Mixed Reality Bloodstain Pattern Analysis Simulation Training System

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ABSTRACT

Bloodstain Pattern Analysis (BPA) is the study of the size, shape, and distribution of bloodstains found at a crime scene. It is a crucial method that can serve to guide the direction of investigations or validate statements of accounts gathered in the course of investigations.

Conventional BPA training requires the creation of mock crime scenes and one such way is to use flipchart papers mounted onto walls and different surfaces, which are then splashed with animal/synthetic blood to recreate different types of bloodstains and training scenarios. This method is not only time-consuming and labor intensive but also lacks precision, as humans are not robots, and slight changes in the force and angle used to create these patterns would cause deviations to the eventual size and distribution of bloodstains observed.

In order to address these limitations, we leveraged on Mixed-Reality technology to develop a simulation training system that could augment and improve training for Crime Scene Specialists (CSS) while providing significant savings in time, cost, and manpower compared to conventional BPA training methods.

The system achieves the aforementioned through the use of an Mixed Reality headset that projects holographic images onto the user's field-of-view to create a realistic virtual crime scene with different bloodstains that trainees could interact with and analyze. This allows trainees to build their confidence and familiarize themselves with using investigative tools. These virtual crime scenes can be easily created or modified by the instructors to provide variation in training and assessment.

The results from assessing the Mixed Reality system demonstrate that the system is highly effective in training forensic professionals.

ABOUT THE AUTHORS

Terence Teng is a specialist in the field of training simulation and Extended Reality technology with more than ten years of experience working alongside government units and members of the industry to develop training simulation systems. He is currently a Lead Engineer for Modelling & Simulation at the Human Factors & Simulation Centre of Expertise (HFS CoE) from the Home Team Science & Technology Agency where he is actively involved in the conceptualization and management of training simulation projects in the Extended Reality domain.

Dr Saravana Kumar obtained his PhD in Electrical and Computer Engineering from the National University of Singapore (NUS) and has held various research positions at NUS, Agency for Science, Technology & Research (A*STAR) and the Ministry of Home Affairs. He is currently a Deputy Director for Modelling & Simulation at the Human Factors & Simulation Centre of Expertise (HFS CoE) from the Home Team Science & Technology Agency. Dr Saravana spearheads key research initiatives in the areas of extended reality, serious games, high fidelity simulators and constructive simulation to enhance operational performance and to comprehensively address workload, fatigue and vigilance issues faced by Home Team officers. He also partners with academia, industry, and strategic government partners to design, prototype and conduct proof-of-concept trials to test and validate cutting edge operational, training and proactive ergonomics assessment capabilities.

Derek Chong currently holds the appointment of Project Manager, Human Factors and Simulation Centre of Expertise (HFS COE) of the Home Team Science and Technology Agency (HTX). Under the research and innovation charter of the modelling and simulation pillar, Derek researches and implements leading-edge technologies in modelling, simulation and human performance analytics to digitize, augment and measure the human factors and performance sphere of training and operations in close collaboration with the various Home Team Departments.

Lei Pei Pei currently holds the position of Assistant Director, Forensics Division ("AD FD") at the Forensics Centre of Expertise in the Home Team Science & Technology Agency ("HTX"). As overall in-charge of crime scene forensics in Singapore, she leads a division of more than 100 forensic specialists in providing 24/7 forensic support to investigations conducted by the Singapore Police Force ("SPF"). In over 30 years of her career, Pei Pei has been involved in many high-profile crime scenes, such as the Kovan Double Murder, and Little India Riot. She is also the SPF Deputy Commander of Disaster Victim Identification, and has participated in overseas missions, such as the 2004 Indian Ocean Earthquake and Tsunami that affected Thailand. In her capacity as AD FD, she supervises and provides guidance to different specialist groups, such as bomb scene technicians and bloodstain pattern analysts, to process complex crime scenes. By identifying and harnessing emerging technologies to enhance forensic capabilities, Pei Pei's role as AD FD is pivotal in steering the strategic direction for crime scene forensics in HTX and Singapore.

Denzyl Tai currently holds the position of Head, Forensics Management Branch ("FMB") at the Forensics Centre of Expertise in the Home Team Science & Technology Agency ("HTX"). As Head FMB, he is tasked with formulating plans, strategies, policies, and training on crime scene investigation to enhance the forensic capabilities of HTX. With more than 10 years of experience in crime scene management, Denzyl has been involved in several high-profile crime scenes, such as the Bedok Reservoir Double Murder. As Lead of the Bloodstain Pattern Analysis Workgroup and Chief Trainer of Forensics Division, he oversees the training roadmap and developmental plans for all forensic specialists within the division.

Jaya Ganase is a Senior Crime Scene Specialist from HTX, Singapore. Deployed to Forensics Division of the SPF since 2012, he has investigated numerous major crime scenes, from homicides to sexual assaults. In addition, Jay has carried out various research to optimize and refine current methods in crime scene investigation (CSI). Trained in BPA, he also conducts CSI and BPA-related training for both local and foreign law enforcement agencies.

Foo Siong Chun currently holds the position of Senior Crime Scene Specialist at the Forensics Centre of Expertise in the Home Team Science & Technology Agency, providing 24/7 forensic support to investigations conducted by the Singapore Police Force. In his eight years of casework experience, he had attended numerous crime scenes, from major crime such as homicide and sexual assault, to volume crime such as theft and affray. Shawn is proficient in method development/validation work in the analytical sciences, with a principal area of expertise in bloodstain pattern analysis. He is also a trainer in his branch and has conducted several training courses on crime scene investigation and bloodstain pattern analysis to both internal and external participants.

Ying Meng Fai is the Director, Human Factors and Simulation Centre of Expertise (HFS COE) of the Home Team Science and Technology Agency (HTX). He leads the HTX Human Factors & Simulation (HFS) Centre of Expertise in research and development strategy and direction, drives significant HFS programs and projects to ensure achievement of valuable technical outcomes to augment human performance and safeguard the safety of the Home Team officers.

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INTRODUCTION

Bloodstain pattern analysis (BPA) is a crucial forensic science technique that has been used for over a century to provide valuable insights into the events surrounding violent crimes. By analyzing the size, shape, distribution, and location of bloodstains, investigators can better elucidate the blood-letting event, such as establishing the position(s) and movement(s) of the victim and perpetrator, the potential sequence of events, as well as other important details about the crime (Acampora, Vitiello, Di Nunzio, Saliva & Garofano, 2014). Investigators can also identify impact patterns and calculate areas of convergence/origin of the impact spatter; these crucial details can be used to reconstruct the events that occurred (Wells, 2006). As a result, BPA has become an essential tool for forensic professionals to use in criminal investigation, providing valuable evidence in a wide range of criminal cases, from homicides to assaults and even to accidents.

Training in BPA is critical to ensure forensic professionals have the necessary skills and knowledge to conduct accurate and reliable analyses. The effectiveness of BPA as a forensic science technique relies heavily on the expertise and training of forensic professionals. Accurate and reliable BPA analysis requires a thorough understanding of the physics of bloodstain pattern formation, and the ability to identify and analyze various types of bloodstain patterns.

Traditional training methods in BPA typically involve classroom lectures, photographs, and physical crime scene mock-ups. While these methods can be effective to a certain extent, they do not provide the level of realism and interactivity needed for effective learning. Creating crime scene mock-ups is a very labor-intensive and time-consuming process involving hours of preparation work. The time and manpower demand limit the number of training scenarios created and how much training can be carried out.

In recent years, Mixed Reality technology has emerged as a powerful tool for creating immersive and interactive learning environments (Lindgren & Johnson-Glenberg, 2013). It combines both virtual and physical elements to create a realistic and engaging experience, and it has been used in various fields, including medicine, education, and training (Zhang, Cui, Shan, Qu, Zhang, Tu & Wang, 2020). In the field of forensic science, Mixed Reality technology has the potential to provide a new and innovative way to train forensic professionals in BPA.

The team has developed a Mixed Reality Bloodstain Pattern Analysis Simulation Training System (referred to as the “system”), which is designed to provide a realistic and immersive learning experience for Crime Scene Specialist (CSS) trainees. This article will outline the design and implementation of the Mixed Reality system and explore the benefits of using Mixed Reality technology in BPA training to provide a realistic and immersive learning experience. Additionally, this article reports the findings of an evaluation study conducted with a group of trainees to measure the performance and training effectiveness of the Mixed Reality system compared to traditional training methods. By delivering a realistic and immersive hybrid simulation learning experience, the system can enhance trainees' knowledge and abilities while providing significant savings in time, cost, and manpower.

Conventional Training and its Limitations

The Singapore Police Force (SPF) conducts regular BPA training sessions for its Crime Scene Specialists (CSS), and it is traditionally carried out through a combination of classroom lectures, textbook readings, and hands-on training exercises. Trainees are introduced to the fundamental concepts and principles of BPA, such as the characteristics of blood droplets and the factors that can affect their shape and distribution.

Once trainees have a basic understanding of the principles involved, they move on to practical exercises where they work with synthetic blood spattered/transferred onto various surfaces, such as fabric, glass, metal, *etc*., to better understand how bloodstains look when they are deposited on these surfaces. Some of these exercises involve using basic tools such as measuring scales, string lines, and protractors, to determine the direction and impact angle of bloodstains and their corresponding origin.

To increase immersion, training is held in a special room to create a mock-up of a crime scene (Figure 1). However, due to the human aspect in the creation of these bloodstain patterns, slight differences in the force/angle would result in variations to the overall size and distribution of resulting bloodstains. Hence, multiple attempts may be required to create a suitable type of pattern for a particular lesson. Depending on the complexity of the scene, instructors may need to spend several hours to create a crime scene mock-up, and if they wish to conduct a new lesson on different types of bloodstain patterns, the room has to be cleaned thoroughly before the preparation process is repeated.

Figure 1. Mock-up crime scene

BPA training relies heavily on hands-on experience and direct supervision from experienced instructors to develop the necessary skills and expertise. While this type of training can be effective, it is often limited by the availability of expert manpower resources and the time and cost required to conduct in-person training sessions.

SYSTEM OVERVIEW

The Mixed Reality Bloodstain Pattern Analysis Simulation Training System is conceptualized and designed by the Singapore Home Team Science and Technology Agency (HTX) in collaboration with the Singapore Police Force (SPF). The initial impetus for the system is to design a solution that would overcome the limitations of conventional BPA training, reduce the setup time required, provide a more immersive form of training, and ensure repeatability in training and consistency in assessing trainees. Another requirement of the system is that trainees need to familiarize themselves with the physical tools they would use for BPA such as measuring scales, string lines, protractors, and cameras.

Considering these requirements, the team opted for a Mixed Reality approach over Virtual Reality (VR). With Mixed Reality, holographic images are projected into the user's field of view to create realistic virtual crime scenes with enhanced immersion. Training could take place in a mock crime scene with holographic bloodstains easily applied onto different surfaces, eliminating the need to create synthetic bloodstains. Mixed Reality also significantly decreases the likelihood of cybersickness, compared to VR and this is reflected in our trial results. An added benefit of the Mixed Reality headset is the implementation of hand gestures so that trainees could interact with the virtual elements of the simulation without the need for hardware controllers, which would have made it difficult for them to hold and use their physical tools simultaneously.

The system is highly portable; it consists of a laptop, wireless router, and the Microsoft HoloLens 2 Mixed Reality headset. The system supports training of up to two trainees concurrently, but it could be easily scaled up to higher numbers if required. Trainees need to only wear the Mixed Reality headset, whereas the instructor views their training progress using either the laptop or a separate headset. The system contains two main modules: The instructor module and the training module (Figure 2).

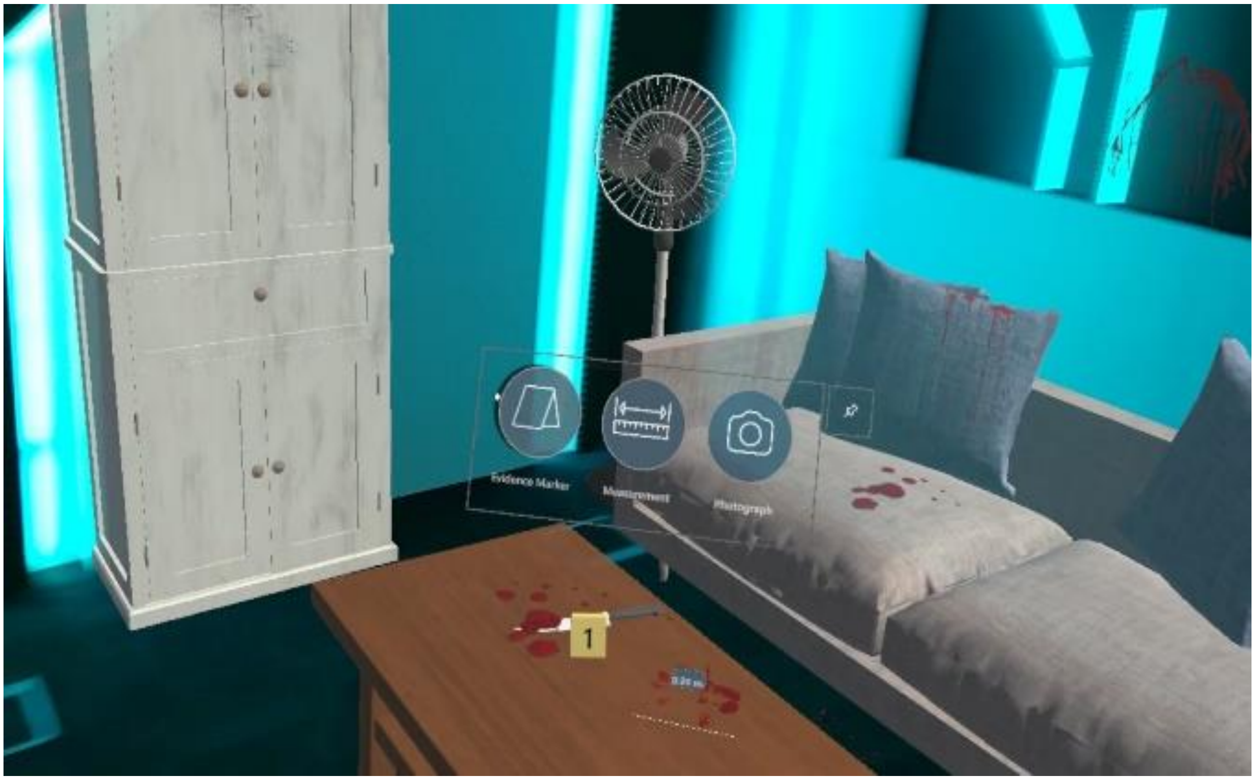

Figure 2. System real-time footage

Instructor Module

The Instructor Module is located on a laptop the instructor use; it provides several functions:

1. **Scene Creation:** The instructor can create/modify the virtual crime scenes (Figure 3). Before creating a new virtual crime scene, the instructor dons the Mixed Reality headset and chooses a suitable area to conduct the training. There are no restrictions on the room size, whereas the maximum training area is only limited by the remaining hard disk space in the Mixed Reality headset. The instructor then proceeds to furnish the virtual scene by selecting pre-loaded furniture models, from the Assets Library, which appear as holographic images on the Mixed Reality headset that the instructor can rotate, scale, and translate within the chosen training area. Once the instructor is satisfied with the placement of the virtual furniture, they can then proceed to overlay bloodstains on different surfaces. These virtual bloodstains are pre-rendered and are modeled based on photograph specimens. The system has 15 types of bloodstains patterns pre-loaded and the instructor can modify their placement. They can also be placed on physical features in the training area, such as walls, flooring, and even physical furniture, should the instructor want to use both physical and virtual furniture in the scene. The instructor can then save the mixed reality crime scene and use it for future training scenarios.

Figure 3. Scene Creation and Assets Library

2. **Exercise Control:** An interface for instructors to manage the training session. New sessions could be created, and the instructor would be able to monitor the trainees' actions through an "in-game" camera view that they can adjust and manipulate when the trainee is using the system. Incomplete training sessions could also be saved to be continued in a future session.

3. **Report Repository:** An exercise report is automatically generated at the end of each training session, registering the different actions performed by the trainee and the virtual photographs taken. The instructors will be able to retrieve these reports from the Report Repository and assess the trainee's performance.

4. **Assets Library:** The system is preloaded with numerous 3D assets which can be used to create virtual crime scenes. These include furniture, weapons, and bloodstain patterns. Instructors can also upload new 3D assets in .fbx or .obj format, which will then be made available under "Scene Creation".

5. **Status Monitoring**: Displays the operation and connectivity status of hardware components. Software patches can be deployed here and wirelessly distributed to the Mixed Reality headsets.

Trainee Module

The Trainee Module is the main interface that trainees will interact with on the Mixed Reality headset and is launched remotely by the instructor. Through the Mixed Reality headset, trainees can see the virtual crime scene created by the instructor and are able to perform the following actions:

1. **Place Evidence Markers:** Trainees are expected to process and document the crime scene by placing different types of evidence markers. Trainees have to select the correct evidence marker and place them at appropriate locations, taking care not to smudge or obscure any bloodstain and not miss any crucial location.

2. **Take Measurements:** As part of the investigation process, trainees have to collect measurements of bloodstains and objects such as weapons. Trainees can use the built-in virtual tool to take these

measurements. However, the Mixed Reality headset allows the use of physical tools such as rulers and protractors to measure holographic bloodstains.

3. **Take Photographs:** Trainees are also assessed on the way they frame photographs as the system allows them to take virtual photographs of both physical and holographic virtual elements. These photographs are then saved in a report for the instructors to review after training.

4. **Conduct "Stringing":** One method which Crime Scene Specialists use to determine the area of origin for an impact bloodstain pattern is called "stringing," whereby physical strings are pull towards the ground from individual bloodstains based on their calculated impact angles. The area where multiple strings overlap indicates the estimated area of origin. This is a tedious and time-consuming process that requires instructors to manually assess if trainees have carried out the task correctly. It would also take an inexperienced trainee more than half an hour to complete the task.

   To enhance the learning process, the Mixed Reality system provides a simple and automated interface (Figure 4) for trainees to measure the bloodstain and key in the relevant data. The system then displays an accurate rendering of virtual holographic strings, based on the inputs and angles derived by the trainee, allowing trainees to better visualize the end-result of the "stringing" process (Figure 5) while cutting down the time needed to assess each trainee individually.

Figure 4. Providing inputs for Stringing

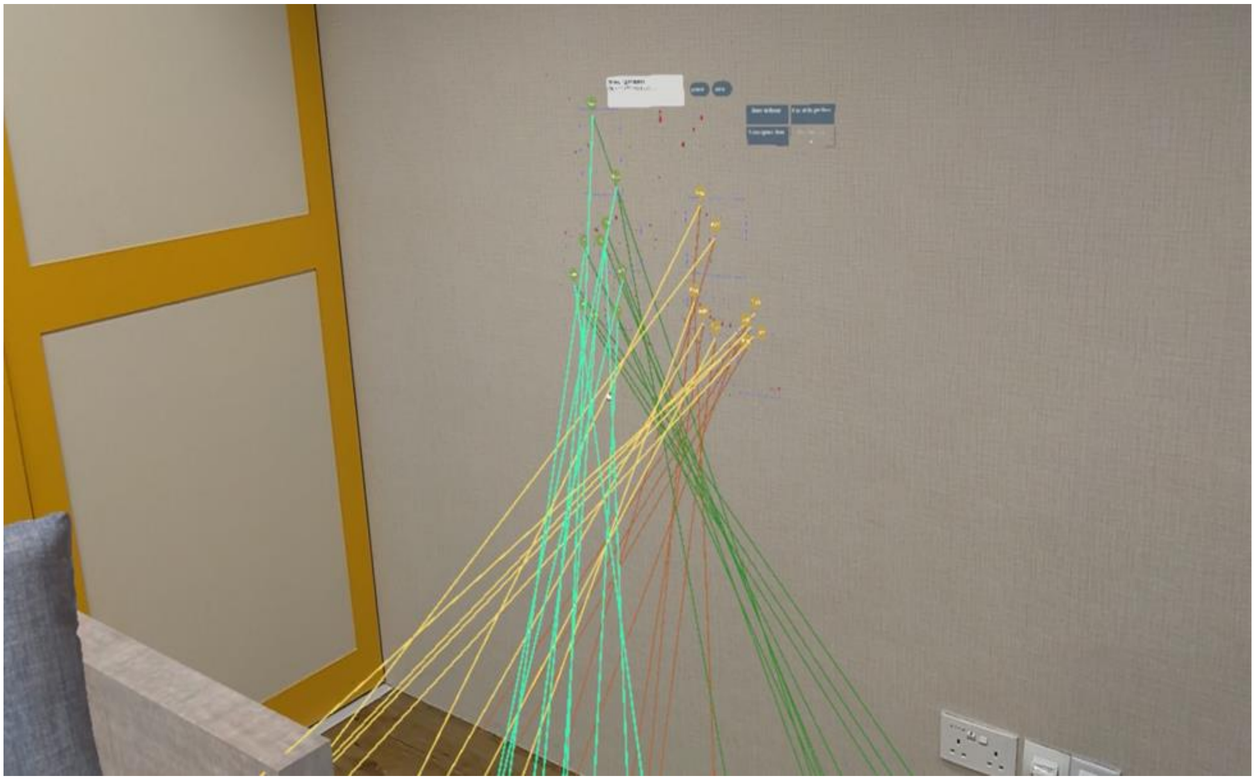

Figure 5. Mixed reality visualization of the digital "strings"

SYSTEM EVALUATION

To examine the system's effectiveness, the team collected user experiences and perceived learning after they interacted with the system to assess user feedback in key areas such as simulator sickness, simulation interactivity/usability, and achieving training objectives. By examining these areas, the study aimed to provide insights into the overall effectiveness and user experience of the Mixed Reality system, ultimately informing the development of future system enhancements.

METHODOLOGY

A system trial was conducted with CSS trainees from SPF. A total of seven trainees participated with ages ranging from 24 to 31 years old and are of equal levels of proficiency. All trainees received the same briefing, demonstration, and surveys.

Two days before the trials, the trainees underwent a BPA introductory module to impart a basic understanding of BPA and the roles and responsibilities of a CSS. A deck of slides was also provided for their reference, containing background information on the POC trial including its workflow, objectives, and requirements. A briefing was also conducted 10 minutes before trial commencement to briefly introduce the system and summarize the trial objectives; a Q&A session followed to answer any queries the trainees may had.

Upon trial commencement, the trainees were given a 15-minute guided session by the instructors, in the form of a dry run, to familiarize them with the hand gestures required to interact with the system during the Mixed Reality simulation.

After the dry run, the trainees participated in a 30-minute training session where they were required to perform a series of tasks consisting of crime scene appreciation, performing scene markings of bloodstain patterns and weapon exhibits, usage of investigative tools and taking photographs of immediate areas and close-ups. At the end of the training session, an after-action review was conducted with the instructor where the trainees' feedback was gathered, and they filled out the surveys described in the next section.

DATA COLLECTION MATERIALS AND PROCESS

The following four surveys were administered immediately after the training session:

1. **Simulation Training Safety - Simulator Sickness Questionnaire (SSQ):** The Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used in this study to measure simulator sickness. The SSQ is a self-reporting checklist comprising 16 symptoms commonly associated with simulator sickness. These symptoms are rated on a four-level scale, which are then converted into individual scores for "Nausea", "Oculomotor Discomfort", "Disorientation" and "Total Severity" to provide an overall determination on the degree of simulator sickness. An additional 4 questions were included to identify potential issues in physical ergonomics as well as audio or haptic discomfort arising from using the system (Stanney, Mourant & Kennedy 1998).

2. **Simulation Interactivity/Usability - Presence Questionnaire (PQ):** A Presence Questionnaire consisting of 32 items (Witmer, Jerome, & Singer, 2005) was employed to evaluate the trainee's sense of presence in a virtual or Mixed Reality training system based on key considerations such as the degree of "Interaction", "Visual Fidelity", "Audio Fidelity", "Haptic Fidelity", "Interface Quality", "Adaptation" and "Immersion".

3. **Training Objective - Simulation-Based Learning Questionnaire (SBLQ)**: The Simulation-Based Learning Questionnaire (SBLQ) (Keskitalo & Ruokamo, 2015) was used to assess the effectiveness of the system in achieving the desired learning outcomes. It consists of 18 items that measure the trainees' perception of the system's usefulness and effectiveness as well as their satisfaction with the overall learning experience, and engagement with the training objectives.

4. **Overall System Feedback:** This questionnaire seeks to gather additional feedback from the trainees about the logistical arrangements of the trials, such as training materials provided, clarity of instructions, and the venue, as well as their overall ratings of the system, POC workflow, and other comments.

Data Normalization

After the survey data had been collected, we normalized the responses to eliminate any potential biases that may arise due to differences in interpretation or understanding of the questions being asked. It ensures that each participant's rating is on the same standardized scale, making it easier to compare the responses across different participants and different aspects being rated. For every data point, the minimum value of that data point gets transformed into a 0, the maximum value gets transformed into a 1, and every other value gets transformed into a decimal between 0 and 1. The poll scale for survey ranged from 0 to 1 where 0 indicates a strong negative rating and 1 indicates a strong positive rating.

RESULTS

Simulation Training Safety - Simulator Sickness Questionnaire (SSQ)

The system achieved a normalized score value of 0.97 across all responses, and there were not any significant differences between the three sickness categories, ranging from 0.95 to 0.98. This suggests that the level of simulator sickness experienced by the participants was relatively consistent across the different aspects of the SSQ, with a small number of users reporting very mild symptoms of oculomotor and disorientation.

The results from the SSQ demonstrate that most participants experienced minor or no adverse symptoms of simulator sickness. This can partly be attributed to the mitigation measures taken, such as calibrating the Mixed Reality headset for each participant and providing familiarization sessions before the actual training session. The most common symptom reported was light difficulty focusing on holographic images, but this could be attributed to participants' lack of prior experience with Mixed Reality technology, which requires some time to acclimate to. These results are significant because they indicate that the Mixed Reality system is well-tolerated by users and is unlikely to cause significant simulator sickness symptoms.

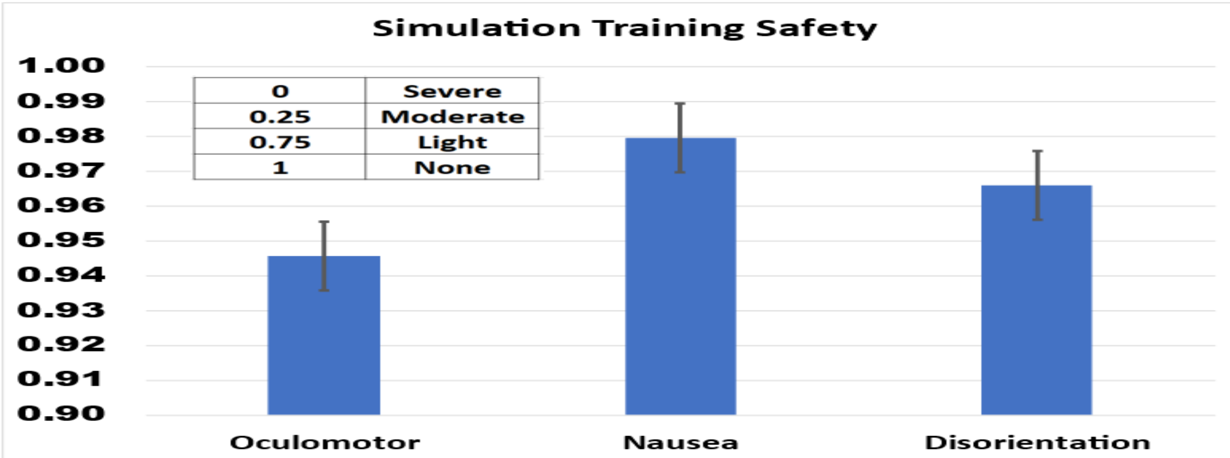

Figure 6. Simulator Sickness Questionnaire

Simulation Interactivity/Usability - Presence Questionnaire (PQ):

The system achieved a normalized score value of 0.71 across all responses, with the two lowest categories being "Audio Fidelity" and "Haptic Fidelity", scoring 0.51 and 0.67, respectively. Based on the normalized results, the overall sense of presence in the virtual environment is relatively high with participants scoring most favorably in "Interaction", "Visual Fidelity" and "Immersion.

Audio and Haptic fidelity hindered maximizing the score on Presence. However, neither audio nor haptic are relevant to the objectives of the system. Participants also commented that hand gesture interactions occasionally appeared unresponsive and that repeated attempts were required to perform the desired task. Overall, the PQ results suggest that the Mixed Reality system achieves a high-level simulation interactivity and usability, but there is room for improvement in certain aspects of the system.

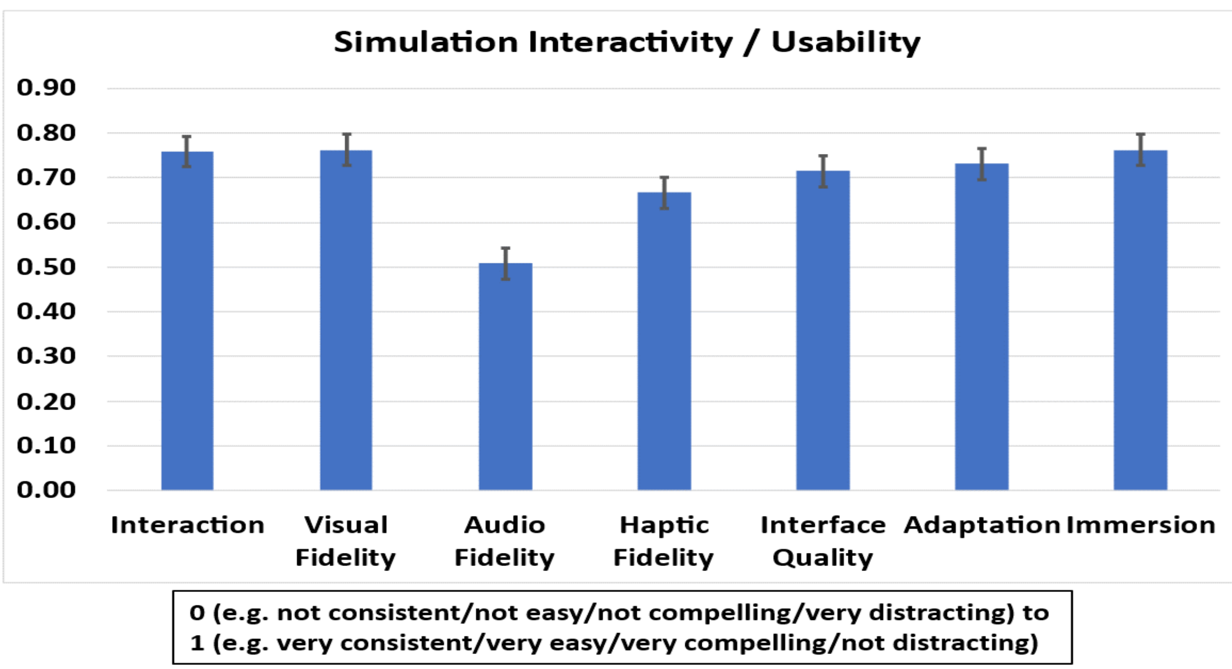

Figure 7. Presence Questionnaire

Training Objective - Simulation-Based Learning Questionnaire (SBLQ):

The data collected from the Simulation-Based Learning Questionnaire (SBLQ) serves as a crucial measure of the overall effectiveness of the Mixed Reality Bloodstain Analysis Training System. The system achieved a normalized score of 0.85, indicating a positive response overall.

Delving deeper into the questionnaire results, the category of "Competence-based and Contextual" focuses on assessing whether training with the simulation led to competency development that will serve the trainees in their work. The system was designed as a supplementary tool for the basic/foundation level BPA training, offering a more immersive alternative to classroom-based lessons. A score of 0.9 on SBQL demonstrated the system delivered well in this category.

The "Active and Responsible" category focuses on whether trainees actively seek, evaluate, and apply information during lessons, while instructors provide support in these activities. This category received the highest score of 0.93, indicating that trainees positively embraced this new medium of training, which allowed them to instantly apply the skills they acquired. The trainees also indicated that they appreciated the level of support provided by instructors in familiarizing them with the Mixed Reality system.

In contrast to the previous categories, the "Reflective and Critical" category aims to determine if trainees can critically evaluate their competency during simulation training and hone their critical thinking skills. This category, along with "Socio-Constructive and Collaborative" received the lowest scores in this questionnaire. This is attributed to the fact that this system serves as an introductory module to BPA, and as such, there are no collaboration or communication components built into the system. Although the system supports multiple users in the same scenario, this POC only caters to two headsets; one was worn by the instructor for monitoring purposes. Additionally, the system does not carry out automatic assessment or guidance of the user's performance, as the trainer handled that role. Overall, the SLBQ results indicated a generally high level of effectiveness in supporting simulation-based learning.

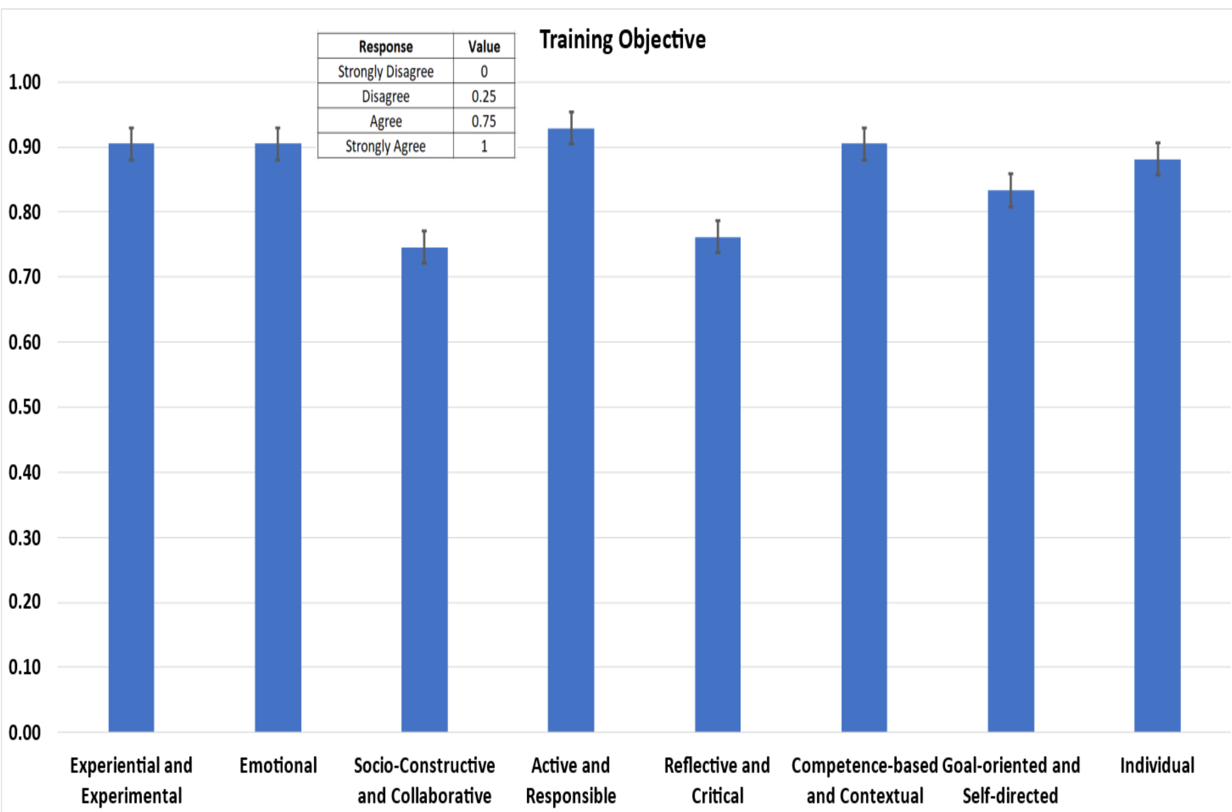

Figure 8. Simulation-Based Learning Questionnaire

Overall System Feedback

The Overall System Feedback survey garnered highly positive feedback from participants. Most commented that the system was useful in serving as an introduction to BPA or for revising their BPA knowledge. Participants noted that they felt more engaged and immersed in the training due to the realism of the graphics. Comments on potential future improvements included enhancing interactions, as hand gestures or virtual buttons sometimes appeared unresponsive, and the placement of virtual objects could be more intuitive. The virtual photography function could be difficult to grasp and required several steps to take a photo. Participants also requested that training be conducted in a group setting instead of 1-on-1, and that trainers be present in the same scenario to provide active guidance. Finally, participants requested additional blood patterns and virtual assets such as furniture and different surfaces.

LIMITATIONS

Interpreting the results of this study entails considering several limitations. Firstly, while the scores on all the questionnaires were generally high, indicating positive responses to the system, it's important to note that the number of participants was relatively limited. This small sample size might only partially capture the entire range of experiences and perceptions that wider system usage could bring. Future studies could involve larger and more diverse participant groups to validate the findings.

Secondly, the participants' professional backgrounds were not extensively varied, as the system serves as an introductory module to BPA training. All the participants were novices in the field of BPA. Consequently, their feedback may differ from that of more experienced BPA professionals who use the system. Ideally, a broad spectrum of professionals, from novices to BPA experts, should be included in future studies to better understand the system's potential applicability across different user profiles.

Moreover, this Proof of Concept (POC) catered to only two MR headsets, one worn by the instructor for monitoring purposes. Consequently, the system only supported one trainee per session and is therefore unable to create a collaborative environment that would have significantly enhanced the overall learning experience. This limitation is reflected in the relatively lower score for the "socio-constructive and collaborative" training objective in Figure 8.

Lastly, all the participants had no prior experience with Mixed Reality and performing interactions on a Mixed Reality device. Despite providing a 15-minute guided session to familiarize participants with the hand gestures required to interact with the UI elements of the system, it's unavoidable that some participants might be unaccustomed to such a novel interface. This lack of familiarity might have impacted the overall user experience and learning outcomes. However, this situation could improve through repeated use.

These limitations present opportunities for further development and improvement of the Mixed Reality Bloodstain Pattern Analysis Simulation Training System. While the current system shows considerable promise, recognizing these limitations will guide future iterations, ensuring that the system continues to evolve in line with user needs and learning outcomes.

FUTURE WORK

Future improvements to the system will primarily focus on enhancing interactions and usability. To provide pseudo-haptic feedback, audio cues can be introduced when trainees interact with virtual objects, which will provide confirmation of successful object selection. The implementation of larger buttons and other user interface elements will improve interactions, and various naturalistic hand gestures such as pinching and dragging will replace the need for button-presses. The process of taking photographs should be simplified, and a tutorial could be introduced to familiarize trainees with this function. These enhancements, driven by the feedback from trial with participants, aim to enrich the overall interaction experience.

To elevate the system's collaborative aspect, the team plans to investigate the potential for team-based training in both localized and remote settings. Utilizing commercial tools such as Microsoft Mesh, geographically distributed teams can collaborate in the same virtual crime scene and attend virtual demonstrations led by overseas experts. Performance evaluation is another key area under consideration, and the team aims to incorporate automatic assessment capabilities into the system for instant performance feedback.

In addition to software improvements, the team is proactively seeking new technology and devices to enhance the system. Given the age of the HoloLens 2 device, released in 2019, and with no newer model announced by Microsoft as of August 2023, alternatives such as Extended Reality headsets are being explored as potential replacements. Such a change could enhance system performance due to hardware advancements.

The proposed improvements and enhancements will require a multidisciplinary team of hardware and software engineers. In collaboration with potential industry stakeholders and the Singapore Police Force (SPF), these enhancements are planned to be incorporated into either a Phase 2 POC or as part of the Initial Operational Capability/Full Operational Capability (IOC/FOC) stages, depending on factors such as the complexity of the enhancements, their impact on the system, and the training requirements.

Each potential enhancement will be evaluated based on its feasibility, cost, resource requirements, and expected impact on training effectiveness. The prioritization and scheduling of these enhancements will be coordinated with SPF to align with their training schedules and operational requirements.

Through the course of the trial, the team recognized the potential of using the system in an operational context in the digital recreation of real crime scenes and automated analysis of bloodstain patterns. With improvements in the headset's cameras, the system could incorporate real-time scanning of indoor environments for post-analysis. This real-time scanning could allow investigators to digitally preserve and analyze crime scenes, thereby facilitating further investigations. Another potential capability would be the integration of an analytics overlay, enabling an automated approach to bloodstain pattern analysis. By capturing and analyzing real-world impact patterns, the system could conduct instant digital stringing to pinpoint the area of origin. Moreover, by studying intricate details of blood dispersion and patterns, it might be feasible to predict the likely weapon used during the incident or even to derive a sequence of events leading up to the scene, effectively creating a digital storyboard.

CONCLUSION

In conclusion, the Mixed Reality Bloodstain Analysis Training System shows promising potential as an effective and engaging training tool. The results from the SSQ suggest that users tolerated the system well and are unlikely to cause significant simulator sickness symptoms. The SLBQ indicates high-level effectiveness in supporting simulation-based learning. Participant feedback has been predominantly positive, with a substantial number noting an elevation in training efficacy and perceived learning value through the use of the system.

Overall, the Mixed Reality system presents a novel and engaging approach to BPA training, offering an immersive and interactive learning experience. Future research endeavors can focus on developing more advanced functionalities, such as collaborative aspects and performance evaluation capabilities to provide a more comprehensive and realistic training experience for BPA analysis. With continued development and refinement, the Mixed Reality Bloodstain Analysis Training System could become a valuable tool for BPA professionals and students alike.

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