Cost-Effective Computer-Vision Interfaces for Educational Virtual Reality Games

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1 PROJECT DESCRIPTION

The application of serious games, digital video games created for both education and entertainment [2], as an educational tool continues to increase as the evaluations of these games in a range of educational environments have shown improvements to student motivation and engagement. Serious games are inherently immersive and therefore increase student satisfaction while learning, which results in increased time on task and better retention of information [1, 8, 13]. Virtual Reality (VR) systems that incorporate serious games can provide a higher level of immersion. Doing this will result in greater engagement with students and lead them to achieve better academic performance.

Virtual reality has been used as an educational tool since 1966. The benefits and motivations of using VR systems in education are well known and widely accepted. VR creates increased access to information, increased details, distance learning and the opportunity to experience previously inaccessible things. While these benefits are widely accepted, VR still has not been adopted worldwide in educational environments. This is due to several barriers to entry, including the high cost associated with the equipment used in a VR system. Hence, development and implementation of cost-effective VR solutions is important and can result in the widespread adoption of these technologies as an educational tool.

VR has seen a rise in popularity with the release of 1st tier systems, like Google Cardboard (figure 2), and 2nd tier systems such as the Samsung Gear VR. These systems make use of head-mounted displays (HMDs) with smartphones acting as the display and content processor. The cost of a new Samsung Gear VR system is around R7000, with a 2016 Samsung Gear VR headset and controller costing R399 (figure 1) and a Samsung Galaxy S7 smartphone costing R6499. CardboardSense, similar to Google Cardboard, is a DIY cardboard-based VR headset that allows users to experience immersive VR environments for less than R200 [15]. These cost-effective VR systems are more applicable in a classroom setting and can provide a way to implement VR as an educational tool. The sensors integrated in the input devices for these systems commonly use 3 dimensional (3D) sensors, to locate and display the device or object in the virtual environment. However, these input devices are expensive and limits the potential usability as it limits them to three degrees of freedom (location in 3D space) with no orientation detection.

This project will investigate alternative cost-effective computer-vision interfaces that utilises a smartphone's camera and computer-vision algorithms to track special markers attached to physical objects. These interfaces can enable the VR system to register the location and orientation of the object in relation to the camera. Thus the virtual object can be attached to the physical object and can be interacted with in a virtual scene as if the the virtual object was a real object. This allows us to bring elements of Mixed Reality (MR) into VR. MR is a step beyond Augmented Reality (AR), where instead of only viewing virtual objects in the real world, the user is able to interact with it.

2 RELATED WORK

2.1 Virtual Reality

Immersion can be described as a person's desire to continue working on a task [4]. According to the reviewed literature, fully immersive VR environments are more efficient, as an educational

Figure 1: Samsung Galaxy S7 (left), Samsung Gear VR Head-Mounted Display (middle) and controller (right)

tool, than non-immersive desktop-based VR [3]. Immersive environments increase the user's sense of presence, which results in increased motivation and ultimately increased retention of the material they are learning [8].

VR systems offer many benefits when implemented in educational environments. These systems provide students with increased details on the subject [6, 11], increased accessibility of information [5, 8, 11] and the opportunity to experience objects and environments that they previously would not have access to [7, 9, 11]. An example of a VR educational game, can be seen in figure 4. In this game the user observes the landscape in front of them and answers questions based on the environment, in the provided time. The user then uses the Samsung Gear controller and uses it to select the correct answer by moving the pointer to the correct position and then pressing the select button. The review of VR systems that were implemented and evaluated in educational environments shows several measures of evaluation. These systems showed improvements to the level of interaction, immersion, motivation, performance, retention and satisfaction. The improvements to these measures resulted in positive learning outcomes such as increased time spent on a task and deeper learning [1, 4, 8, 13].

2.2 VR Interfaces

The immersion of a VR game is influenced by the type of interface used. The selection of a suitable interface is important, as this will increase the level of immersion experienced by the user [12]. Complex VR systems tend to have high costs, making them less accessible in educational environments. While cost-effective 1st and 2nd tier systems have been developed, these systems use a head-mounted display with a smartphone as both the processor and display. Due to the smartphone being placed in the HMD, the user is unable to interact with the smartphone's touchscreen. This is an issue as the touchscreen is the primary form of input of the device. To deal with this issue, an alternative interface must be used. VR systems generally use standard input devices like the Samsung Gear VR controller (figure 1). These devices create a limit of 3 degrees of freedom with no orientation detection, and tend to be expensive. The high cost of these devices limits the applicability of these systems as an educational tool. However, cost-effective alternative interfaces have been developed. A computer-vision algorithm known as marker-based feature detection makes use of the smartphone's camera to track the location and orientation of the markers that are placed on physical objects. These markers contain a unique pattern that when sampled and decoded, relates to a virtual object specified by the developers. The algorithm then uses the location and orientation to simulate the required virtual object on to the physical object. This allows the user to interact with the virtual object in the virtual environment as if it were a real object. The development of a 3D controller equipped with markers, allows users to interact with the controller physically and see the outcomes in the virtual environment. The literature reviewed stated that the built-in object detection capability of marker-based tracking algorithms remains unchanged and that the reliability is the main benefit of these systems [14].

Figure 2: CardboardSense Head-Mounted Display

An example of a cost-effective, 3D printed interface is shown in figure 3. When used in the example educational game previously mentioned, the user can view the questions on the new controller and select the answers by rotating the embedded green wheel (figure 5). An added feature to this is that the user is able to zoom into the landscape by turning the controller over to the other side and using it as a magnifying glass (figure 6).

3 PROBLEM STATEMENT

3.1 Research Problem

Before Google and Apple showcased VR and AR in their devices, there were limited resources available for processing in mobile phones. As a result, people were not confident to investigate computer-vision based AR interfaces. The technological advancements in

Figure 3: Example of a 3D printed controller with a detection pattern on it

modern smartphones, has made the combination of VR and AR possible, which offers multiple benefits. Cost-effective VR systems have been developed, such as google cardboard, but these systems make use of expensive input devices. Therefore, it is necessary to design low-cost interfaces, that uses MR technology, to interact with the virtual environment. The development of cost-effective alternatives, will make VR and AR systems more accessible in educational environments and could enable a widespread adoption of these systems as an educational tool.

This research project aims to investigate alternative low-cost interfaces for educational games, and whether these interfaces provide the same level of immersion as a standard controller. The main objective of this project is to design and implement a 3d printed controller, with unique markers attached to it, to interact with the virtual environments developed in the first phase of the research process.

3.2 Research Questions

To achieve our aims outlined above, we propose the following main research questions for this project:

(1) What new features of the new controller make it stand out from the standard controller?
(2) Is the new controller easier to use than the standard controller?
(3) Does the new controller provide the same level of immersion as a standard controller?

4 PROCEDURES AND METHODS

The research process will be carried out according to the following steps:

(1) Develop two serious games for use in the final user evaluation. Jesse Mark will develop the virtual environment for a virtual art gallery and Mu-Ath Toefy will develop the environment for a virtual crime scene. These games will be iteratively developed simultaneously with the development of a controller. Information gathered during this stage will be used to answer the two secondary research questions posed above.
(2) Design and prototype a controller that will be used to test the effectiveness of the interface.
(3) Build game logic for both VR serious games.
(4) Run two iterations of user evaluation[1] to get feedback on the game and controllers to make improvements as we will be implementing user-centered development.
(5) Build the interface for the controller.
(6) Implement framework for marker based feature detection.
(7) Run user evaluations[1] to test the immersion and effectiveness of the interface, using the two serious games and the associated 3D printed marker objects. The developed controller will be evaluated in comparison to an external controller that is versatile and has a higher cost. This information will then be used to answer the research questions stated above.

[1] Note: Due to the Covid-19 pandemic, if user evaluations cannot be carried out, heuristic evaluation will be carried out with close relatives and colleagues.

Figure 4: Example of an educational game

Figure 5: Example of the 3D printed controller in the educational game

5 ETHICAL, PROFESSIONAL AND LEGAL ISSUES

Cybersickness is the most frequently mentioned issue of VR systems. The participants selected for the research process, will evaluate the interface in a virtual environment which could cause them to experience motion sickness, blurred vision, dizziness or headaches [10]. This is an ethical issue that must be addressed when conducting the evaluation. According to Young's et al. findings, the participants that think about getting sick before interacting with a system, are more likely to experience negative symptoms [16]. The educational aspects of the serious games and the continuous engagement with the content, should occupy the user's mind and prevent any negative symptoms. Nonetheless, ethical clearance - from the University of Cape Town Human Research Ethics Committee - is required before testing. To allow for delays in the application process, an ethical admittance form will be submitted to the committee at the start of the development process.

The details of the evaluation process and the reasons for conducting the research, must be explained clearly to all participants. These details will be sent to the selected participants as emails, and this information will be readdressed before conducting the user evaluations. All participants will be required to sign an informed consent form, allowing their results to be included in the research of this study. Personal details of the participants will not be included in the results. Participants must be informed, that they have the option to withdraw from the study at any time without any penalties. These participants may also request for their results to be excluded from the research regardless of whether they completed the evaluation or not.

Figure 6: Example of the 3D printed controller zoom feature in the educational game

The results obtained by this study, will potentially benefit the field of VR in an educational context. These potential benefits outweigh the short-term effects of motion sickness, that may be experienced by the participants.

The intellectual property of this project will belong to Jesse Mark, Tashiv Sewpersad, Mu-Ath Toefy and the University of Cape Town. Our final products and report will belong to the developers and will be free and open-source for distribution and future research.

6 ANTICIPATED OUTCOMES

6.1 System

The system developed for this project is a combination of hardware and software components. The hardware components will consist of a 3D printed controller, a Samsung Gear VR Headset and controller and a Samsung Phone (Figure 1). The software components will include the virtual environments of the serious VR games and the interfaces for the controllers, that the participants will engage with.

The environments developed for the serious games, are a virtual art gallery and a virtual crime scene.

The VR art game will allow a user to select an artist who they wish to learn more about. The user can choose whether they learn information about the artist - including their story, the medium they use or the work they have published - or to continue to the artist's virtual exhibition. The user will be able to move freely between the artworks that are displayed in the virtual environment. Once a painting has been selected, the user can interact with the artwork in a number of ways by selecting the respective option. These interactions provide further education on the artwork, allow users to zoom in on paintings to see greater detail, and will have an additional feature that allows the user to add a single piece of art - from the exhibition - to their own virtual collection. The virtual art gallery acts as an educational platform, where users can learn about artists and the art they have created. The controller will be designed to increase the level of immersion experienced by the user. Similarly to the controller in (figure 3), this controller will use a rotating pattern to allow users to interact with the paintings. Additionally, when turned around the controller will act as a magnifying feature to allow users to see increased details of a painting.

The VR crime scene will expose a user to a room where a break-in and theft has occurred. This game will not contain any graphic elements as this may be inappropriate for certain users. In this room, multiple hidden clues will be scattered around the room for the user to find. The user is able to select these clues, which will display text above the clue on the observation made about it. For example, glass found inside the room by a window, when selected will display a text that states "The thief must have broken into the room from the outside". Once the user has collected all the clues, the user will then take a multiple choice quiz to build the narrative of how the crime was committed. The controller for this environment will look similarly to a magnifying glass, with the ability to zoom, as this might increase the immersiveness of the game. For the user to select objects, they would just need to aim the controller at it for a few seconds. When selecting answers the user can rotate the circular part of the controller to select the appropriate answer. The educational aim of this game is to educate the users about forensics in a safe and immersive way.

6.2 Impact of the Project

The research conducted during this project, will provide valuable insight into cost-effective alternative interfaces for virtual environments. This study aims to generate a deeper understanding of the issue of immersion in VR environments and will record the reactions of the participants that feel physically present in a virtual world, due to a high level of immersion. As the level of immersion experienced by a user increases, so does the user's satisfaction, this results in increased time on task and better retention of information [1, 8, 13].The development of low-cost interfaces in combination with cost-effective VR systems, provides access to a larger range of people who aim to use VR or to research further into topics regarding VR. These interfaces are more affordable and therefore more applicable in educational environments, and can offer many benefits - including increased engagement and retention - when implemented as an educational tool.

6.3 Key Success Factors

To determine if this project is successful, the following criteria must be met:

- Users should not report the 3D printed controller not working with the virtual environment or the system not detecting it at all.
- The 3D printed controller is less expensive than the standard controller and is easy to assemble
- Users find the 3D printed controller easier to use and have the same level of immersion, than the standard controller.

7 PROJECT PLAN

7.1 Risks

The table in Appendix A defines the various risk factors for this project, the probability of occurrence and the impact of the risk on the project. All of the identified risks outlined in the table, can be managed effectively and mitigated. These risks and their potential impact must be tracked throughout development as the values in the table are likely to change during the research process.

7.2 Timeline

This project runs from the 14 April 2020 to the 12 October 2020. The Gantt Chart in Appendix B, displays the structure and sequence of the events and tasks that will occur during the project. An unusual aspect of the Gantt chart, is the dates that have been dedicated to the collection of the necessary equipment. Due to the Covid-19 pandemic, this equipment will only be accessible once the University of Cape Town resumes. These dates are based off the expected reopening dates of the university. In order to meet the deadlines outlined in the Gantt chart, the development of the serious games must begin before the equipment has been collected.

7.3 Resources Required

The resources required for this project and the evaluation are as follows:

- Laptops or desktop computers that can render and edit the 3D environments and objects.
- Unity Game Engine and Visual Studio to allow the creation of the virtual environment, alongside writing code to integrate functionality within the environment.
- Assets provided by the Unity Store and other online repositories, that will be implemented in the virtual environment, to speed up development.
- Access to two Samsung Gear VR headsets, for each team member to develop their own game, capable of VR and to track the marker object.
- Access to a 3D printer and Blender to design and develop the physical marker object.

Both members have access to the required computers and software. The other required equipment, the 3D printer and VR headsets, will be provided by the supervisors.

7.4 Deliverables and Milestones

The main deliverable for this project is two VR serious games, complete with the D printed controller, features and functionality, outlined in the previous sections. Additional deliverables include:

ID	Deliverable / Milestone	Due Date
1.2	Literature Review	12 May 2020
2.2	Project Proposal	2 June 2020
3.1	Initial Software Feasibility Demonstration	3 August 2020
6.2	Final Complete Draft of Paper	4 September 2020
6.3	Project Paper Final Submission	14 September 2020
4.6	Project Code Final Submission	21 September 2020
6.4	Final Project Demonstration	5 October 2020
7.1	Poster Due	12 October 2020
7.2	Web Page Due	19 October 2020

7.5 Work Allocation

This section discusses the tasks assigned to each member of the project:

Jesse Mark will lead the design process for the 3D printed controllers and will develop the virtual environment for the virtual art gallery and implement the marker's interface into the game.

Mu-Ath Toefy will lead the 3D modelling process 3D printed controllers and will develop the virtual environment for the virtual crime scene and implement the marker's interface into the game.

While the members will develop each of the environments individually, both members will contribute towards the design and prototyping of the 3D printed controllers, conducting the user evaluation study, the final report, the development of the project poster and the development of the website.

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A RISK TABLE

No.	Risk Description	Probabilty	Impact	Mitigation Strategy
1	Hardware required for this project could not be collected due to the regulations of Covid-19 lockdown.	High	High	Hardware to be collected once regulations allow for post-graduate students to return to university or make arrangements with our supervisors to collect it.
2	User evaluation cannot occur due to social distancing or the Covid-19 lockdown regulations.	High	Low	Implement heuristic evalution with close relatives, friends and colleagues.
3	Scope of the project is too large and requires more time (also known as scope creep)	Medium	High	Keep scope of the project realistic. Have regular meetings to consult with the supervisors on the main features and only add features once main features are completed.
4	Not being able to meet project deadlines	Low	Medium	Control the scope and follow the gantt chart. Have reqular meetings with team members and supervisors on progress and any issues.
5	Development takes longer than expected due to inexperience or any other reason	Low	Medium	Start development early and request help from other team member and supervisors while self learning needed knowledge.
6	Delay in the application for ethics clearence to do user evaluations	Low	Medium	Submit application ealry to allow for leeway and start developing or prepare user tests.
7	Designed controller not working with the tracking algorithm	Low	High	Work with the algorithm to design an effective controller before creating the main controller

B GANTT CHART TIMELINE

Gantt Chart for Period: April 2020 to October 2020

ID	TASK TITLE	START DATE	END DATE	DAYS	% DONE	April 2020				May 2020				June 2020					July 2020				August 2020					September				October 2020			
						6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12	19	26
1	**Literature Review**																																		
1,1	Draft Version	14-Apr-20	24-Apr-20	10	100%																														
1,2	Final Version	28-Apr-20	12-May-20	14	100%																														
2	**Project Proposal**																																		
2,1	Draft Version	14-May-20	25-May-20	11	100%																														
2,2	Final Version	25-May-20	02-Jun-20	8	100%																														
2,3	Revise Final Version	03-Jul-20	10-Jul-20	7	0%																														
3	**Project Preparation**																																		
3,1	Initial Software Feasibility Demonstration	03-Aug-20	11-Aug-20	8	0%																														
3,2	Hardware Collection	01-Sep-20	08-Sep-20	7	0%																														
4	**Project Development**																																		
4,1	Design and Prototype Controller	02-Jun-20	09-Jun-20	7	0%																														
4,2	Vitual Enviroment	06-Jul-20	24-Aug-20	49	0%																														
4,3	User Evaluation and Feedback	24-Aug-20	31-Aug-20	7	0%																														
4,4	Fixes and Improvements	31-Aug-20	07-Sep-20	7	0%																														
4,5	User Evaluation and Feedback	07-Sep-20	14-Sep-20	7	0%																														
4,6	Fixes and Improvements	14-Sep-20	21-Sep-20	7	0%																														
5	**Project Evaluation**																																		
5,1	User Experiments	21-Sep-20	28-Sep-20	7	0%																														
6	**Project Completion**																																		
6,1	Final Report Outline	09-Jun-20	12-Jun-20	3	0%																														
6,2	Final Report Draft	06-Jul-20	06-Sep-20	62	0%																														
6,3	Final Report Complete Version	06-Sep-20	14-Sep-20	8	0%																														
6,4	Final Demonstration	05-Oct-20	09-Oct-20	4	0%																														
7	**Project Media**																																		
7,1	Poster	07-Sep-20	12-Oct-20	35	0%																														
7,2	Website	24-Aug-20	19-Oct-20	26	0%																														