can be problematic because of the confidential essence of the work; confidentiality and security must be upheld.

During their ethnographic study sessions of MDTMs, the researchers identified the informal exchanges between meeting attendees to play a vital team-building and socialization role, which is one of the reasons they do not welcome being recorded.

They identified that when developing a method of evaluation for an MDTM, tech specs should not be evaluated in isolation but should consider the organizational needs, patient management system, and socio-emotional aspect of the meeting. For example, different room setups impact a discussion's flow, and thus its technology needs. Likewise, team member's stress and cognitive load impacts the way they handle equipment and communicate. In the end, when evaluating technology, we must ensure that it contributes and facilitates, benefitting the patient. As such, the development of technological tools that increased support for interaction, decision-support tools, which are usable in a group setting, are seen as having the potential to impact patients' welfare directly. Finally, the researchers acknowledge that understanding the complex dynamics at play between MDTM attendees, the information shared in constrained time and space dimensions, and organizational protocols that narrow the conduct of the team can potentially motivate and guide the development of technological tools.

In an extensive over 10-year period of ethnographic studies and interviewing multiple multidisciplinary teams, Kane et al. [8] have analysed and documented the changes in practice and technology used in these meetings. As a result, they found that work rhythms changed over time due to the volume of work and changes in technology. For example, the introduction of the Picture Archiving and Communication System (PACS), videoconferencing, and the electronic patient record (EPR) bring valuable enhancements while still enabling cohesive workflow, dependability, and most of all, patient safety. Notably, the steady rising in work volume is correlated to the ever-increasing cancer patient number over the last years, in part due to increased life expectancy and improved healthcare opportunities.

The researchers point out that an ever increasingly technological work environment is inevitable but that it must be ensured that no harm is done when introducing novel technologies to the complex extent of cancer treatment. As long as reasons and measurable improvements in patient outcomes are unproven or not backed up with adequate evidence, technological alterations may threaten a team's workflow and patient services down the line; improving one aspect might worsen a multitude of others.

From all the gathered data over the years and constraints observed, time and timing are correlated with the greatest observable effects on an MDTM concerning information communication, coordination, and synchronous and asynchronous interaction. For example, when radiologists review images via the PACS system in preparation for meetings, they cannot easily annotate or add visual cues to the images for later display, so in an MDTM, they must recur to taking written notes on paper to help them relocate ideas and the images associated to them—a tedious, timely task which could definitely be improved upon. Most often than not, radiologists and pathologists would tend to describe their findings in talk supplemented with gestures instead of images.

Additionally, patient record management has received continuous technological support over the years, creating an infrastructure that cements practical work and coordination mechanisms. However, MDTMs did not receive this kind of support in record generation tools. When adding up with high work volumes and patient numbers, discussion records need to be maintained if a proactive and collaborative environment is to be upheld. For this reason, some countries like the UK have MDTMs follow the protocol of dedicating one person of the meeting to a laptop which projects the display onto a tv screen for all members to see. This person would take records in real-time about important information. However, this is generally seen as impractical as there is not enough time to do this efficiently, and it hinders the actual meeting. For this reason, most members take personal notes according to their experience and field for their own use afterward. This is important to note as it shapes people's attention span and interaction during a meeting, which ultimately must be considered when supportive tech is developed.

One example of a technological system review by the researchers was designed to tackle the challenges of remote image sharing, in particular. Critical issues related to this approach were the lack of standards and protocols between the different remote institutions, use of low-powered PCs, and slow networks. These issues that arise when transitioning MDTMs into a hybrid setup, using technological solutions that lack the infrastructure and toolbox to work effectively, create the need for further development of systems that better encompass specialists' needs and introduce novel visualization protocols that better fit the hybrid setting.

Traditionally in the MDTM setting, a single specialist is responsible for controlling the images, performing actions such as zooming, changing image slices, or rotating in the case of a 3D model [9]. There is little work that provides feedback on giving such controls to multiple entities during an MDTM and if it would be beneficial to a mixed local and remote meeting setup.

Considering the increased workload, future groupware systems must take into account the ever-reducing time per case discussion, the group communication hindering introduced by turn-take-like interaction of a hybrid setting, and the coordination of patient and meeting related records.

1.2 Goals

We consider that information technology, with the appropriate considerations of social interactions and interface design guidelines, can lead to the development of systems that facilitate and positively impact MDTMs, either in face-to-face or remote settings. This work aims to respond to a set of research questions regarding collaboration in a medium-sized group where people shift between individual and shared spaces during a session. Contributing to answering how beneficial added image control for all users can be to an MDTM's workflow and provide valuable insights on how to enhance group awareness in a hybrid setting. To this end, we intend to design and evaluate a cost-effective, portable, and tendentiously wearable-free prototype.

1.3 Thesis Outline

Chapter 2 will begin by focusing on giving a brief overview over cancer treatment and move onto MDTMs, going over how they function, how collaboration between its participants is achieved, and provide background on interactive systems used in them as well as their characteristics. Chapter 3 will present an extensive collection of works we considered essential, and which dictated the development of our work. The design and implementation process of our solution and key explanations of its functions is presented in Chapter 4. In Chapter 5, we go over an evaluation process for our work, and in Chapter 6 we present the results and discussions for our findings. Finally, in Chapter 7, we present the conclusions of our work as well as remarks on possible future work.

2. Background

In this chapter we will provide a brief background on cancer care and collaboration in the medical setting.

2.1 Theoretical Overview

Our work will focus on working with imagery concerning the treatment of cancer in the gastrointestinal tract. Colorectal and prostate cancer are the third and fourth most common cancers, registering 10.2% and 7.1% of all new cases worldwide [10].

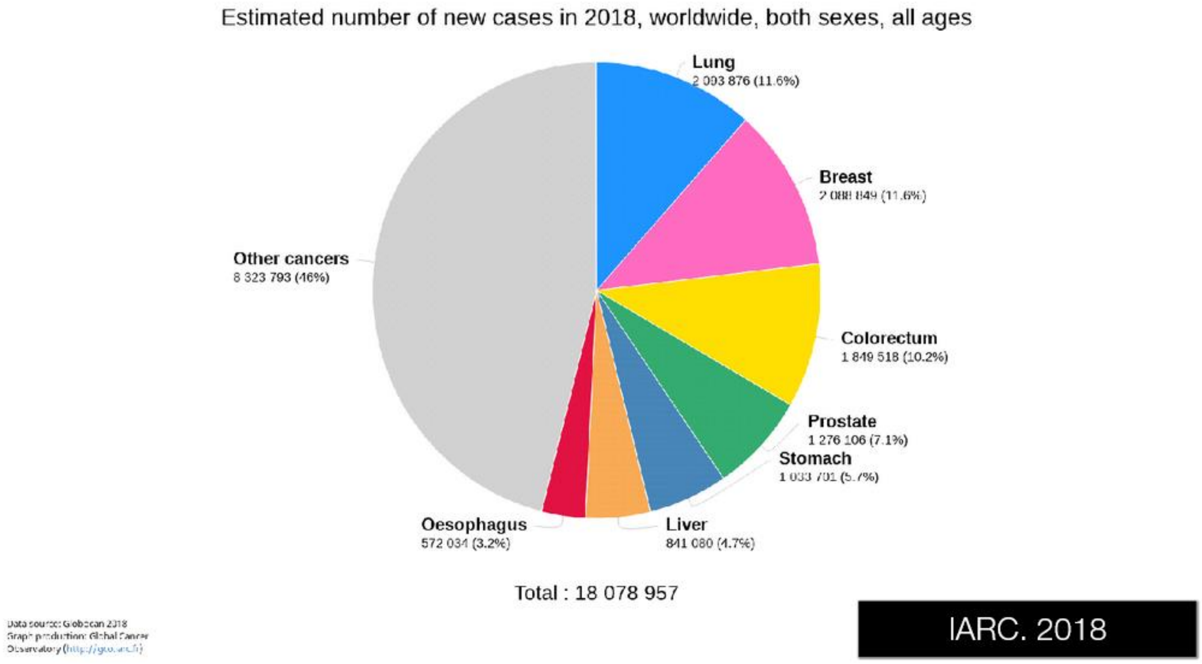


Figure 3. Cancer cases in 2018. Adopted from the International Agency for Research on Cancer.

Cancer therapy has diverse approaches, from chemotherapy to surgery, radiation to immunotherapy, and has been continuously evolving over the years [11]. While MRI is the standard image of choice for diagnosis, preoperative planning, and follow-up care, MDTMs resort to other types of medical images to complement and enhance the discussion. Nonetheless, the effective decision-making process which leads to choosing the correct therapy in a timely manner is not only dependent on imagery but heavily relies on collaborative group input, even more so when considering the complex anatomical configuration of the pelvis region.

2.2 Collaboration

Collaboration is the act of working together to achieve a joint goal and can have multiple variables which impact success. Developing Computer Supported Cooperative Work (CSCW) workspaces which assist aspects such as communication and data sharing, requires understanding what aspects condition it in the first place, such as coordination. Coordination relies heavily on the ability of individuals to harmonize in their activities, enabling them to operate together efficiently. Studies such as [12] have shown that aspects such as social and hierarchical status in a group, diverging work goals or motivations, communication issues, and extensive formal regulation of procedures greatly influence this capability and hinder collaboration. The quality of coordination varies on the type of activity in question and its perceived value. For instance, in a medical setting, standard discussion procedures which require little to no specialist intel are more likely to include failures in examination than high-status examinations, which require more expertise and administrational processing, thus given more importance.

According to Kane et al. [13]**,** in an MDTM setting, participants perceive their benefit from attendances is proportional to their contribution to the meeting itself, and medical imagery is the most vital asset to assist this. The collaborative work between healthcare professionals is highly dynamic and involves a multitude of practices and mechanisms. This creates the need for flexibility and makes it an ideal object of study for developing systems to help assist these meetings and their final goal, decision-making. If we intend an effective collaboration over digital displays, the natural interactions and social bonds of the physical world, and workplace, have to be taken into account so that users feel comfortable and motivated to use a remote groupware system [14].

Furthermore, in a medical setting, communication between departments is seen as beneficial, but perceptions of how collaboration is achieved, what defines its success or failure, differ from role to role, and diverging expertise can hinder each other's understanding. Thus, a healthy informal relationship between healthcare specialists is positive to level communication and avoid misunderstandings, and any system that restrains these informal practices would eventually obstruct work activity. Medical collaboration depends heavily on adapting to different perspectives and goals while still offering valuable and distinct inputs on patient care, so too much rigidity is detrimental, and assisting technologies must consider this [12].

Notable work has already been put into the development of interactive systems to help improve collaboration in a group setting, and essential principles have emerged to guide it. Applications like real-time distributed groupware allow multiple users to work in a shared workspace even when these are at different locations. The foundation for high usability in these systems is linked to workspace awareness, which means understanding another individual's interaction at any given time of work. In addition, knowledge about what, how, and why someone is performing an action is helpful in collaboration as it enables better coordination, communication, and assisting opportunities.

Greenberg et al. [15], pointed out the importance of awareness in groupware system design, especially when it comes to a remote setting where attendees heavily depend on the system's tools and mechanics to understand what is going on. Regarding sound and visual on colleagues, remote MDTMs usually use some third-party software to enable the use of microphones and cameras, facilitating synchronization between actions vital to the meeting such as imagery discussion for a given patient.

The interactive systems developed for the MDTM setting have to take into account the "What You See Is What I See" (WYSIWIS) paradigm [15-16]. It is often referred to in the development of multiuser interfaces, and it means that when users interact in a shared workspace, they share the same perception of the work area. For example, when discussing a patient, all medical specialists view the same dataset on their interface. This paradigm is fundamental in the development and interface design choices. As such, to successfully understand the needs of end-users according to WYSIWIS, the importance of observational field studies is amplified, enabling developers to identify requirements in a guided way. If a developer is able to balance the individual interaction capabilities, group awareness, and technical constraints, there is a considerably better chance for successful development.

An important aspect of collaboration is always the environment in which it takes place, as predictable behaviour can be used to guide the development of media spaces to support the interaction [17]. Often, the devices and design of groupware software diminish the flow of this perceptual information between colleagues by having poor information collection and display mechanisms. As a result, using such groupware can feel disorganized and cumbersome. Thus, effective gathering and presentation of information on-screen or via sound is a design must in order to promote awareness and workflow, as it helps to stay aware of others and simplifies communication. This way, work tasks and ultimately decision-making can be enhanced, and the recreation of face-to-face interaction can better be achieved or improved upon.

3. Related Work

In this section, we present research we considered valuable to the development of our work. We start by going over some infrastructure and design considerations for our remote groupware, followed by valuable user interface contributions for examining medical imagery, prior groupware proposals for the MDTM setting, and general collaborative groupware solutions.

3.1 Infrastructure and Design Considerations for Collaborative Systems

For decades now, researchers have been investigating and supporting the ever-growing interest in collaborative groupware for use in the same room or over the internet network. Early works such as Bier et al. [18] in 1991 focused on developing multi-device, multi-user, and multi-editor (MMM) user interfaces to be used by groups who share a single screen. This approach enabled them to set aside issues regarding network coordination of multiple workstations and focus primarily on the interface and architectural obstacles. Although evaluating their system in its early stages, it already provided valuable input and testing plans for future work. In addition, it established that systems could achieve fine-tuned usability and individual user customizability. A notable feat for the reduced computational capacities of computers compared to now.

While our work is applied to the medical area, it can be helpful to look at other general approaches to collaborative groupware development. In 2009**,** Wallace et al. [19] analysed behavioural patterns and how interface design impacts the workflow of groups in multi-screen setups. For this, they had groups of three undergo collaborative tasks with single and multi-display systems. Results suggest that a multi-display system enables better individual task completion, as users have their own space and produce more accurate solutions, and are less error-prone. On the other hand, users share one workspace in a single screen setup, becoming cluttered the more users there are. Still, better coordination of shared resources and communication is possible at acceptable user numbers, as no network delays are present, and awareness of one another's actions are more instant. The results also show that designers should aim for familiar and ergonomic design choices when it comes to co-located groupware systems. Considering a co-located MDTM setting and according to this research, providing users with their own workspace each with their own device, while still enabling them to share their input via, for instance, stream-sharing capabilities, would make the best out of the positives of both a single and multi-display approach and join that together into a single system.

Considering the MDTM setting and how a radiologist usually loads medical images onto a pc, an approach that places this computer as a centrepiece to a multi-device system's infrastructure seems reasonable. In 1998, Myers et al. [20] developed a system that connects multiple Personal Digital Assistants(PDAs) to a central computer and permits the use of a whiteboard software to interact collaboratively, with drawing and writing features. When evaluating the system, infrastructure worked as intended and without failures, and input from users on the PDAs being sent to the PC was seen as intuitive and fast, suggesting that such types of setup can be viable solutions to a multi-device setup.

In another work, Epps et al. [21] investigate the awareness of co-located and remote users in a collaboration setting when using a shared application. The results showed that awareness issues regarding remote users were not observed and that, if anything, remote users seemed more aware than co-located ones. Awareness cues within the application, cursors, and nameplates seemed to benefit users since 96% of the time they looked at the application during tasks. In addition, the visual channel was seen as less critical, as long as an audio channel between sites was upheld. This study enables for valuable further research points, such as the inclusion of different and diverse awareness cues in multi-user application sharing.

In a different approach, Li et al. [22] developed a remote shared application that transmits high-quality medical imaging, video, and audio over the internet (Figure 4). This, coupled with attention to social interaction and group awareness in the design process, was critical for the system's success. In addition, the researchers showed that keeping human factors at centre of the design process and good image quality is essential to keep in mind for groupware software.

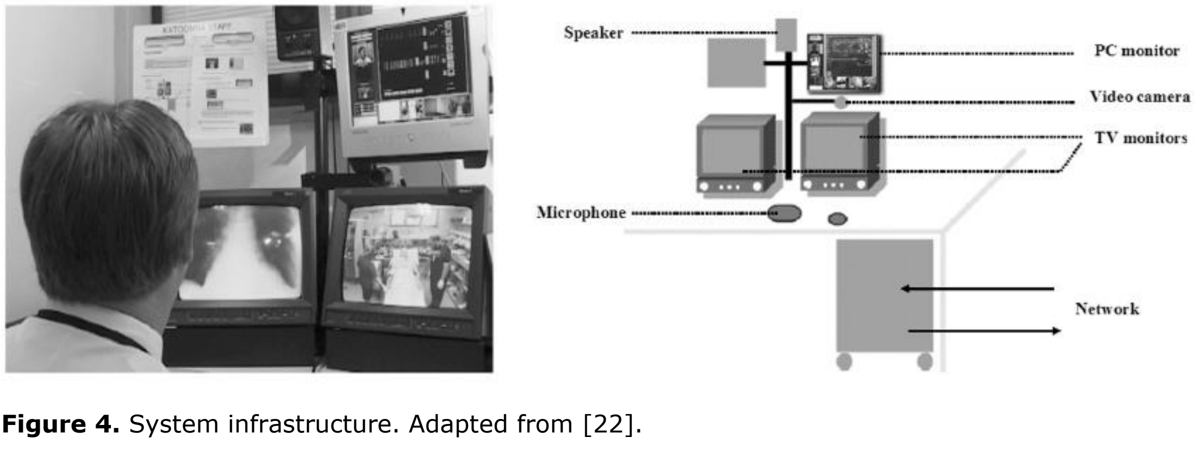


Figure 4. System infrastructure. Adapted from [22].

Researching the value of videoconferencing, Kane et al. [23] analysed how users' attitudes shifted towards video over an eight-month phase of experiencing videoconferencing. Analysis of participants' display use showed that 60% of case discussion time was viewing remote sites, contrary to the original views of giving remote interaction a degree of unimportance. Video had a higher value than expected.

In another work, Groth et al. [24] also studied how video technology affected videoconferencing-based MDTMs involving 2-5 sites at once with up to 20 participants (Figure 5). In observational studies, the audio and radiology images were considered most valuable, and video was not critical for reaching decisions themselves but provided added awareness and social presence. Therefore, the researchers referred that high-quality audio and video should be strived to maximize group awareness.

Figure 5. Meeting setup, plasma screen on the left to see remote sites, radiologist in the front controlling imagery, participants sit in rows. Adapted from [24].

Li et al. [25] studied three different MDTM setups and showed that designing a collaborative work environment depends on the appropriate configuration of physical space and technology. This enables effective information sharing and social interaction. Furthermore, allowing all users to have equal access to shared information can improve communication flow and enhance workflow. New technological solutions must be designed considering each individual meeting context, or they will always be limited to work in local constraints.

3.2 User Interfaces for 2D and 3D medical imagery

In this section we will go over some user interfaces that incorporate 2D and 3D medical imagery.

Considering the potential benefits of complementing 2D with 3D content in the oncologic setting[26-30], this opened a new field of research regarding UI design, dedicated to exploring how to represent and interact with such images in order to improve clinical workflow. Recognizing the valuable insight these works can provide regarding interface design for the medical setting and possible future work regarding 3D inclusion, we consider the following works relevant to our research.

Despite its positive feedback, issues related to spatial abilities and interaction behaviours with 3D content lead some specialists to prefer conventional medical visualization techniques due to their established familiarity [30], creating a more difficult entry point for novel 3D methods to be used in the clinical workflow. Furthermore, 3D rendering techniques often require specialized personnel to generate high-quality images from large datasets [31]. As the 3D content generated by automatic segmentation algorithms frequently does not present the level of detail required to be clinically acceptable, specialized personnel manually trace the boundaries of relevant structures to overcome such limitations, which is tedious and time-consuming [32-33]. These difficulties underline the importance of complementing and not substituting 2D content with novel 3D imagery when introduced into the medical meeting context.

To be of clinical use, medical image applications usually adhere to the two main guidelines: *(i)* The UI which the specialists interact with when visualizing content should have all necessary adjustable parameters easily accessible; and *(ii)* The pre-processing needed to be able to interact with content has to be fast and of minimal complication [34].

Recent work by Iannessi et al. [35] performed a review of interfaces of applications for modern radiology. With the increasing interest in 3D content and computer-aided detection (CAD), they highlight the need for the creation of specific UI's in order to improve the radiologist's workflow, promote a faster transition into 3D manipulation, and not jeopardize productivity.

Additionally, it is necessary to consider that interaction with the audience is also part of communication in an MDTM setting. Usually, a designated radiologist presents the imagery he prepared beforehand, while the rest of the specialists observe. Sundén et al. [36] performed a study on combining 2D and 3D content and possible presentation techniques regarding situational context. Results suggest that if the audience can follow the spokesperson's interactions, this improves their understanding of what is being displayed. While interface design dictates which controls are visible, the type and size of screens in a presentation setup significantly influences the level of engagement and ability to comprehend the speaker.

In a local MDTM setting, the ability to communicate and visualize gestures is apparent as the audience is a small group and distance to the presenter is short. A natural interaction and a direct touch approach that mimic the sense of control over the 3D object could, therefore, enhance the viewer's engagement. Lawonn et al. [37] developed an application that combines the informational benefits of both PET and CT scans. By allowing a 3D visualization in a focus-and-context application, the region of interest of possible metastases has the combined functional data of the PET and the structural information of the CT to enable a quick and practical overview for the specialists (Figure 6-a)).

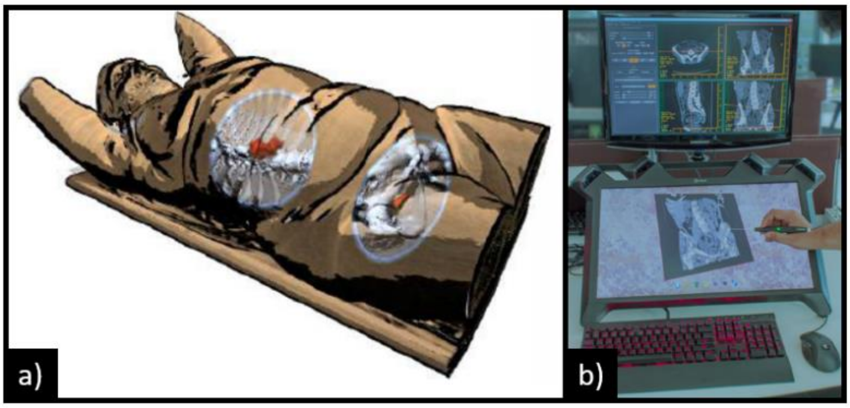


Figure 6. The functional PET data in red is complemented by bone and skin information of the CT(left). Hybrid interface setup with 2D (top) and 3D (bottom) screens (right). Adapted from [37][38], respectively.

The CT's standardized intensity enables the dynamic application of different transfer functions, resolving occlusion issues of traditional volume rendering techniques like maximum intensity projection. However, specialists would mostly prefer the traditional method due to comfort [35], suggesting a need for strict collaboration between developers and stakeholders regarding the clinical usability of applications and their content.

The usability issues experienced by specialists when confronted with novel visualization methods suggest that balancing new and old techniques into hybrid visualization interfaces is worthwhile, so that a smoother transition into future technology is possible. Mandalika et al. [38] created such a hybrid interface for radiologists analysing CT datasets based on a dual-screen setup (Figure 6-b)). On one display, there is the traditional 2D imaging with keyboard and mouse interaction to which they are accustomed. On another display, a 3D model extracted from the volumetric CT data is visible, using a stylus pen as primary input. Results showed that novice physicians performed faster and with significantly more accuracy using the hybrid interface, while the experienced physicians performed slightly slower, but still produced more accurate results using the hybrid interface than the conventional condition. Although the hybrid interface is welcomed, the interaction with the stylus pen introduces precision and handling issues, which indicate that a more conventional input method could produce better results.

Another example is given by Hemminger et al. [39] with their development of the SeeThru app, which aids the visualization of CT scan based content for cardiothoracic diagnosis and surgery planning, including tumour resection cases. The approach is a real-time 3D display application that combines the central 3D visual focus with 2D slices in separate smaller windows, with sliders for easy manoeuvring through slices (Figure 7). Changes to parameters regarding the model's visualization, clipping, positioning, and others, can be done in real-time and affect both the 2D and 3D components.

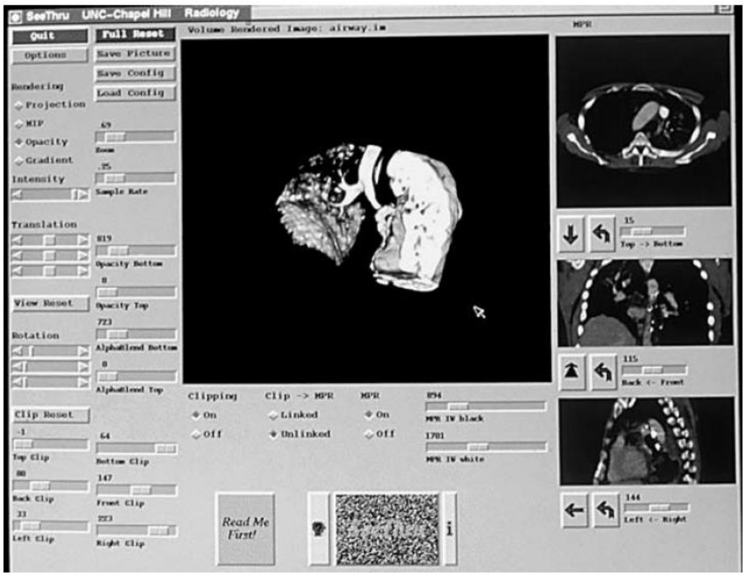


Figure 7. Screen capture of the interface layout of the SeeThru application. Adapted from [39].

Surgeons reported positive benefits of using 3D imaging for surgical planning, leading to changes to the plan in 65% of cases. Furthermore, surgeons' confidence increased an average of 40%, and the anatomic accuracy of the models saw a 95% of satisfaction. Yet, radiologists reported a lower impact on their workflow. While they made new findings thanks to including 3D in about 66% of the cases, changes to the radiology report only happened 14% of the time. Nonetheless, when undergoing the mandatory analysis of imagery pre-surgery, it was easier to communicate with the surgeons.

Since visualization of 3D-rendered content on a flat-screen can make depth perception a hard task, 3D printing is also a considered technique. Wake et al. [40] provide a technical review on MRI-based 3D prints in oncology. They highlight the potential that 3D printed models have recreating tissues like tumours and their surrounding structures, omitting the learning curve of using designated software. This can be especially useful for a preoperative analysis and doctor-patient communication. However, options such as changing colours, opacity, adding visual cues, are lost. Considering an MDTM setting, the effective presentation of printed content seems unlikely due to time and cost restraints. Even if only highly complex cases were considered, effectively transmitting information while holding an object or circulating it in a room full of people is not going to grasp the attention of all attendees equally. Considering our work focuses on a remote approach, depth perception and time related issues as listed above would still be relevant on even amplified due to the unconventional use of 3D printed content.

Other examples of medical imaging visualization and 3D content production rely on commercially available solutions. The Volume Viewer is a medical diagnostic application by General Electric (Figure 8-a)). It allows processing, analysing, and communicating 3D models together with their CT, MRI, and other imaging techniques. By enabling the radiologist to add notes to the model, diagnostic procedures become more manageable, and communication with other specialists, such as surgeons, improves.

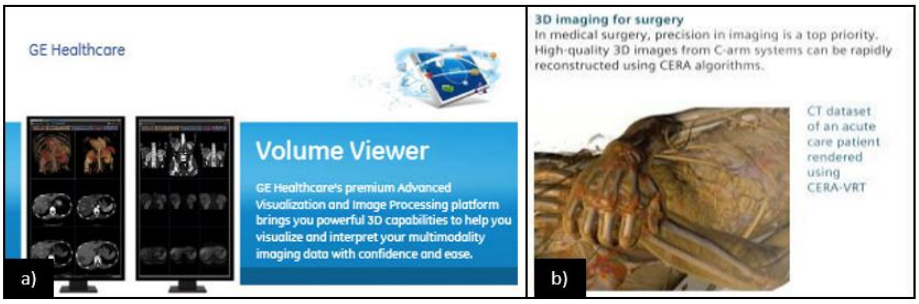


Figure 8. Volume Viewer application by GE (left). CT rendering example CERAs software by Siemens (right) Adapted from [53], respectively.

The counterpart Siemens offers the CERA software for reconstruction and visualization of 3D content, specializing on CT datasets (Figure 8-b)). The rendering algorithms offer high-quality 3D reconstructions and performance due to the incorporation of ray casting and intelligent memory management.

Yet, these commercial solutions are limited by their high price, non-remote meeting capabilities due to security, and the potential obligation of overhaul needed to preestablished PACS, while they do not explore new forms of input to manipulate and present such 3D contents, especially using MRI datasets.

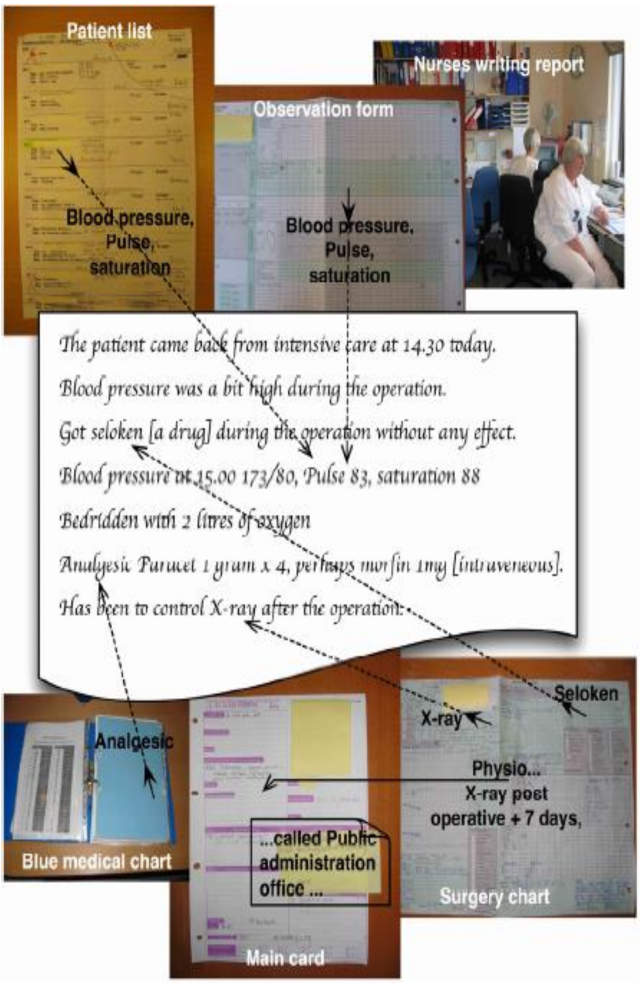
3.3 Prior Groupware Proposals For The MDTM Setting

In order to develop groupware software, researchers have pointed in the direction of using ethnographic studies as a meaningful way to analyse MDTMs and participant's behaviour. Furthermore, these observational sessions enable acquiring a requirement list and are fundamental to backup design choices and therefore go hand-in-hand with human-computer interaction [41]. In the medical setting, CSCW systems have shown that it is crucial to aid and support the collaboration and workflow of specialists rather than provide rigid and immutable programmed solutions which do not offer the flexibility needed in a hospital ecosystem [42].

As mentioned by Berg et al. [43], information technologies enable the effective organization of medical data and coordination of activities. However, an emphasis on their role as support and transparency to the user must be made for them to integrate into healthcare workers' day-to-day successfully. An example of a meanwhile widely adopted computer system in hospitals is the electronic patient record and the electronic nursing plan (Figure 9). Research on these further corroborates the idea of being helpful additions to workflow, but they do not substitute the complex relations between professionals and traditional work practices as a whole [44].

Some work has been done regarding developing systems and tools for use in MDTMs that rely on interactive technologies. In this section, we will go over some of these interfaces and their contribution.

In a deep-dive research on design and usability, Li et al. [45] present a socio-technical approach to the development process of groupware software when considering MDTMs between two hospitals, performing observational studies to identify relevant challenges to collaboration, ranging from the awareness requirements to issues regarding communication. In addition, the researchers point out the importance of combining advanced technology with appropriate design considering current work practices and how target users should play an active role during the design cycle. Semi-structured interviews with healthcare specialists help identify interaction and behaviour, task distribution, and user needs for what a groupware system should improve for an MDTM. Furthermore, novel technology should be tested in a controlled environment rather than a live setting, so the crucial meetings are not interrupted. Primary elements to keep in mind when developing such software should be that remote users should be able to see and hear each other, the requirement for high image quality, and reduced image delay. Healthcare professionals also referred that they value some form of pointing or laser pointer tool to assist explanations. Finally, the prototype should accommodate to the socio-emotional space and informal interaction of team members to reduce any awkwardness introduced by a novel system.



The patient came back from intensive care at 14.30 today.
Blood pressure was a bit high during the operation.
Got seloken [a drug] during the operation without any effect.
Blood pressure at 15.00 173/80, Pulse 83, saturation 88
Bedridden with 2 litres of oxygen
Analgesic Paracet 1 gram x 4, perhaps morfin 1mg [intravenous].
Has been to control X-ray after the operation.

Figure 9. ERP in the middle, and all different documents that are used to write it. Adapted from [44].

Sallnäs et al. [46] provided an important insight into the use of laser pointing in MDTMs via a software solution that combines 2D slices and 3D volumes. For this, a field study was conducted where participants used a laser pointer tool to communicate about patient imagery in preoperative meetings. Results showed that the tool clearly benefited discussions, adding valuable awareness cues and supporting verbal referencing. This encourages the inclusion of a laser-type tool into our prototype development.

Frykholm et al. [5] proposed a high-fidelity prototype for tablet devices to support collaboration in MDTMs and tested it in a real setting. Their prototype presents an extensive patient overview, and the system allows to add visual cues to medical imagery to aid discussion (Figure 10).

Figure 10. Interface snapshot while using the drawing tools. Adapted from [5].

Various devices can be used simultaneously by meeting attendees, and data is synchronized in live time between them. To enable a streamlined usage experience, the system has two modes. A Shared navigation mode, where any change made by the user in the interface is sent to other devices, and a private navigation mode where users are able to navigate and manipulate content without affecting other devices. The software was field-tested in a local simulated MDTM setting with medical specialists such as radiologists and surgeons who had an active role in the designing process of the system. Each attendee had his tablet device and interaction was individually logged in the system, meaning each click and mode change was timestamped and recorded for later evaluation. Additionally, the evaluation was recorded by a camera. This allowed researchers to understand how the devices were used and what tools and modes were the main focus in usage. Overall, the groupware was well received, and the evaluation shows great potential for such types of software to make MDTMs more efficient when it comes to case discussion. Our work focuses on the remote setting and thus we mean to contribute with how such an approach fares compared to an in-room setting. The successful evaluation method used encourages us to follow a similar approach especially considering a remote setting, where logging interface utilization helps understand behaviour and assess the system's strong and weak points in a posterior analysis.

Olwal et al. [9] proposed a multi-display groupware prototype for the MDTM setting to augment the discussion capability of medical imagery. They developed a multi-user interface that enables different interaction techniques, including touch and pen-based interplays (Figure 11). As guidelines, extensive observational sessions of a gastrointestinal cancer team and interviews with surgeons and radiologists set the foundation for the design and tools to be implemented. The heavy reliance on mouse and laser pointer pens to discuss parts of the medical imagery was identified in these sessions, and the lasers are regarded as disadvantageous from a communication flow perspective, as radiologists responsible for image control would have to direct their attention onto projection screens and away from their workstation. It became clear that visualization tools have to be adapted so that even though a multi-device system is to be deployed, a single device should enable the visualization of all information and visual cues added. With the adaptation of design guidelines that respect minimal modification to the established workflow, simple and quickly accessible functionality, scalable infrastructure, and synchronization among multiple displays, the system should simplify the discussion, increase collaboration, and enable faster and safer decision-making. The researchers also pointed out the importance of time for determining the efficiency of the meetings and that new interactive systems have to take this into consideration.

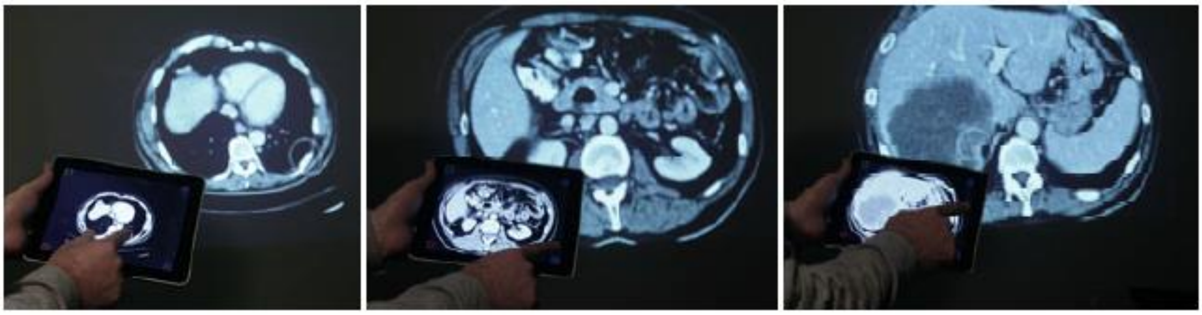


Figure 11. Synchronized interaction on handheld device and big screen on the back, using multi-touch gestures. Adapted from [9].

Given that the system is to be used in an in-room setting, a PC server projects medical imagery, while mobile tablet devices are synchronized over the local network, enabling users to interact using their own devices. The users are allowed to use a pointing and sketching tool, and image navigation is allowed to all users; typically, only the radiologist would control these (Figure 12).

Figure 12. Touch display with interface to the left. Combination of PC screen projection and mobile device on the right. Adapted from [9].

Regarding the image navigation, a discussion about a private and shared mode emerged. Private interaction enabled working in parallel on one's mobile device without disturbing other meeting attendees, and the users could request to share their view when they had something valuable to share. However, some specialists were concerned about users only focusing on their private screen and hindering collaboration, but no in-depth evaluation on how long users used each mode was performed to back up this claim. Furthermore, users were concerned about the disorder that could emerge if multiple people tried to interact simultaneously with the imagery, suggesting that via order should be kept via social protocols or keeping the power to delegate control of imagery solely on the radiologist.

Overall, the groupware proposed in both works [8-9] was well received, and results indicate great potential for such types of software to make MDTMs more efficient when it comes to case discussion. Since our work focuses on the hybrid setting, we mean to explore how such an approach fares compared to an in-room co-located setting, considering the valuable insight into design considerations gathered here.

3.4 Remote Collaboration Groupware Solutions

In 1992 Ishii et al. [47] presented "Clearboard", a prototype supporting remote collaboration through shared video drawing. By using a camera to record user's expressions and combining this content with what they draw on a glass board with digitizer pens, a video stream can be sent to a remote user (Figure 13). However, this solution is costly and limited considering an MDTM setting as it can only be used effectively by two users not to clutter the screen, display transparency issues hinder visualization, and the equipment required is expensive. Nonetheless, in their evaluation, the researchers got positive responses regarding the added awareness of others.

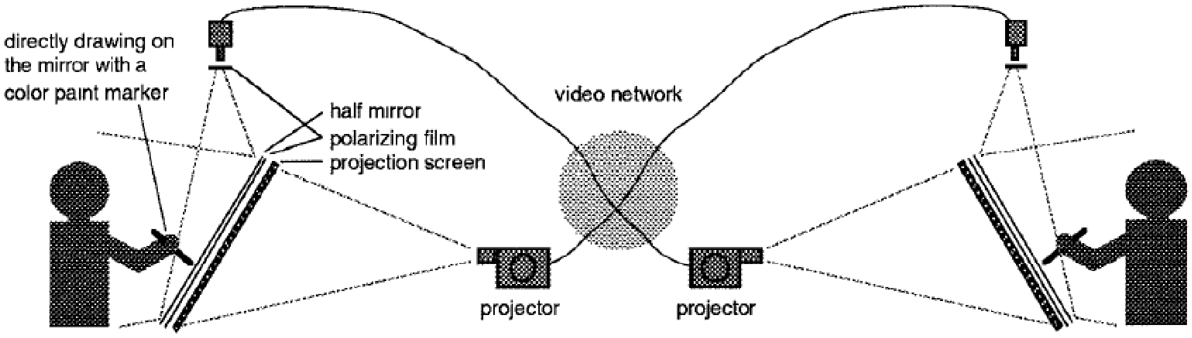


Figure 13. System infrastructure of the Clearboard prototype. Adapted from [47].

Morikawa et al. [16] presented HyperMirror, which enables local and remote participants to appear on a shared video wall via a combination of cameras and sensors, effectively giving them the feeling of being in the same room. Their work reinforces the importance of the "What I See Is What You See" (WISIWYS) design philosophy when developing collaboration software. In this approach, awareness is achieved to a great extent because people have the sensation of physically interacting with each other.

Considering an MDTM setting, these last two works are limited by allowing only two participants at a time, which is not compatible with the medium-sized groups we want to focus our work on.

Wittkämper et al. [48] investigated the use of augmented reality video streams for remote interaction and, although still in its infancy, AR shows promising possibilities to enhance real-time cooperation in the future (Figure 14). The main drawback of AR systems is their expensiveness. But if one user couples AR with a live stream, various participants could view a real-life artifact-filled environment via a web browser. Nonetheless, this still requires an expensive multiple-camera setup, and image quality is highly dependent on the speed of movement and bandwidth of the streamer.

Considering an MDTM setting, where time is crucial to discuss all patients effectively, the fiddly and unreliable state of image quality and difficulty of use for the average user are strong deterrents to try and adapt an AR solution for medical discussions at this stage in time.

TIME LEFT: 01:17

SELECTION: Cam 2

SCORING: squad x: 386 squad y: 512

Figure 14. Live video stream(left) with AR cues. Map of location(right). Adapted from [48].

In a similar fashion Dai et al. [49] proposed an approach that allows remote participants to see each other from different viewpoints via a combination of cameras. They understood that users require low latency in order to communicate their ideas in a way that doesn't deteriorate their activities. This design need is essential to keep in mind for any groupware system.

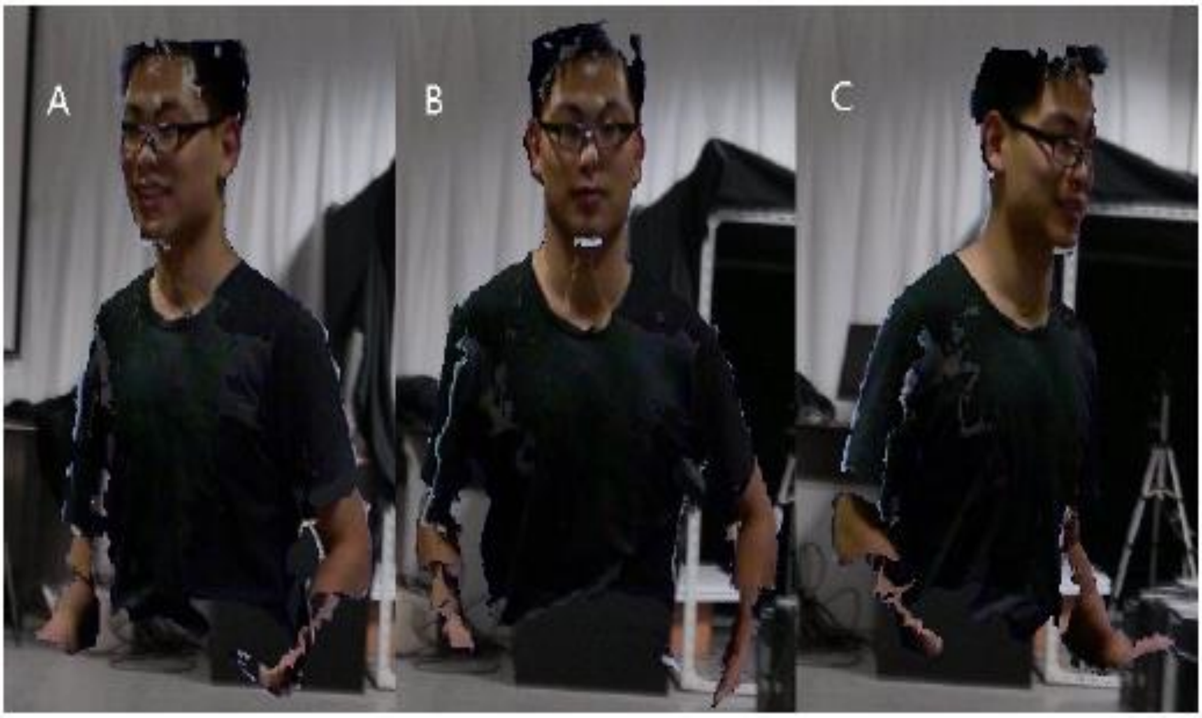


Figure 15. Remote participant when seen from different camera angles used for streaming. Adapted from [49].

When considering a group meeting, some sort of whiteboard or dashboard is often used in combination with pens and laser tools to explain complex ideas in a digestible manner to other participants. Expanding on this Pizarro et al. [50] adapted the dashboard for a remote meeting setting. In their case, the dashboard is an infrared-based multi-touch whiteboard mounted on a wall interactable with board pens that emulate a mouse (Figure 16). Information is projected on the board and a person can interact with it. The user's positioning is recorded by a camera and later on combined with the dashboard content to be streamed to other users. Respondents had an overall pleasant reaction to the silhouette solution and said it brings them closer to a face-to-face encounter like the in-room setup. Nonetheless, considering the traditional exploration of medical imagery and needs for different specialists to provide input in a MDTM setting, the limitation of only one user presenting and manipulating content is not always ideal.

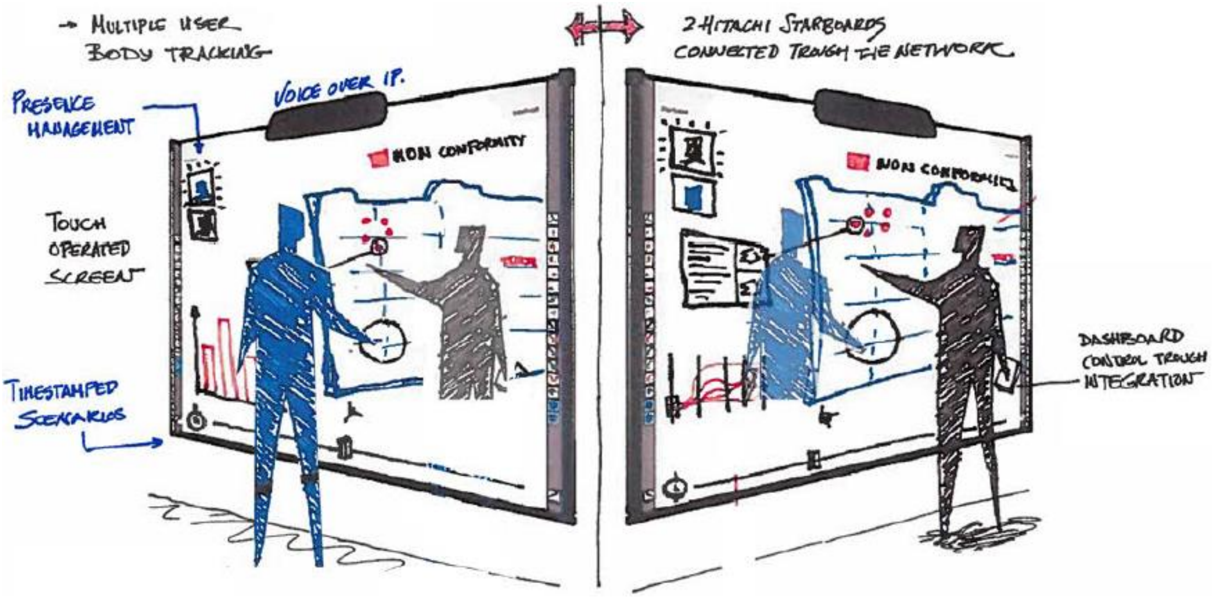


Figure 16. Concept sketch of silhouette system. Adapted from [50].

In a similar design philosophy Greenberg et al. [51] presented a transparent display where two users can work in tandem on each side of a glass screen fitted with sensors and cameras so they can see each other (Figure 17). The researchers also identified issues with the transparency of the screens due to lighting problems and graphical nuances, which deeply hindered awareness. While they considered transparent displays as a suitable option for collaborative work, they acknowledged the technical difficulties related to them. They further recognized that newer and upcoming technology could help diminish this issue in the future.

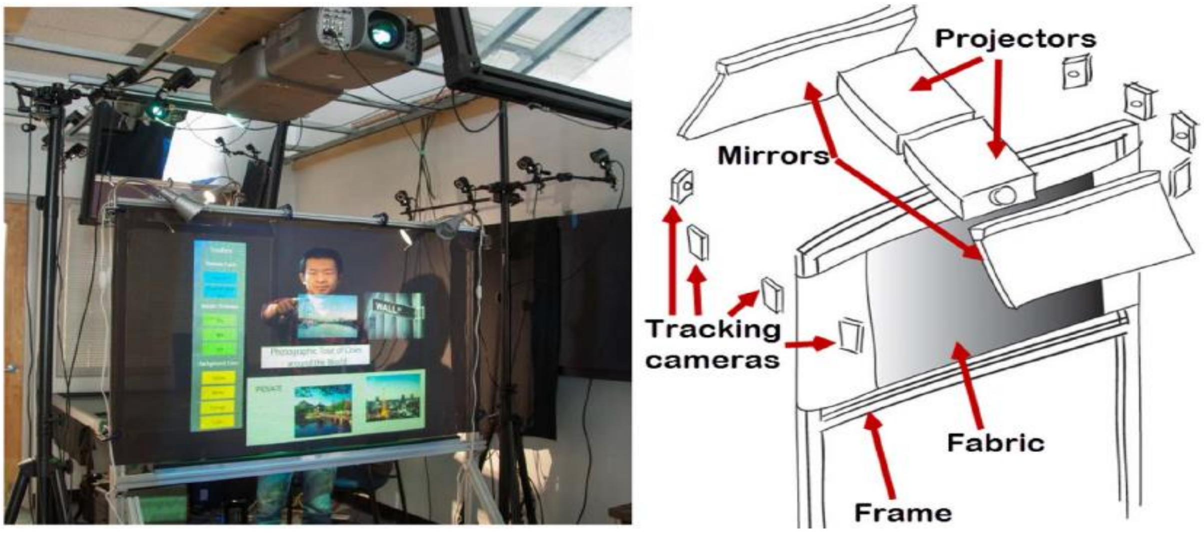


Figure 17. Architecture of the system prototype, Adapted from [51].

In another solution Greenberg et al. [52] approach a remote solution that embraces a large group collaboration setting. The researchers developed a software prototype that expands on the ideology of an instant messenger. The framework can share media items, display Web items to all users or share the host's screen while maintaining a simple, straightforward design. Although early evaluation with Human-computer Interaction (HCI) experts was optimistic when going over use-cases scenarios, no further field testing was deployed due to bugginess and limitations of no voice communication. Nonetheless, the prototype was seen as promising if made more robust (Figure 18).

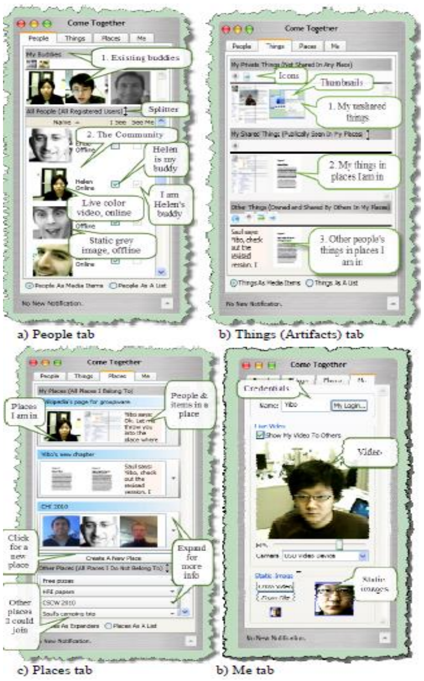


Figure 18. The Come Together interface and different tabs. Adapted from [52].

3.5 Discussion

In this section we will briefly discuss the related work presented. The work by Mandalika et al. [38] shows a promising use of a multi-screen setup, which could encourage the engagement and inclusion of an audience, rather than a single screen proposal. In this sense, the MDTMs we have observed already explore this kind of setting, using one large screen to display imagery contents and the other to share the report that is written during the meeting. Furthermore, their idea of exploring hybrid input could also be viable in the MDTM setting, where mouse and keyboard could be complemented by a device like a handheld screen. The use of a hybrid input leveraging a handheld screen, such as a tablet, would create the opportunity to share direct control of a device, potentially enhancing collaboration and communication. Simultaneously, this would enable us to use familiar gestures such as pinching or tapping on a touchscreen to manipulate 2D, which is broadly used on smartphones to interact with images.

The simplicity and straightforward interface design of [33], [35] and [36] are examples of user-friendly approaches which keep visualization as the primary focus, regardless of working with multiple imaging modalities or not. The ability to use annotations such as description boxes in [36] with other types of markers could be adapted for the MDTM setting, showing potential to convey an idea more effectively and create a sense of shared understanding.

In conclusion, many works have explored and enhanced groupware collaboration with novel systems. Early remote solutions for such as [47] and [16] provide valuable insight into awareness and collaboration needs, even if limited to two users. Additionally, other works like [48-50], provide relevant information regarding remote interaction and the use of diversified novel technologies. Still, we must consider the time-constrained and dynamic setting of an MDTM and provide a solution that is not only economically viable but easy to adopt and flexible in use. Furthermore, [52] provides a solution that upholds these requirements but lacks critical communication channels and visual tools to manipulate medical imagery, which we want to provide. Finally, the distinguished contributions to MDTMs we reviewed, [5][9][45][46] lack the support for remote meetings which is increasingly important in recent times, given the global pandemic, and do not explore how different approaches of image control can impact the workflow of the meetings themselves.

4 Design & Implementation

4.1 Design Choices and Requirements

This section describes the different development stages for the design of our prototype, details our implemented system's infrastructure, and how our interface works.

4.2 Requirement Analysis

In order to make the design and requirement choices for our prototype, observed 4 hybrid MDTM meetings and took relevant notes for development, which we will discuss below.

In our observational sessions, the hybrid MDTM meetings were held over Microsoft Teams and had between 13 to 20 participants. The average meeting time was 55.3 minutes(SD=23.96). The meeting format follows: a coordinator would introduce each of the patients and briefly introduce their case, followed by the responsible doctor asking image specialists for their input. After this, the specialists would discuss the matter in collaboration. Notable issues fall upon communication, regarding persons interrupting each other, difficulties knowing who is talking, and screen-sharing delays.

4.3 Implementation

To further expand on the concept of collaboration in these meetings, we decided to adopt a multi-device set up to stimulate the individual participation of the MDTM attendees. The imaging specialist controls a desktop device which loads, controls, and enables adding visual cues to the datasets to be discussed, while other attendees can view and make such visual contributions on tablet devices.

Moreover, we adopted a clean and simplistic interface design inspired by the works discussed in the related work section—an uncramped and user-friendly approach with image visualization as the primary focus.

For the interface development, we used Unity (v.2019.3.1f1), and to enable a multi-device setup, we use the FMETP Stream Unity asset to enable effective screen streaming.

The implementation requires a remote-friendly infrastructure as the majority of the MDTM's attendees are not in the same room and connect via the internet. Below we present a simplified overview of how we achieved this (Figure 19).

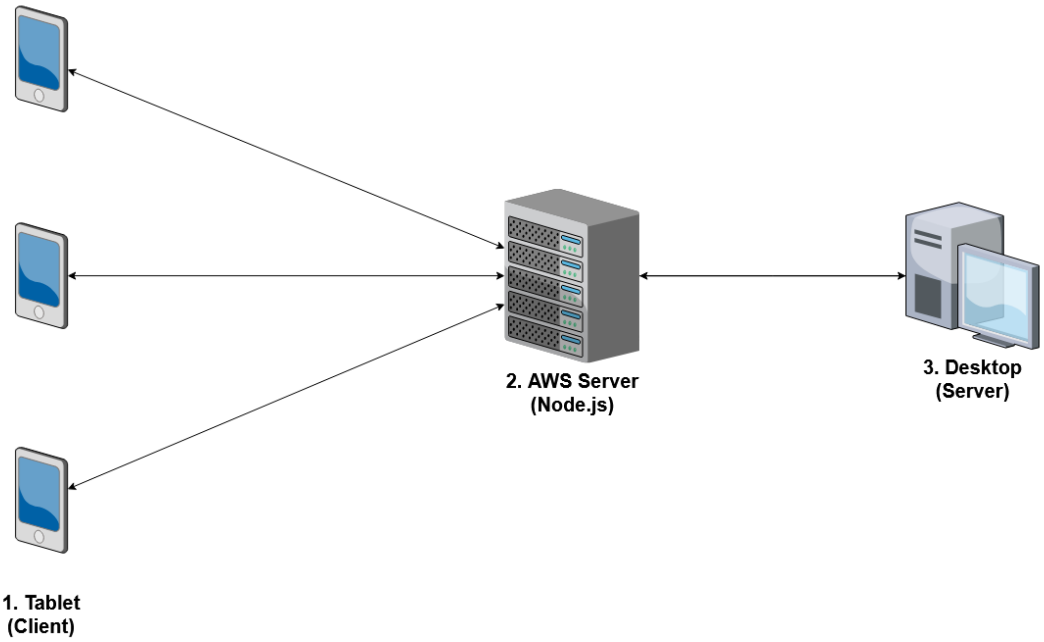


Figure 19. Implementation infrastructure.

As a central piece, we have a backend server deployed on the Amazon Web Services using the Node.js runtime environment (2), which handles all connections and data transfers between the tablet clients (1) and the desktop computer (3) controlled by the specialist responsible for the imaging. The primary data transferred between the meeting attendees is by streaming. Inspired by the work of Frykholm et al. [5] the application has two modes available to each user: **Solo** and **Collab**. In Solo mode, users are in a private session where they can study and prepare visual cues on the loaded dataset. When in Collab mode, users can see the screen of whoever is streaming at the moment, we will further explain this below. This way, the act of viewing is centralized. To emphasise what mode a user is currently in we use a coloured text and application border. For Solo we use blue, and for Collab we use green. Figure 20 highlights the server-side interface of the desktop computer.

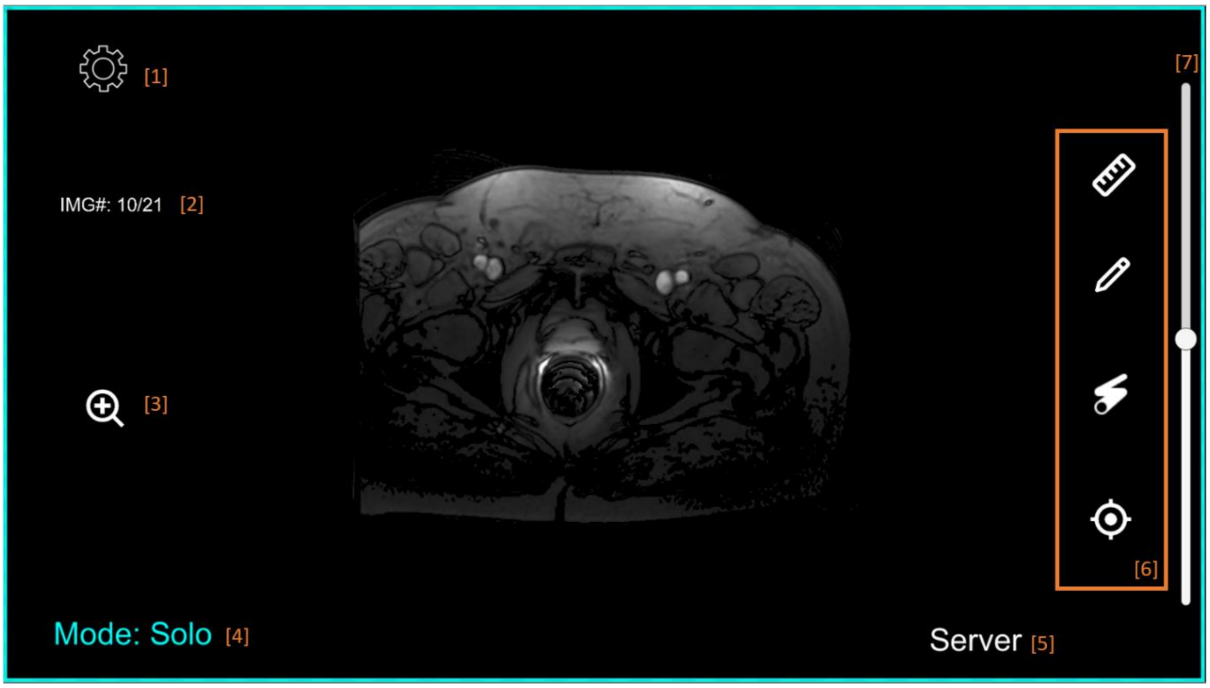
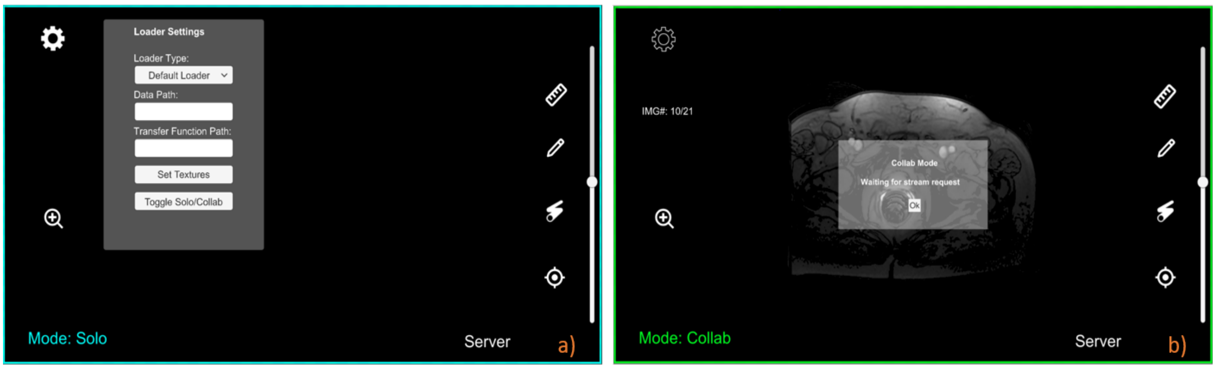


Figure 20. Interface Overview. [1] Settings, [2] slice number, [3] zoom, [4] mode display, [5] name display, [6] toolbar, [7] image slider.

The settings interface enables the user to load a dataset (Figure 21-a)). When the aforementioned Solo/collab toggle button is pressed we switch to Collab Mode and can wait for a client to stream their view Figure 21-b).


Loader Settings
Loader Type: Default Loader
Data Path:
Transfer Function Path:

Collab Mode
Waiting for stream request

Figure 21. a) Desktop server settings interface. b) Pressing Toggle Solo/Collab and entering Collab Mode.

The tools are the same for both the server and clients and help to produce visual cues to support communication and ultimately improve collaboration (Figure 22).

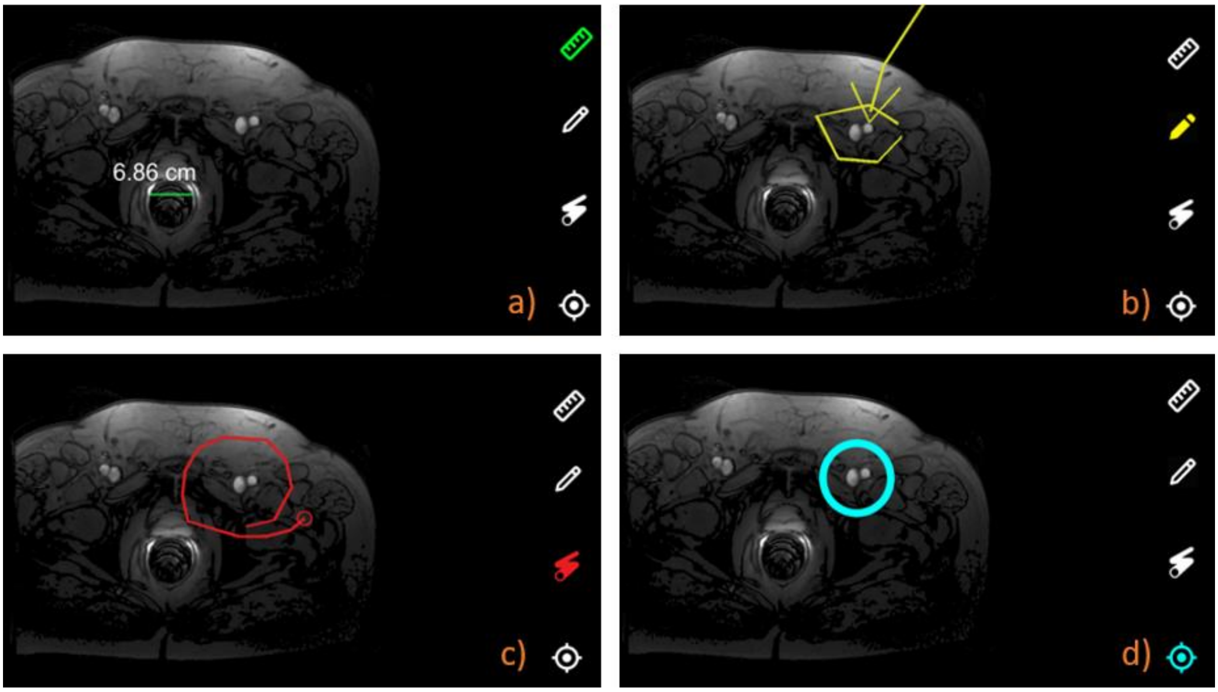


Figure 22. Visual tools. a) ruler. b) drawing. c) laser. d) pointer.

At (Figure 22 a)) we have a ruler tool to allow the measuring of distance in centimetres. In (Figure 22 b)) we have a sketching tool that enables the user to draw any combination of lines to appear, (Figure 22 c)) is a laser tool which, similarly to sketching, permits the creation of lines, but these disappear after a couple of seconds. We consider this could be useful to go through a detailed demonstration without cluttering the screen with too many visual cues over time. Finally, in (Figure 22 d)) we have a Pointing tool that works like a zoomable circle to hover over target areas.

Instead of a mouse, the handheld user uses their fingers for drawing and a pinch-to-zoom gesture for sizing the pointing tool.

There are two versions of this prototype, Version A and Version B. In Version A, the desktop computer has complete and only control over the imaging and how long a tablet client can stream their screen. The client can only make visual annotations and start streaming their view via a button. Stream stopping is controlled by the desktop server, by switching to solo mode. In Version B, each tablet client has their separate instance of images that they can manipulate. Streaming can not only be started but also toggled by users. The main interface changes between the versions are exclusive to the client-side application.

4.3.1 Version A

When clients open the application, they are greeted with an input field to insert their name (Figure 23).

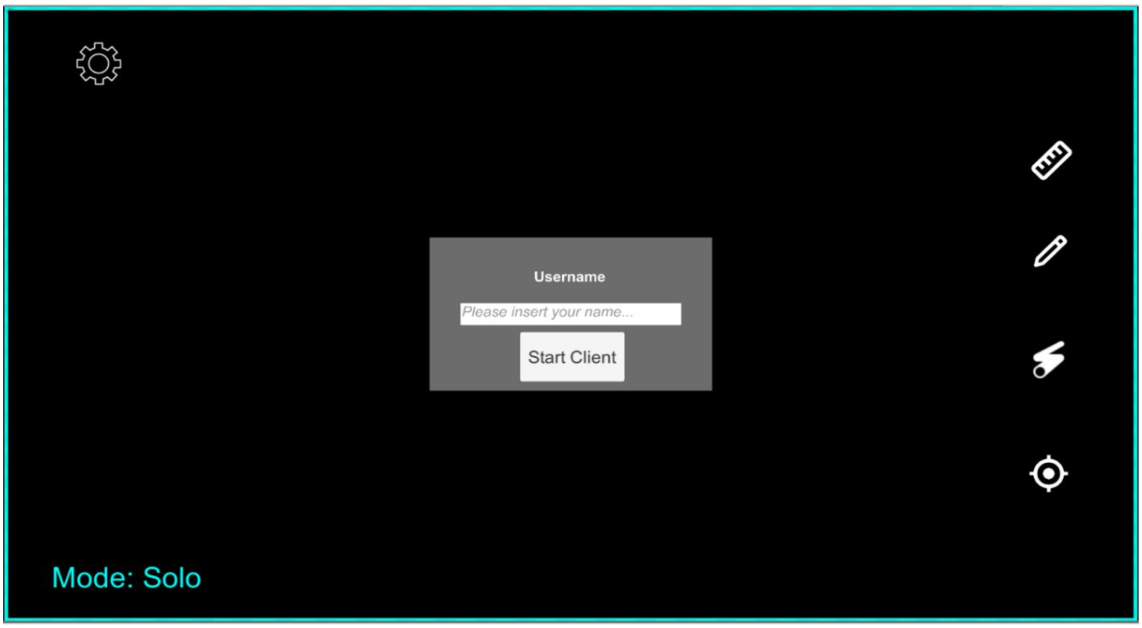


Figure 23. Client-side application start screen.

This information is then shown on the lower right part of the screen, like on the server-side application. This way, when a user streams their view, others have an awareness of who is streaming. When a user presses the start button, the application connects to the AWS server, and communication with the desktop server is established. Datasets loaded by the server will now appear on the client's screen to add visual cues, and they are able to toggle between their private view and view the shared workspace by pressing the solo/collab button (Figure 24). If a user is streaming, their screen appears, else the default screen to appear is the desktop computer’s view, in case the imaging specialist is providing his own input.

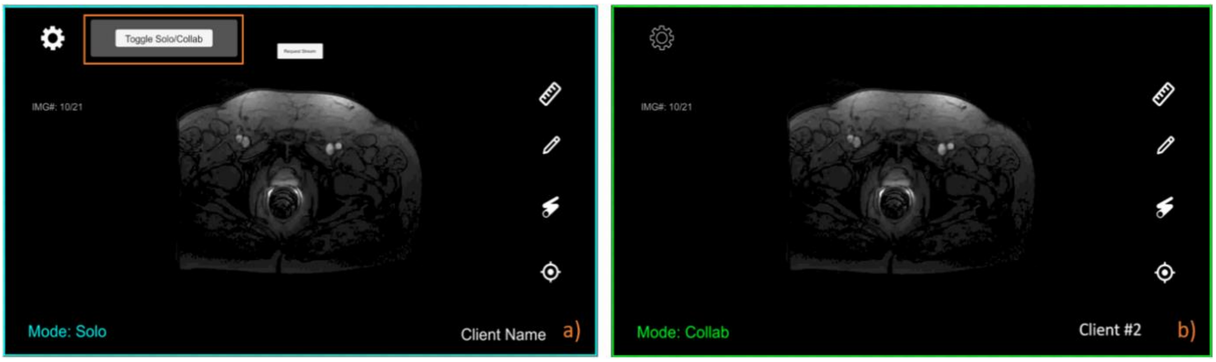


Figure 24. a) Toggle Solo/Collab Button. b) Entered Collab mode, viewing current streamer.

Figure 24 illustrates what happens when a user with the name Client #2 is streaming. A simple click on the solo/collab button again, brings the user back to his private workspace, as seen in Figure 24 a). This way users have a simple way of shifting between viewing a colleague's stream and analysing the imagery at their own pace. In version A the control over the imaging and stopping one's own streaming process is non-existent. The server has total control over what content is discussed and how long and when someone can stream their view for collaboration. Next, we will present the interface differences of the client-side application for Version B and what differentiates it from version A.

4.3.2 Version B

In version B, the client has the added ability to control his separate instance of images (Figure 25). In this version the request stream button changes position to avoid cluttering.

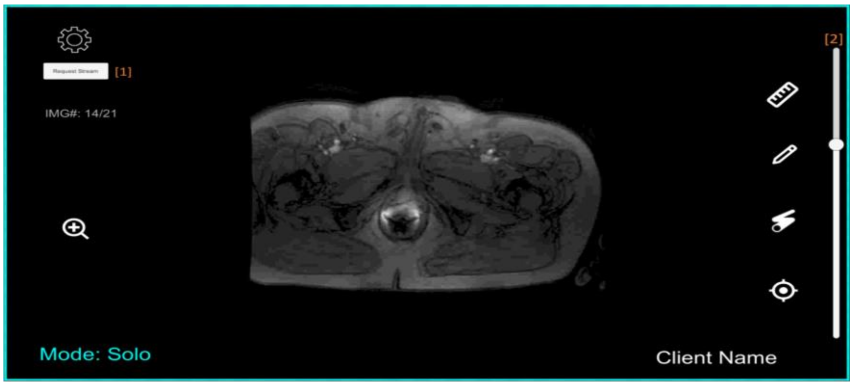


Figure 25. Client version B interface in solo mode. [1] Request stream button. [2] Slider.

When streaming, the client now has the ability to stop at will and go back to solo mode which is not possible in version A as the desktop server has complete control(Figure 26). All other capabilities of version A including the visual tools work the same.

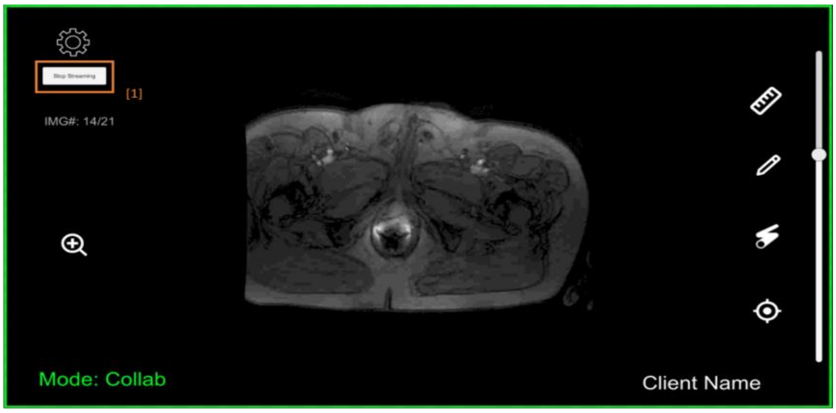


Figure 26. Version B client interface while streaming. [1] Request/Stop streaming button.

5 Methodology

In this chapter, we will discuss the methodology used to evaluate our prototype. We underwent a qualitative/quantitative user study with groups of lay people as participants.

5.4 Setup & Apparatus

Participants used their own portable android devices in the setup, be that phones or tablets, with a minimum of Android version 11 installed, and connect to a zoom call with their pc. The person acting as the server used the same computer to run the prototype and enter the zoom call. Zoom was used as the communication medium for people to exchange ideas and enhance group awareness, seeing and communicating with each other while using the application on their handheld device.

The following image (Figure 27) illustrates a potential evaluation setup where all users are connected in a Zoom call on their respective computers. In (Figure 27 a)), two local users connect remotely to the application using their handheld devices, while in (Figure 27 b)) the user acting as the server has the application running on his computer, where he uploads the datasets to be discussed. Lastly, in (Figure 27 c)) the fourth participant connects from another location via his handheld device. Once all users are connected and the dataset is loaded, they can collaborate using the visual tools and share the screen function explained earlier.

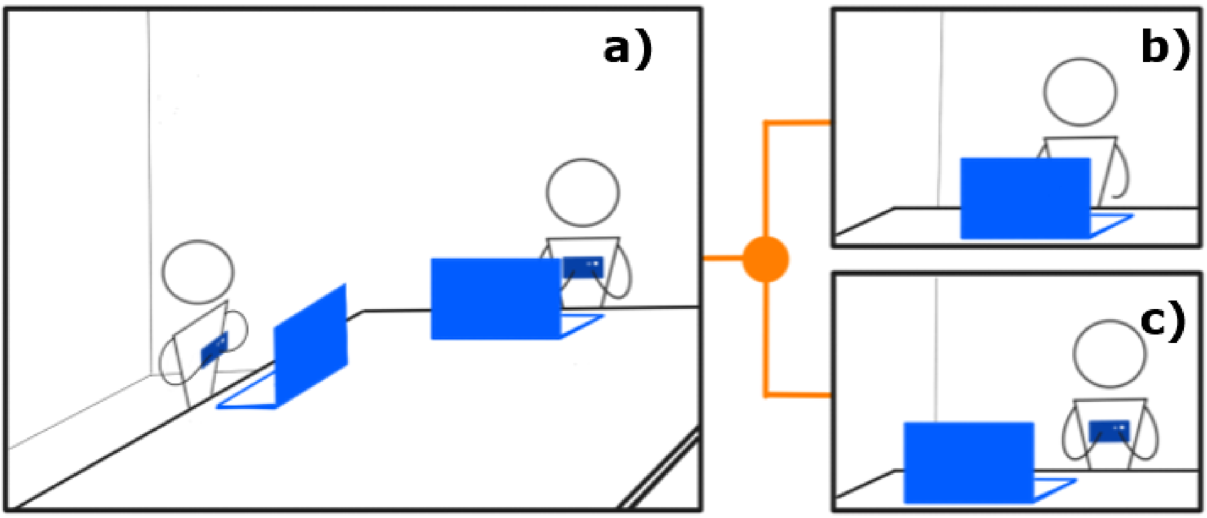


Figure 27. Setup Overview. a) Two users connected who are in the same room. b) Remote user acting as the server via pc. c) Remote user.

5.5 Participants

We had 16 participants, 12 male 4 female, who were between 16-66 years old ($\bar{x} = 26$) and received no compensation, participating in their own will. 5 participants were students, 6 worked in the IT branch, 4 were entrepreneurs and 1 was a social educator.

Pre-test questionnaires assessed their familiarity with other types of collaborative software, established a demographic profile, and acquired their consent for participating and being recorded. When asked about their experience in collaborative work in a mixed remote setting, 37.5% of the participants expressed average and 43.8% above average experience level. 46.7% of participants stated they usually worked in groups of 4, while 53.4% reportedly work in larger groups. Visual cue tools such as drawing or pointing tools were used regularly by 56.4% of them.

Regarding the profiling questionnaire, 56.3% of participants acknowledged they had an above-average degree of familiarity with collaborative work, with 37.5% expressing very high experience levels with this setting. However, regarding a mixed setting with both co-located and remote users, only 25% expressed an excellent experience level. Concerning the number of people participants usually interact with in such a mixed setting, 46.7% worked in groups of 4 as they did during our evaluation. About two-thirds of the respondents expressed an average or above-average use of visual cue tools for drawing or pointing. From a set of collaborative systems, 81.3% of respondents answered they are most familiar with Zoom for collaborative work (Figure 28-29).

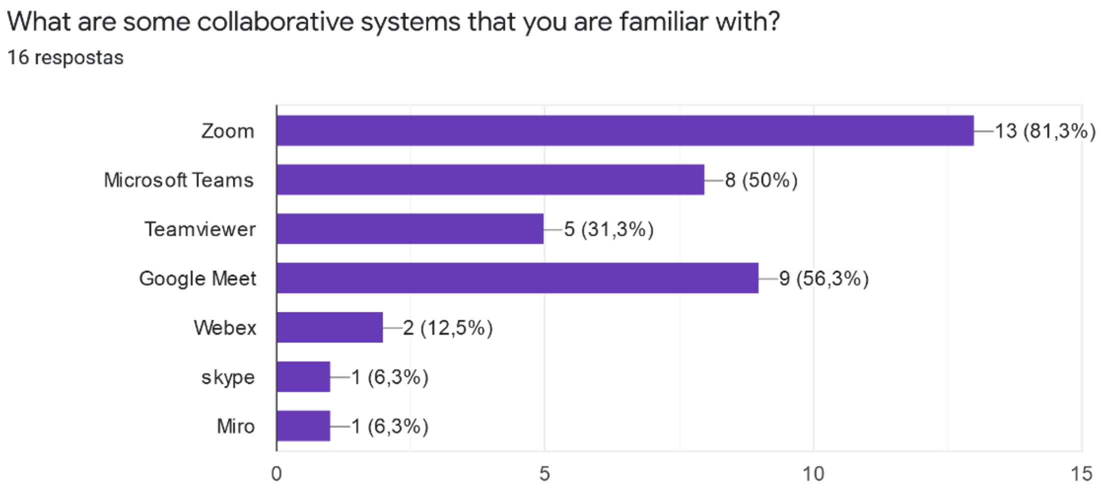


Figure 28. Results from the pre-test questionnaire.

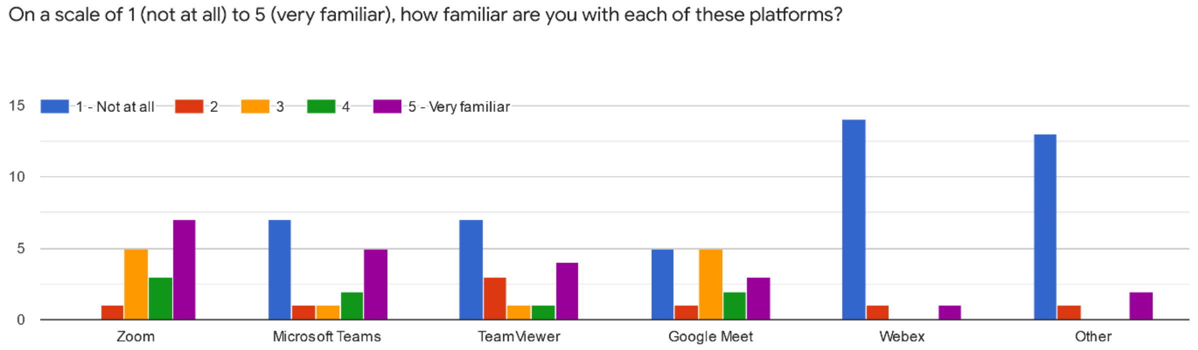


Figure 29. Results from the pre-test questionnaire.

5.6 Methodology & Procedure

The user study aimed to evaluate our interface and explore how four groups of four persons each interacted when asked to complete tasks in collaboration. For this, the participants explored a selection of images prepared in advance, using the visual cue tools, and share the screen function explained in the implementation section of this paper. The choice of which version to start with was chosen via the Latin square method.

The study's objective was to identify the potential of our implemented interface and access its functionality in a setting that could mimic a remote MDTM. Having a participant function as responsible for loading images, we pretend to bring him closer to the role of radiologists who usually control imagery from a workstation.

Participants were introduced to both versions of the prototype and allowed to explore the interface and familiarise themselves with its functionality while using the think-aloud method. After this, the participants were asked to make sure they were in solo mode, and a task was given. This process was repeated for all tasks in order to make sure all participants were ready to proceed. After completing the given test tasks, post-test questionnaires in the form of a system usability scale (SUS) and individual preferences were filled out. Finally, individual semi-structured interviews were held with the respondents. All sessions and interviews were recorded and transcribed for further analysis.

5.7 Tasks

Participants were asked to complete three tasks per prototype version. The tasks were simple and equal for each version, completed on different sections of the images used, and required collaboration for best accomplishment. Task one was to measure a given distance between two objects. Task two was to identify a mistake in the drawing present in a given image, and task three was to identify an object somewhere in the dataset. Participants were free to use any combination of tools to accomplish the tasks. The tasks were designed to simulate potential interactions during an MDTM, such as measuring a given malignant tissue, identifying a tumor, or discussing a given region of an image with particular interest. This way, we were able to get the most value out of the completion of the tasks given our work's goal.

Due to the testing with laypeople the imagery used is not of medical nature, in Figure 30 present an example of the interface loaded with these images.

Figure 30. Imagery used for laypeople testing.

6 Results & Discussion

Our mean SUS score (Mean=88.44, SD=9.83) suggests that our interface does not have major usability issues and is easy to use. One participant even reported that: *When you look at the buttons, you can understand what they are going to do and how you should use them* [the tools].

This general idea is further corroborated by the feedback received during the semi-structured interviews, where participants expressed no significant issues when using the application, as well as by our post-test questionnaires. Some delays related to network bandwidth and internet speed occurred specifically in Version B, but users said it did not majorly impact them. When asked about the usefulness (*I found this tool was useful*), usability (*I found this tool was easy to use*) and memorability (*I found this tool was easy to remember how to use*) of each tool, participants strongly agreed that all tools were useful and user-friendly (Table 1). The most common idea among participants confirmed that the visual tools were especially useful to convey ideas in a more accurate and quicker way, which aligns with findings by [9]. Some participants mentioned:

[R: *Did you feel the tools enhanced or helped communication?*]
P22: *I used the tools a lot, for example, the drawing tool, I used it to select the objects critical to the tasks and make it evident to others.*

P4: *Yes, especially the laser (…). When you're trying to describe or explain something and you can point and indicate things, I think it helps putting the idea across.*

P10: *Yes, a lot, because I can quickly get what the speaker wants to point out…When you asked about the location of a specific object, the others said the object was somewhere I could not get, but when they used that blue pointer, I got it right away.*

Even though they recognized the potential utility of each tool, participants had different opinions about their tools of choice and the best-use case scenarios for each tool. One participant mentioned:

P5: *Yes, some more than others. The ruler was good, it's not something I'd seen before. I also liked the sketch tool which leaves the drawings there* [sketch tool]*. I did not find the pointer or the laser as useful, but I believe they should also be necessary.*

While the ruler appreciation might have suffered from the novelty effect, it was clear the user preferred a sketching tool rather than the laser, due to its limited duration. However, others recognized the potential of the laser as a better support for someone who wants to describe a number of aspects in a row, without constantly going back to erase and update the drawings, and avoiding images that become too cluttered:

P6: *I thought that the sketching tool was the most useful. On the other hand, the laser…I understand that it disappears automatically and when someone is describing something about their field of expertise, for example, it makes sense to explain something quicker…*

it is useful, because it disappears and the expert already knows what they are going to say next, so they can use it following a sequence of ideas. When you're doing something at a given moment and you're still processing the idea, I don't find it very useful.

Table 1. Results of the questionnaire regarding the visual tools. Values and Median followed by Interquartile Range in parenthesis.

	Usefulness	Usability	Memorability
Ruler	4.50 (1.00)	5.00 (1.00)	5.00 (0.00)
Sketch	5.00 (1.00)	5.00 (0.00)	5.00 (0.00)
Laser	5.00 (1.25)	5.00 (0.00)	5.00 (0.00)
Pointer	5.00 (1.25)	5.00 (0.25)	5.00 (0.00)
Zoom	5.00 (0.00)	5.00 (1.00)	5.00 (0.00)

Overall, participants reacted positively to the visual tools, claiming they supported communication even further when coupled with screen-sharing. Participants considered the sketch tool ("the drawing tool") as the most valuable, mainly because they found it the most versatile. It could function as both a pointer or a more complex highlighting tool. Others found the laser tool more valuable, but also agreed that the disappearing line could confuse others if explanations were sloppy. Nonetheless, 87.5% of respondents found that all tools were average or above average in their usefulness.

Regarding the dual application setup, with zoom for communication and the prototype for image manipulation, participants expressed a mixed reaction. Nine participants liked the current setup, expressing how they enjoyed being conscious about verbal communication on one application and dominating the image manipulation on the other, as there is no cluttering of a single screen. Participant 3 mentioned that looking ahead onto the pc screen to see others and down at the phone to manipulate images simulated a round table type environment as if all participants were in the same room, saying, "*Because it is as if we are in a real context, we manipulate stuff on the phone, and when we look ahead we see the people sitting around the table*". Participant 10 said that "*I felt the dual setup was an advantage, I was dominating both things. I was conscious about being on Zoom, seeing what was happening and interacting with others, while dominating the application on another device*". Besides this, participant 9 also referred to the practicality of nowadays nearly everyone having a smartphone and a pc they can handle simultaneously, "*I think the way this is accomplished, Zoom on one device and application on the other is well done, nowadays nearly everyone has a phone and a pc, I think it makes sense*". Nonetheless, we must consider that due to work ethics and protocols, in an MDTM setting, this might not always be true. According to our observational sessions, in a remote setting, attendees usually only use one device to view presentations shared by peers. In some cases, there were users who were in their cars running from one hospital to another, and that used their smartphones to attend the meeting while moving, occasionally stopping when they wanted to actively participate. This makes it difficult not only to use our dual device setup, but also to highlight the most important type of visual content at each given moment and to find approaches to enhance the feeling of presence from and towards this type of remote participant. The latter is particularly challenging to our purpose, namely because it may create an obstacle for such remote participants to provide their input, ultimately hindering the MDTM's workflow.

Participants who took on the server role, using their laptop or desktop pc's only, pointed out that their physical screen setup made a difference in the system's convenience. For instance, participant 5 found the setup positive as he said, "*Having Zoom and the application on separate windows is positive, because I have two monitors, so I do not have to switch tabs*". On the other hand, participant 15 said, "*Maybe if everything were on one application, it would be best...I was alt-tabbing when I wanted to see others*". Considering that Zoom shows the webcam of whoever is talking in a small window overlay, essential awareness cues of seeing who is talking at a given moment are still upheld, even if a user cannot see everyone without tabbing.

The other 7 participants felt they would prefer a single application setup as that is how they usually work. Communication and webcams should be integrated into our prototype, but some participants argue that a larger device like a tablet would be preferred in this case. Participant 12 said, *"I think it would be easier to have all on a single screen and application as I usually only work on the pc. But it would have to be a tablet, a smartphone is too small".* In fact, such feedback is aligned with our initial design that had foreseen a tablet as our target device, but due to the constraints imposed by the pandemic, we could only test our prototype with participants using their own android smartphones.

When asked about their individual preferences and experiences, most participants found that controlling the images themselves was more natural to them (Median=4.5; IQR=1). Moreover, most users strongly agreed (37.5%) or agreed (31.3%) that this accelerated the speed of finishing the tasks at hand (Median=4; IQR=2). Such results suggest a preference towards version B of our prototype, namely because participants felt that they could "*share the workload*" , thus speeding up the process of reaching a common goal. This preference for an individual instance of the images at hand was also verified through the log files we collected from each participant. In both versions, participants primarily used their private individual workspace, in Solo mode, for all tasks.

The screen-sharing capability was seen as positive by all 16 participants. Most said that seeing another person's screen and what they were doing helped them better understand their explanations rather than only hearing and watching their faces. If a user draws something and all others can see it, it accelerates the collaboration process. One participant mentioned that: *It helps a lot, mainly because when working as a team, the fact we can see the screen of the other people enables us to share ideas better*.

In version B, logs suggest that participants made more use of the screen-sharing tool, which may be explained by the fact that in version A they all shared the same imagery instance and would instead cooperate verbally with the user controlling the imagery rather than streaming each other's screens.

Two participants reported they felt some differences between the collaboration of co-located and remote participants. Participant 6 was in a co-located setting and felt it was somewhat easier to collaborate with the user in the same room as they could show them their screen in-person but felt no significant differences to using the screen-sharing with remote users. The participant said, "*I was sitting next to the other* [local] *participant, it was easier to communicate and show my screen, but using collab mode was also no problem for interacting with remote persons*". Participant 9 felt that local users had more ease than remote users due to occasional system delays, "*I felt local participants had it easier at times, due to occasional system delays*".

Participants agreed that the simultaneous use of the application facilitated the collaboration process, rather than each person working alone and sharing their findings at a later stage. All participants strongly agreed they felt part of the group and participated in the collaborative process of completing the tasks (Median=5; IQR=1).

Improvement suggestions of users regarded minor design changes and system performance enhancement. For example, some participants suggested changing the image slider into two arrows which instantly change to the following or previous image. However, considering an MDTM setting where large datasets are used, arrows might not be practical, and an image slider is widely adopted for navigating medical imagery in most applications to date. Further suggestions included adding more visual guides to annotate where the images are situated on the slider to simplify finding a specific image. Participant 21 said: *"The slider gives the impression of that there is something continuous, but the number of images is discrete... you cannot see when a certain image stops and another one begins... so I think adding some range indicators or some other sort of referencing where images are would be good"* .

As it stands now, the slider does not adapt in dimension in relation to the size of the dataset loaded and presents no visual indications for where a specific range of images is.

Regarding performance improvements, the occasional delays of Version B compared to Version A comes from the added load on the system to provide individual image instances to all participants and must be mitigated by improving encoding and decoding of streamed data to others.

While these sessions cannot fully simulate the interaction of an MDTM, they allowed us to gather relevant feedback on the system's functionality, ease of use, and applicability to a group setting, without hindering the actual setting of a time-constrained medical meeting. In the following section we will discuss some of the limitations we faced in our evaluation.

6.1 Limitations

While not negatively impacting an MDTM with our evaluation process, given the fact that these sessions were completed with groups of laypeople who were not entirely familiar with each other, specifically regarding work-related interaction, we were limited in the observational value that social interactions between them gave us, when compared, for instance, to an established medical team. Furthermore, the varied range of internet connections from our participants, ranging from very good to poor, provided issues regarding system performance and introduced a technical limitation to our evaluation in a way we did not foresee. This issue was further amplified due to the use of a free-tier server from Amazon Web Services, which introduced a bottleneck into our bandwidth for server-client communication. Nonetheless, this was our only viable solution, given our resources at the time. Moreover, we had to settle for the use of personal devices, which did not interfere much in the case of computers. However, concerning handheld devices, participants used phones of diverse ages, sizes, and shapes. Ideally, we would have wanted participants to use tablet-sized devices, which was the screen size our interface was intended for, but we were unable to provide these due to logistical reasons.

Given these limitations, if we could have proceeded differently, we would have provided our participants with our own test devices and made an effort to ensure a strong internet connection for all and improve on our networking bottleneck regarding client-server communication.

7 Conclusions & Further Work

In recent years, and accelerated by the ongoing pandemic, medical teams have adopted workflows that involve working remotely. With this work, we have developed and evaluated a prototype technology for supporting these emerging needs for hybrid collaboration in MDTMs. Prototype evaluation and semi-structured interviews with groups of lay people provided insights into how our system improves collaboration and what further improvements can be made when considering an MDTM setting. The simplified interface coupled with visual tools that allow users to communicate their ideas better has proven to be a valuable contribution to group discussion.

Given the goals we set for our work, our evaluation results indicate that we successfully created a cost-effective and portable prototype that improves hybrid collaboration for medium-sized groups and received encouraging feedback regarding our research question regarding image control for various users. We learned that this added image control can speed up tasks and boost individual contribution to a meeting, potentially improving a meeting’s workflow. Unfortunately, we could not test this in an MDTM setting yet.

Based on the results of this work and further building upon our solution, we can introduce updated versions of our prototype into a medical setting to potentially improve communication and collaboration, leading to safer and faster medical decisions with a positive impact on patient outcomes. Our primary future goal is to evaluate this improved system with our target audience, medical specialists in a MDTM setting. Considering the limitations we faced during evaluation, an essential first step would be to improve on the network bottleneck experienced. Furthermore, given the positive feedback of our interface's usability during evaluation, we consider further fine-tuning our tools and awareness cues during screen-sharing a valuable improvement to our system. Additionally, we consider the future inclusion of 3D models to complement traditional 2D imagery to further aid communication between specialists by following the design philosophies of presented research.

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