Assessing the Feasibility of using Augmented Reality to Visualize Interventional Radiology Imagery

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Keywords: Medical Visualization, Augmented Reality, Interventional Radiology, Surgery, Human Computer Interaction.

Abstract: Image-guided procedures, such as those in radiology, are frequently reliant on data which is visualized on traditional monitors. In an operating theatre, these monitors are often placed at poor ergonomic positions, causing physicians to rotate their heads to the side while their hands are working before them. This study seeks to investigate whether visualizing data on an augmented reality headset that projects an image in front of the participant will reduce task-time and increase efficiency. The primary purpose behind this study is to alleviate neck and back pain in physicians performing data/image guided procedures. A number of augmented reality headsets were tested in a clinical setting and a number of experiments were undertaken to test the viability of this technology in an operating theatre. The experiment consisted of comparing the use of an augmented reality headset against a computer monitor while performing tasks that required similar hand eye co-ordination to that needed during a surgery. The research hypothesized that the use of an augmented reality headset would increase accuracy and efficiency; while decreasing eye fatigue and neck/back pain.

1 INTRODUCTION

Interventional Radiology (IR) is characterized by minimally invasive procedures which are guided by images such as Computerized Tomography (CT), fluoroscopy and ultrasound. These visualization modalities allow interventional radiologists to guide small instruments through the body in hopes of avoiding invasive open surgeries.

Vascular Interventional Radiology (VIR) is a subfield in which endovascular disorders are treated using catheters, typically guided through fluoroscopy. Peripheral artery disease, deep vein thrombosis, and abdominal aortic aneurysms are examples of some of the conditions treated through VIR.

VIR is one of the fastest growing fields in radiology as it combines surgical procedures with real time medical imaging and visualization. In order to accomplish this, special operating suites in the hospital have been designed with live diagnostic imaging (fluoroscopy) in addition to the standard surgical equipment. In these operating suites several large monitors surround the room to display the live data from the scanners.

Physicians wear heavy protective vests while they operate. These surgeons watch the images come on the screens as they thread catheters through the patient's vascular system (BSIR, 2017).

Due to the need for multiple large pieces of equipment to be installed within the operating suite, space is at a premium. Often, the monitors displaying VIR data and images are situated away from the physician's view of the patient and catheter controls, causing the physician to consciously keep their hands in the right position while their view is, in some cases, at 90 degrees, or even behind their view of the patient. This issue is unfortunately common, surgeons often have to coordinate their movements with monitors in distant locations while trying not to damage the patient, an example is shown in Figure 1. It is delicate work that can easily go wrong (Shinohara, 2015).

Due to the heavy vests that must be worn and the badly positioned monitors, many surgeons using VIR present neck and spinal pain and injuries from constantly turning to see the images (Sacks et al, 2003). Not only does this present a health risk for the surgeon, but it creates a larger risk in the patient as erroneous movement of the catheter can lead to injury or potentially death.

Bartlett, C., LeRoy, N., Schofield, D., Ford, J. and Decker, S.
Assessing the Feasibility of using Augmented Reality to Visualize Interventional Radiology Imagery.
DOI: 10.5220/0008947701690176
In *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020) - Volume 3: IVAPP*, pages 169-176
ISBN: 978-989-758-402-2; ISSN: 2184-4321

Figure 1: A surgeon rotates to view data on a monitor.

Common ergonomic problems during IR include (Shinohara, 2015) :

- Neuromuscular fatigue due to heavy lead protectors.
- Inappropriate work postures from unfavourable arrangements of imaging equipment and their displays.
- Impaired manoeuvrability due to placement of imaging equipment and their displays.
- Eyestrain due to dim lighting.
- Neuromuscular fatigue during small calibre catheter placement.
- Lack of intuitive usability and standardization of IVR devices and their instruction manuals.

Shinohara (2015) specifically stated that the configuration of the X-ray apparatus, displays and the procedural table in the operating theatre usually cannot be freely arranged, forcing the physicians to manipulate the devices and their posture to ergonomically poor positions.

This paper describes work undertaken to alleviates the risk of injury during VIR operations, increase perceived accuracy and precision, and potentially decrease the surgical duration through the introduction of an Augmented Reality (AR) based visualization system into the operating theatre.

1.1 Medical Applications of AR

The use of VR has been widespread in the medical field over the past few decades. The key application area has primarily been in the realm of training simulators. Clinicians can learn crucial perspectives on surgical anatomy and repeatedly practice surgical procedures until they gain the required skills before performing surgery on 'live' patients. A number of commentators have stated that this educational technology is potentially as important to surgery as the flight simulator is to aviation (Satava, 1993; Ahlberg et al, 2002; Gallagher et al, 2005).

In recent years, many companies have announced new AR products, specifically for the medical field and the use of AR in many other fields of surgery continues to be reported (ITN, 2017; Fritz et al 2012). AR surgical applications have been reported in the fields of maxillofacial surgery (Badiali et al, 2014), dental surgery (Wang et al, 2014), soft tissue surgery (Mountney, 2014), and endoscopic surgery (Ishioka et al, 2014).

The use of AR in surgery is not a new idea, the use of such systems have been discussed by academics for many years. The first 'see-through' HMDs used for medical purposes were monocular optical see-through devices which were typically used to display a patient's vital information (Keller, State, and Fuchs, 2017).

Chen et al. (2015) used an optical 'see-through' HMD for surgical navigation. Using this AR surgical navigation system, the surgeon can view a fused image that virtually displays anatomical structures such as the soft tissue, blood vessels and nerves within the intra-operative natural environment. A preoperative CT scan is performed on the patient, and the obtained images are segmented so that 3D models of the hard and soft tissue can be reconstructed. The AR system is then used to integrate the virtual model of the patient's anatomical structures with the real anatomical structures to aide in surgical navigation.

Diaz et al. (2017) undertook an interesting project using the Google Glass display for image-guided brain tumor resection. During brain tumor removal, neurosurgeons look back and forth between the surgical field and the navigation display which can create a delay or, in worse cases, surgical error. The resulting video feed was transmitted wirelessly to the Google Glass display. The researchers did note that cognitive attention could not be simultaneously given to the operative field and the Google Glass display, due to the fact that this display technology cannot superimpose its image onto the surgical field, forcing users to switch from one view to the other.

Although, at present there is no reported work on real-time visualization of IR data using AR techniques in a surgical situation, there is comparable work being undertaken with Magnetic Resonance Imaging (MRI) data. Marker et al (2017) report on work undertaken on MRI-guided paravertebral sympathetic injections utilizing AR navigation and 1.5 T MRI scanner. The underlying premise for using imaging guidance is accurate needle placement in order to provide optimal treatment while avoiding problems. The study showed that the combination of image-overlay navigation and the image quality of interventional MRI at 1.5 T was able to readily define accurate needle paths and provide safe needle guidance in all cases (Marker et al, 2017).

The only similar project to the work described in this paper was undertaken by the Maryland Blended Reality Center (MBRC) at the University of Maryland. In 2018, MBRC performed a live demonstration where a trauma surgeon at the Cowley Shock Trauma Center, performed an ultrasound examination of a patient's heart using AR displayed on a Microsoft HoloLens. The success of this demonstration led researchers to state that they believe that AR and VR will become a widespread technology used in surgery, making procedures simpler and easier (Salopek, 2018).

2 MONITORING

The goal of this project is to improve the current use of IR with vascular surgical procedures, leading to fewer mistakes and patient complications. The research project aims to reach this goal by reducing the risk of injury during IR procedures by increasing surgical accuracy and precision. This will be achieved by decreasing the duration in which the radiologist is looking away from the patient by introducing an AR based visualization system into the operating suite.

2.1 Data Collection

Initially, data was collected on the existing conditions under which the surgeons work. Presently, radiologists at Tampa General Hospital work while viewing the IR images on a monitor located on a swinging arm within the operating theatre. Initial data collection was undertaken in two discrete phases.

The first phase involved monitoring VIR procedures and collecting data on how the physician was positioned when they looked at the monitor with the live IR feed. The second phase involved timing how long the physician looked at the fluoroscopy feed on the monitor with a stop watch.

The purpose of this data collection was to develop a baseline which could be used to demonstrate whether the AR headset could significantly reduce the time the physician spends viewing the monitor feed.

2.1.1 Physician Position

Four lengthy VIR procedures were monitored and the radiologist's viewing of the monitor containing the live visualization was recorded. The radiologist's head position, whether their hands were working, whether they were standing upright or leaning over, and the monitor's position in relation to the radiologist were all logged during each procedure (Tables 1 and 2).

Table 1: Head rotations during each procedure.

Procedure Number	80° Rotation	60° Rotation	55° Elevation
1	10	5	0
2	0	0	5
3	5	1	0
4	16	15	0
Total	31	21	5

Table 2: Time viewing monitor during each procedure.

Procedure Number	Surgery Time	Viewing Time	Working & Viewing
1	2h 35m	3m 54s	3m 0s
2	1h 26m	12m 35s	7m 33s
3	1h 15m	12m 28s	6m 12s
4	2h 53m	13m 29s	8m 42s
Total	8h 9m	52m 26s	25m 27s

2.1.2 Physician Timing

Four additional, shorter procedures were viewed while the physician's time spent looking at the live visualization was recorded using a stopwatch. Recording began when the physician's gaze shifted towards the live monitor feed and ended when the physician's eyes shifted to any other object within the room (Table 3).

Table 3: Time viewing monitor during each procedure.

Procedure Number	Surgery Time	Viewing Time
5	28m	8m 11s
6	30m	12m 44s
7	20m	6m 15s
8	28m	4m 42s
Total	1h 46m	31m 52s

The State University of New York at Oswego and the USF Health Morsani College of Medicine at the University of South Florida in Tampa experimented initially with two AR visualizations modalities:

- A micro-projector that could sit on a stable surface and project an image onto the patient.
- A monocular headset that could be easily moved around the physician's line of vision.

Due to problems with both systems, it was decided to take a step back, identify a different AR syatem and undertake some formal and rigorous experimentation to empirically demonstrate the benefits of introducing this technology into and operating suite to view real time IR data.

3 EMPIRICAL TESTING

In deciding on the next steps to take, the team investigated the work of the team from the MBRC, viewing ultrasound visualisations on a Microsoft Hololens (Salopek, 2018). After extensive discussions with the medical faculty and surgeons in Tampa, it was decided to take a similar path and investigate the use of a Hololens to visualize real time AR data during surgical procedures.

Initial trials were undertaken with the Hololens allowing the surgeons to test the equipment and discern whether they thought they could use it, or if they would find it too bulky and obtrusive. Each radiologist who tried it, gave a positive review, so it was decided to proceed on this project using a Microsoft Hololens.

Hence, the HMD that was selected for this phase of the project was the Microsoft HoloLens (1st gen). This was chosen due to its compact size, low weight (579g), Wi-Fi and Bluetooth connectivity, see-through holographic lenses, high output resolution (1268x720), and battery life of approximately 2-3 hours. In addition, the HoloLens had the ability to place projection-based AR anywhere within the physician's line of sight.

Following the problems experienced with the Brother AiRScouter AR headset in a surgical setting it was decided that the team should undertake some empirical work to demonstrate the effectiveness of this equipment in a surgical setting. It was decided to run a sequence of experiments using an AR based system, asking participants to undertake a series of tasks that simulated the clinician viewing the imaging feed, the patient [their task], and their hands with minimal head movements. This study would then compare the usage of an AR headset to complete the tasks in order to evaluate whether the use of an AR device would increase perceived accuracy, as well as, speed efficiency of the tasks undertaken. We hypothesize that the AR HMD will increase efficiency, by decreasing timed tasks and neck/back discomfort.

3.1 Experimental Method

These experiments attempted to test whether the HoloLens will increase efficacy in the specific Tampa operating suite under consideration. In this operating suite, surgeons consciously keep their hands in the right plane while frequently turning their head 60˚ to 80˚ away from the patient. A mock operating suite was constructed to simulate the conditions under which the surgeons operate (Figure 2).

During the experiments undertaken, participants were requested to sit facing the workspace, monitor A was set up above the workspace and was intended only to be used in the high-level task phase of the experiment. Monitor B is meant to imitate the VIR monitor a surgeon would turn towards and was used during both low-level and high-level tasks. Monitor B was set up at an angle of 80˚ from the view towards monitor A to simulate the operating suite conditions. A video camera was set up to capture and record the movements each participant makes while undertaking the experimental tasks.

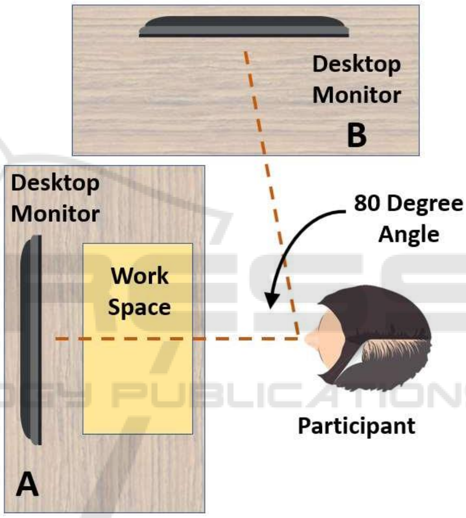

Figure 2: Experimental setup, a mock surgical suite.

The experiments were designed to require participants to undertake tasks in which they would need to coordinate their hand movements using information displayed on a monitor and/or the AR headset to determine which is more efficient and allows for greater levels of focus on the task at hand.

In order to test whether the AR headset visualization would outperform data displayed on a static monitor (the control group), two different skilled tasks were created, a high-level task and a low-level task :

The *high-level task* is meant to require a sense of direction, where navigation instructions come from data and images displayed in a visualization that is displayed separately to the task being undertaken. This high-level task has the participants navigating and completing a maze on Monitor A while the maze layout is provided on either the Hololens or Monitor B located at an angle of 80˚ on their right.

The *low-level task* was intended to be simpler than the high-level task, but to involve a higher level of haptic, physical manipulation – simulating the physical operations a surgeon must perform while operating. Here the participant will construct a Lego object on the workspace, while the instructions are provided on either the Hololens or Monitor B located at an angle of 80˚ on their right side.

Each participant undertakes both tasks, one with instructions being displayed on an AR headset, the other getting instructions from monitor B. Half the participants use the AR headset for the low-level task and Monitor B for the high-level task, the other half switch the visualization modalities.

The dependent variables within these experiments are the time taken to complete the tasks, the number of times the participants reference monitor B, and the time's spent looking at the visualisations rather than at the task in hand.

This constructed environment will hopefully simulate the radiology environment in such a way that results from these tasks will not only correlate with results found during testing in Florida but also provide a justification for the introduction of this technology into a surgical setting.

3.1.1 High-level Experiment

The high-level experiment utilized an immersive dungeon game (Figure 3). Half of the participants completed the high-level task using the HoloLens, while the rest were asked to complete the tasking using monitor to get instructions and navigation information.

When using the AR HMD, the participant was guided step by step, using several visual cues, to complete the navigation task through the maze.

A series of contextual slides containing navigation information were displayed and viewable to the participant through the Hololens, this information floated above monitor A, its position varied slightly depending on the orientation of the participant's head while undertaking the task. In the screen modality, the contextual navigation information was displayed on monitor B.

When viewing through the AR HMD, the participant was guided step by step, using several visual cues, to complete the navigation task through the maze.

A series of contextual slides containing navigation information were displayed and viewable to the participant through the Hololens, this information floated above monitor A, its position varied slightly depending on the orientation of the participant's head while undertaking the task. In the screen modality, the contextual navigation information was displayed on monitor B.

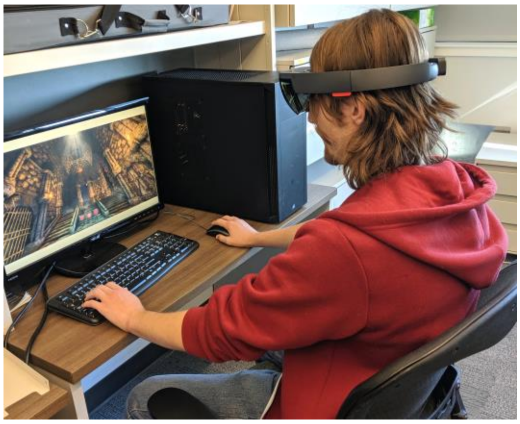

Figure 3: A participant using the game.

Figure 4: A Participant using the Lego.

3.1.2 Low-level Experiment

For the low-level LEGO task, participants are asked to follow a step by step visual guide that, if followed correctly, builds a LEGO bird in the workspace provided in front of them (Figure 4).

A series of contextual slides containing construction information were displayed and viewable to the participant through the Hololens, this information floated above monitor A, its position varied slightly depending on the participant's head orientation while undertaking the task. In the screen modality, the construction information was displayed on monitor

Table 4: Experimental results, average completion times compared to time viewing visualization.

	Game (Monitor B)	Game (Hololens)	Lego (Monitor B)	Lego (Hololens)
Average Time (s)	617.5	650.3	258.8	350.0
Number of Tasks	17	17	14	14
Time per Task (s)	36.3	38.3	18.5	25.0
Average View Time	2.87	4.35	3.31	4.07
Number of Views	37	29	39	27
Total View Time (s)	138.4	144.9	128.5	115.9
Viewing Ratio (%)	21.1	15.11	51.9	33.9

Table 5: Results of t Test comparing task times, number of views and view time (%) for the game task.

	Modality	Mean	Std Dev	DF	t Stat	t Crit	p
Total Time	Monitor	617.5	231.5	10	-0.28	2.23	0.78
	Headset	650.3	169.4				
Number of Views	Monitor	38.8	26.8	10	0.79	2.22	0.44
	Headset	29.5	10.0				
Total View Time	Monitor	138.4	173.2	10	-0.07	2.23	0.93
	Headset	144.9	105.8				
View Time (%)	Monitor	19.8	22.6	10	-0.11	2.23	0.909
	Headset	21.1	15.11				

Table 6: Results of t Test comparing task times, number of views and view time (%) for the Lego task.

	Modality	Mean	Std Dev	DF	t Stat	t Crit	p
Total Time	Monitor	258.8	58.5	10	-1.37	2.23	0.20
	Headset	350.0	151.6				
Number of Views	Monitor	39.0	8.2	10	2.32	2.22	0.04
	Headset	28.2	7.9				
Total View Time	Monitor	128.5	12.9	10	0.92	2.23	0.75
	Headset	115.9	30.8				
View Time (%)	Monitor	51.9	13.3	10	2.79	2.23	0.02
	Headset	33.9	8.5				

B. Discussion with medical professionals indicated that these two tasks would sufficiently replicate the navigation and haptic skills required during a surgical procedure.

3.1.3 Procedure

There were a total of sixteen participants in this study, who each undertook both tasks using a different information modality for each task. The average age of the participants was 22 and 66% of the participants were female. It was felt that although the number of participants was small, the sample size was large enough to provide meaningful results.

The data is discreetly arranged into four experimental conditions, for a 2x2 independent sample t test. The modality of the display method (AR headset, monitor B) was the between-subjects factor and the difficulty of tasks (high-level, low-level) was the within-subjects factor. The rejection level for all analyses was set at p = .05.

A questionnaire was provided post experiment and completed by every participant. This questionnaire measured device comfort, image quality rating and device satisfaction. It also measured the perceived speed, accuracy, and eye fatigue that the participant experienced.

4 RESULTS AND DISCUSSION

A summary of the results of the experiment are shown in Table 4. The average completion time of the low-level Lego task was lower than the completion time of the high-level Game task. This was due to the nature of the tasks themselves. The Lego task consisted of 14 separate steps whereas the Game task had 17 individual steps.

Participants viewed the AR headset visualization, on average, for longer than the image on the monitor, even when view times included the times taken for the participants to rotate their head to see the screen. This could be due to the unfamiliarity of the participants with viewing information in the Hololens or perhaps it took participants longer to focus and read information from the Hololens display.

The majority of participants looked at the monitor more often than looked at the visualization on the AR headset. It is difficult to understand why this occurred it could perhaps be because participants are used to glancing at a monitor, whereas looking at the Hololens screen was a more thoughtful action.

Participants viewed the Game visualization, on average, for less than the Lego instructions on each view. The time taken viewing the Lego instructions was high ranging from 34% of task time on the Hololens to 52% of task time on the monitor. Again this is thought to be primarily related to the nature of the task where participants had to spend more time understanding the complex construction information, rather than quickly checking their location on a map.

The visualization viewing time for the game task was similar on both the Hololens and monitor, with the monitor viewing time being slightly less. However, the average time spent viewing the Lego visualization on the Hololens was much less, as a percentage of task time, than the time spent viewing

Running a number of t tests on the metrics from the game task shows little significance between the monitor visualization and viewing the visualizations on the AR headset or on the monitor (Table 5).

This indicates that during the game task when using either an AR headset or a monitor :

- The difference in time taken to perform the game task is not significant.
- The difference in number of views of the visualization is not significant.
- The difference in the total time viewing the visualization is not significant.
- The difference in percentage of time spent looking at the visualization is not significant.

Running a number of t tests on the metrics from the Lego task however, shows some significance between viewing the visualizations on the AR headset or on the monitor. This indicates that during the Lego task when using either an AR headset or a monitor :

- The difference in time taken to perform the game task is not significant.
- The difference in number of views of the visualization is significant.
- The difference in the total time viewing the visualization is not significant.
- The difference in percentage of time spent looking at the visualization is significant.

A possible explanation for the significance in the different lower number of views was explained above, where participants are used to glancing at a monitor, whereas looking at the Hololens screen was a more thoughtful action, taken as and when needed.

The difference in the view time can possibly be explained by the time taken to rotate the head when looking at the monitor. If this is removed from the time looking at the screen, the two values would become closer and the difference less significant.

While it is interesting to look at the time taken with each modality, perhaps a more useful measure is whether the Hololens worked as effectively as the monitor as a visualization tool. Qualitative survey results which were rated on a 5-point Likert scale :

- Participants rated the Hololens comfort at 3.2
- Image quality of the Hololens at 4.2
- Image quality of the monitor at 4.4
- Eye fatigue with the Hololens at 3.6

5 CONCLUSIONS

This study aimed to alleviate the risk of injury during VIR operations, increase perceived accuracy and precision, and potentially decrease the surgical duration through supplementing the operating suite with an AR based viewing system. It is believed this would grant a clinician, a greater range of movement, decreased cognitive load and improved focus.

We found evidence that shows a significance regarding the number of times the participant's looked at the screen during the Lego task, which required the participants to understand a range of complex instructions (Table 6). Although the participants viewed the visualization on the Hololens less, they did look at the visualization for longer periods of time. This could have been affected by a participant's familiarization with using a monitor.

The time spent viewing the visualization during the game task was similar on both the Hololens and monitor. However, the average time spent viewing the Lego visualization on the AR headset was significantly less, as a percentage of task time, than the time spent viewing the monitor visualization. If the time taken to rotate the head to the monitor is factored in then the viewing time becomes equivalent.

The crucial aspect of this work involved determining the effectiveness of the AR headset as a replacement for the badly positioned monitor.

Participants rated the image quality of the visualization on the AR headset slightly lower than the monitor. A couple of participants complained that the HoloLens sat heavily on the bridge of their nose during the experiment. This is perhaps an alternative form of discomfort, replacing the back/neck strain experienced by the surgeons.

A few participants mentioned that there was some eye strain when trying to view the visualizations on the AR headset. Another limiting factor was that the virtual object rendered by the HoloLens may begin to fade out if participants move their head or do not have their view completely aligned. However, it should be noted that the head movements required to correct this problem involve only a few degrees of rotation.

However, it is perhaps important to note that overall, ten participants greatly preferred the Hololens to the monitor.

This experiment demonstrated the potential of our hypotheses, that the implementation of an AR headset as a visualization tool in a surgical setting could increase the efficiency of timed tasks and decrease neck/back pain among medical practitioners.

ACKNOWLEDGEMENTS

Many thanks to Bruce Zwiebel, MD and all the other medical staff from the Morsani Center for Advanced Healthcare in Tampa, Florida who donated their time.

We acknowledge the funding support of the SCAC and the Festa Fellowship Programs at the State University of New York.

Thank you to Brother International for providing the Brother AiRScouter-200B for the initial trials.

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