Evaluating the Benefit of Assistive AR Technology through Eye Tracking in a Surgical Simulation System

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Keywords: eye tracking, augmented reality, surgical training, surgical simulation, assistive technology.

1. Introduction

1.1. General Background

Modern surgery evolves rapidly towards minimal invasive surgery (MIS) where an increased number of procedures are performed through small-sized incisions, so-called, keyholes, made into the body. The surgeon introduces long and slender instruments through these keyholes and operates under visual feedback from a camera (endoscope) that is introduced through one of the keyholes. This technique is highly beneficial for the patient who, in general, suffers less, has smaller scars and recovers faster. For the surgeon these procedures are more difficult to execute. It takes considerable time to become proficient. Vickers *et al.* reported a learning curve between 250-350 procedures for radical minimal invasive prostatectomy (Vickers, 2009).

Robotics and assistive technology have been introduced to simplify MIS, but the development and associated cost is significant. Furthermore, there is little room for experimenting as for every small adjustment or addition, a long regulatory and accommodation process follows. Virtual and physical simulators can help speeding up the design process. These systems, and especially the virtual simulators, can help keep the cost for validation of new instruments, novel assistive techniques or robotics lower, as validation can take place *before* actually creating a physical embodiment of an instrument or mechanism. This work further explores *eye tracking* as a technology to help validate new developments in a dedicated trainer for a surgical procedure to treat the Twin-to-Twin Transfusion Syndrome (TTTS) a fetal complication affecting 15% of monochorionic twins.

The paper is built up as follows. After surveying the state-of-the-art of eye tracking for similar applications in subsection 1.2, the setup of the proposed system is introduced in section 2. Experiments are described and discussed in section 3. Finally, a concluding section 4 wraps up this report.

1.2. Eye tracking for validation of assistive AR

The aim of eye tracking is to acquire the vector of gaze and/or the movement trajectory of the eyes of the person who is observed. Eye tracking has been used by researchers to estimate cognitive processes for over 30 years now. At its early stages, eye tracking put a lot of restrictions on the person under investigation, affecting the reliability of estimation. For instance, the Yarbus recording device, one of the first devices for eye tracking, required the head of the subject to be completely fixed (Tatler, 2010). Nevertheless, technology has become more sophisticated and less intrusive since then, enabling real-time gaze estimation without affecting the process the person is performing.

At present, eye tracking has become a method that is mature enough for considering its use in training programs to help evaluate the progress of trainees. In combination with AR, MR and VR training systems, eye tracking allows a tutor to understand where the attention of the trainee is concentrated upon, thus opening up possibilities to interactively correct actions during a session or through post-processing provide more in-depth analysis and feedback. Eye tracking may also help controlling the user's gaze as it can initiate actions to re-focus to key points of the program. This approach is widely used in VR training and is reported to significantly decrease the learning curve. Wilson *et al.* proposed gaze tutoring as an alternative to movement tutoring. In the study, they compared learning curves of three groups: free-to-discovery subjects, who were free to discover how to solve the task on their own; gaze-trained subjects, who were shown a video of an expert performing the task with a footage of his visual control obtained from the eye tracker; and movement-trained subjects, who were shown the same video, but without a footage of visual control. Gaze-trained participants completed the tasks 55% faster, whereas movement-trained subjects only experienced a 32% reduction (Wilson, 2011). Ferrari *et al.* reports using eye tracking based navigation to maintain the attention of the student in an attention bias modification study. The study aimed to change the selective attention of participants by letting them perform a series of trials, where their attention was controlled and navigated by eye tracking (Ferrari, 2016). Chetwood *et al.* propose the use of eye tracking navigation to train laparoscopic surgery. This approach is based on collaborative eye tracking, where the point of regard of the supervisor is projected on the laparoscopic screen of the trainee, thus providing real-time guidance (Chetwood, 2011).

Another important use for eye tracking is as a validation tool of the study program itself, such as interface design, cues effectiveness, etc. Multiple studies report increase in efficiency of user interfaces (UI) with the help of eye tracking validation. Barkana *et al.* used eye tracking to improve the surgical interface for kidney tumor cryoablation. Through eye tracking the decision-making process can be halved (Barkana, 2013). Toni *et al.* validated a pediatric patient training system investigating the effect of using life-like animations of patients and identifying the most optimal layout to attract attention to keypoint areas (Toni, 2014).

Along similar lines in this work, eye tracking is used to evaluate the benefit of novel guidance information that is displayed on the user's screen. The running hypothesis would be that if trained surgeons make use of this guidance information while conducting the experiments, this would mean that it could be useful to consider incorporating this guidance information in the real world as well.

2. System Overview

2.1. Virtual TTTS simulator

The setup of the TTTS trainer can be seen in Figure 1. On the right, a robotic arm representing a fetoscope with embedded laser fiber can be seen. The trainee is to introduce this fetoscope through a narrow incision into the patient's uterus. He/she is to navigate the instrument to the placenta and is to laser ablate a number of vessel on the placental surface. A foot pedal positioned below the table is pushed to activate the laser. The user input (instrument motion and pedal state) is transferred to the simulation where the view, as seen by the fetoscope, is updated. The simulated view is visible on the left of Figure 1. This setup closely resembles the layout in a conventional TTTS surgery. As such a trainee can get used to the movements that would need to be made during a real intervention. Because the placenta can be in difficult to reach locations, the instrument might be turned in such a way that movements and the way they are seen on screen are not intuitive anymore. This is one of the main challenges that makes this surgery very difficult to perform.

An attempt is made to recreate an environment that visually resembles the reality closely. One particularly complex part of the operation is the limited visibility because of working within the amniotic fluid. This creates a grey fog-like effect. There is one light source available with controllable intensity that is used to illuminate the scene. A circular dot in the centre of the camera view represents the location of the laser. The pointing laser works as an aiming mechanism for coagulation in reality and has thus the same function in the simulator. When the pedal is pressed, coagulation takes place. The trainee will see a white burn mark on the surface. The area and intensity of this burn grows proportional to the time that the pedal is pressed.

Several settings are foreseen to adapt the scene for a specific type of surgical scenario. For example, the light intensity of the scene can be increased or decreased, the turbidity of the amniotic fluid and the presence of floating particles can be controlled to make the training task more challenging or more closely approach a real-world scenario. Since the placenta can be in many different positions, one can place the placenta at a desired position. All the settings can be saved into a file on the system and loaded at a later time.

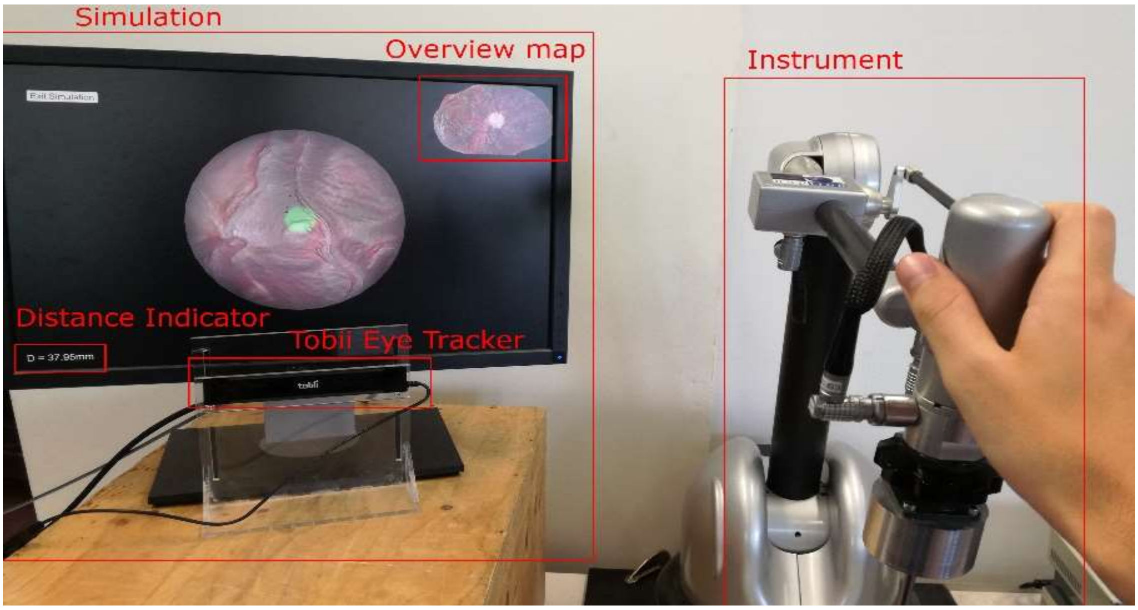

Figure 1. Setup of TTTS trainer; left: screen with eye tracker and visual cues; right: fetoscope handle simulated by the handle of a robotic arm that tracks the user movements; not visible foot pedal below the table.

There are two modes available, a free mode and a training mode. The free mode is meant to be used by a trainer who can investigate a set of the settings and save them. The trainer can use this mode to design training tasks. He/she can use the task menu and his/her mouse to place circles the trainee will then have to laser and then connect them by a continuous ablation path. Another task is designed as follows: upon placing a circle a random letter is inscribed in the circle. The trainee will then have to ablate circles following a sequence of letters. When one target has been coagulated satisfactorily, the next letter in the sequence, appears as it was inscribed. The different settings and tasks can be loaded in the training mode where these settings cannot be altered.

Eye tracking is being implemented to analyse how much the user is looking at certain areas of the screen. Especially it is used to see if the assistive features of the simulation are being used, whether they have no effect at all or whether they are even distracting to the user. These features are explained next.

2.2. Assistive technology under test.

There are two features under test: *1)* an indicator that reports the distance between the instrument tip and the placenta; *2)* a map that provides an overview of the placenta. Both features can be seen on in the respectively left bottom and right upper corner of the screen. At present this information is not available to the surgeon, but the distance could be measured by a dedicated sensor that could be embedded in the fetoscope and the map could be created online by a so-called mosaicking algorithm that stacks small-sized images taken from the fetoscope and builds these – much like a mosaic – up to a large placental image.

The distance information is important the instrument is sharp and one should at all cost try to avoid piercing it through the placenta. At such time the operation would be considered to have failed as the visibility will be completely blocked by the blood that comes free. Secondly, an ideal distance to laser anastomoses is estimated to be about 10 mm distance, the distance information could simplify maintaining this distance.

During a surgery, the surgeon has to memorise the points that have to be treated with the laser and remember the points that have been treated. By simply displaying this information on an overview map this task could become much easier. The map could also help planning the navigation to next targets.

These features are not available in surgery today. Their success and popularity will depend on whether the surgeon will take the liberty to adjust his gaze during the intervention to observe these features. To avoid finding this out in the operating room after a huge development investment, here we propose to use a virtual simulator to investigate the said features and to make a more profound decision regarding their potential and the value of further developing them. In the following section experiments built around a Tobii X2-30 Compact eye tracker are described.

3. Experiments

3.1. Description of the experimental protocol

First, a short analysis of the eye tracker's accuracy was performed. The accuracy depends both on the distance to the person as well as on the gaze angle, the angle between tracker and user's gaze. First, the tracker has to be calibrated using Tobii's calibration tool to get an accurate tracking. The error after this calibration is documented in the user's manual of Tobii (Tobii Technology AB14). The user will be at a 60 – 65 cm distance, resulting in a gaze angle accuracy of 0,2° to 0,6°. The gaze angle accuracy is reported to be same for ideal conditions up to a 30° angle, this gives an accuracy of 0,5°. Angles further than 30° are not listed, but Tobii states the angle should not exceed 36° to gain optimal tracking. A 24 inch monitor is used with a 16:10 aspect ratio which is reported as to fall within this 36° angle limit. So the maximum tracking error that can be expected would be approximately 1,1° by adding both errors. An experiment was designed to confirm the accuracy of the tracker experimentally. The user is asked to look at different targets with known pixel coordinate, tracking coordinates are collected and a root mean square (RMS) error calculated.

After confirming the accuracy, the experiments of the value of the assistive features during TTTS surgery are performed. A singular researcher, who has prior experience with fetoscopy, was used to perform these experiments. The two different tasks that are to be performed are described in section 2.1. The user does not need to identify the anastomoses, one can simply search and follow the targets that are placed on the provided placenta image. Five different experiments are conducted: three tasks consist of lasering circles and connecting them by a path (further mentioned as "Lines"), for the other two the user needs to laser targets in a sequential order (further called "Seq"). While the task is being performed an eye tracker mounted at the bottom of the screen () is used to estimate what the user is looking at. This information is then analysed. The percentage of time spent looking at a certain user interface elements is computed. Secondly, a *heatmap* is created that provides a visual rendering of the points where the user has been looking at.

3.2. Discussion of experimental results

From the accuracy tests an RMS error of 54,34 pixels for the X coordinate and 56,56 pixels for the Y coordinate was found. This error is used to provide a margin around the user interface elements, so that there is no overlap in their bounding boxes. This then simplifies association of the user's gaze to a certain feature.

The combined heatmap of the experiments is plotted in Figure 2. The figure shows clearly that the main focus is in the centre of the screen with some attention going towards the distance indicator and the map. In Table 1 the percentages of which element the user looked at during the experiments is provided for each experiment. The experiment suggests that when ablation targets are separated further the trainee resorted more to the use of the map. When targets are closer to each other the user may have found it more convenient to quickly scan around instead of moving the gaze up to locate the map. From talking with the user, it was found that the distance indicator is especially used when closing in to a correct lasering distance. When compared to each other, the map may be used more, as navigation from one point to another point takes more time than keeping a laser at a desired distance.

Table 1. Summary of experimental results; in both tasks the main focus lies at the screen centre, while other elements draw attention based on the design of the task.

	Lines 1	**Lines 2**	**Lines 3**	**Seq 1**	**Seq 2**
Overview Map	2.361%	6.87%	14.038%	15.038%	0%
Distance Indicator	3.127%	2.021%	3.472%	2.506%	1.657%
Centre of Screen	94.512%	91.109%	82.483%	82.456%	98.343%

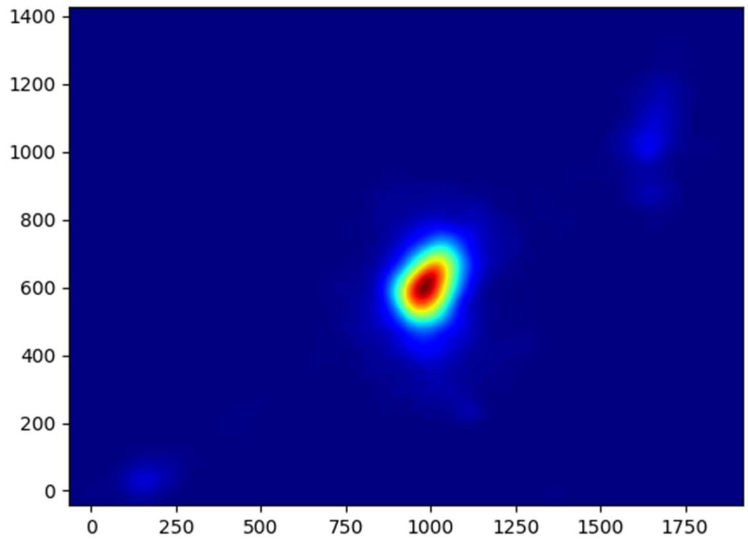

Figure 2. Combined Heatmap of all experiments; centre of the screen has main focus; distance indication on the bottom left and map with overview on the top right both gained attention; x and y axis in pixels.

4. Conclusion

This work aims to validate the use of assistive AR technologies for TTTS surgery. Two assistive technologies are investigated via a virtual simulator: a distance indicator and an overview map of the placenta. Both features were validated using an eye tracker. Firstly, it can be concluded that the accuracy of the tracker is sufficient to be able to distinguish what element of the screen the user is looking at. Secondly, from the data, it can be seen that the proposed assistive technologies have been used. The time spent looking at these elements is relatively low so it appears that at such level it is not distracting from the main task which is still happens in the centre of the screen. To conclude it appears that there is a good potential for both assistive technologies under test. The map could help navigation between points as well as reducing the mental load for the surgeon who does not need to memorise anymore all the details of the surgery. When unsure, the distance indicator may offer more certainty as to what depth has been reached and how far this is from an ideal laser distance. To confirm this potential more extensive experiments are needed however with more participants including expert surgeons. A follow-up study would link also the outcome metrics to the information obtained from the gaze as it is still to be confirmed that the extra information – even if used by the operator – effectively results in a better surgical outcome which is of course the ultimate goal.

References

Bickmore, T. (2014). Intelligent Virtual Agents: 14th International Conference, IVA 2014, Boston, MA, USA, August 27-29, 2014. Proceedings (Lecture Notes in Computer Science, 8637). Cham: Springer International Publishing : Imprint: Springer.

Chetwood, A., Kwok, S., Sun, A., Mylonas, K., Clark, L., Darzi, G., & Yang, P. (2012). Collaborative eye tracking: A potential training tool in laparoscopic surgery. *Surgical Endoscopy, 26*(7), 2003-2009.

Erol Barkana, Duygun, Açık, Alper, Duru, Dilek Goksel, & Duru, Adil Deniz. (2014). Improvement of design of a surgical interface using an eye tracking device. *Theoretical Biology & Medical Modelling, 11 Suppl 1*(Suppl 1), S4.

Ferrari, G., Möbius, M., Van Opdorp, A., Becker, E., & Rinck, M. (2016). Can't Look Away: An Eye-Tracking Based Attentional Disengagement Training for Depression. *Cognitive Therapy and Research, 40*(5), 672-686.

Tatler, B. W., Wade, N. J., Kwan, H., Findlay, J. M., & Velichkovsky, B. M. (2010). Yarbus, eye movements, and vision. *I-Perception*, *1*(1), 7–27. http://doi.org/10.1068/i0382

Thomas, L., & Lleras, E. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. Psychonomic Bulletin & Review, 14(4), 663-668.

Vickers, A. J., Savage, C. J., Hruza, M., Tuerk, I., Koenig, P., Martínez-Piñeiro, L., ... & Guillonneau, B. (2009). The surgical learning curve for laparoscopic radical prostatectomy: a retrospective cohort study. The lancet oncology, 10(5), 475-480.

Wilson, M., Vine, R., Bright, S., Masters, J., Defriend, E., & McGrath, R. (2011). Gaze training enhances laparoscopic technical skill acquisition and multi-tasking performance: A randomized, controlled study. *Surgical Endoscopy, 25*(12), 3731-3739.

Tobii Technology AB, User's Manual Tobii X2-30 Eye Tracker, Version 1.0.3, June 2014, Available: https://www.tobiipro.com/siteassets/tobii-pro/user-manuals/tobii-pro-x2-30-eyetracker-user-manual.pdf