Mobile Onsite Exploration of Parallel Realities with Oculus Rift

CJ Davies
School of Computer Science
University of St Andrews
cjd44@st-andrews.ac.uk

Alan Miller
School of Computer Science
University of St Andrews
alan.miller@st-andrews.ac.uk

Richard Fawcett
School of Art History
University of St Andrews
rf41@st-andrews.ac.uk

***Abstract*—This paper reports experience in developing a parallel reality system which allows its user to observe and move around their real environment whilst wearing a stereoscopic 3D head mounted display imbued with video-see through capabilities, with their position and gaze tracked by an indoor positioning system and head tracker, allowing them to alternately view their real environment and an immersive virtual reality environment from the equivalent vantage point. In so doing the challenge of the vacancy problem is addressed by lightening the cognitive load needed to switch between realities and to navigate the virtual environment. Evaluation of the usability, system performance and value of the system are undertaken in the context of a cultural heritage application; users are able to compare a reconstruction of an important 15th century chapel with its present day instantiation.**

***Index Terms*— Cross reality, parallel reality, immersive interaction.**

I. Introduction

The central theme of this paper is the concept of *parallel reality*, a new category of alternate reality comprising two environments, one real and the other virtual, each complete unto itself and wherein the user may freely switch between them. The Mirrorshades platform has been developed and evaluated as a first foray into this exciting new modality of interaction with real and virtual content, combining a wide field of view (FOV), stereoscopic 3D head mounted display (HMD) modified with video see-through cameras, with an indoor positioning system (IPS), allowing its user to observe and move around their real environment while imbued with the ability to alternatively view a complete immersive virtual environment from the equivalent vantage point.

The application of this platform to the field of digital heritage has been investigated through user studies at the 15th century St Salvator's chapel in St Andrews, Scotland, where participants were granted the ability to explore the real chapel in tandem with a virtual reconstruction of it as it originally stood (see Fig. 1)[1].

A parallel reality system that presents the user with the choice between immersive visual stimuli from both its constituent environments allows that user to engage with both real and virtual content in a manner that is similar to, but has a number of advantages over, previous alternate reality systems, including augmented reality implementations and cross reality systems.

[1]This image is taken from a video that is available to view online at https://www.youtube.com/watch?v=UsDRPjDwr8A

Fig. 1. The *Mirrorshades* parallel reality platform in a 15th century chapel.

A parallel reality system is less critical of registration (the accurate positioning/alignment) between real and virtual, as virtual objects are seen as part of a larger virtual environment instead of being rendered atop a view of the real environment [1]. The use of a complete virtual environment allows virtual content to be more encompassing and immersive, allowing total control over lighting, shadows, reflections, particle effects, etc. which would be difficult or impossible for an augmented/diminished reality platform to render atop a view of a real environment. The vacancy problem describes when a user finds it difficult to be present in two realities simultaneously, often being present in one and vacant from the other. Parallel reality addresses this issue, alleviating vacancy in both environments by furnishing users with the ability to transition between perceiving visual stimuli from them both.

II. St Salvator's Chapel

The Mirrorshades platform was evaluated at St Salvator's chapel in St Andrews. Founded in 1450 but internally stripped of its medieval fittings during the Protestant Reformation (1517 - 1648), the chapel looks markedly different today than it did upon its completion. An existing virtual reconstruction of the chapel as it stood in the period 1450-1460 and the marked differences between the internal appearance of the VR building and the current building (including the replacement of the original stone roof with a wooden one and drastically different dividing of the internal space) make the chapel an ideal candidate within the context of cultural heritage for the Mirrorshades parallel reality system to be deployed. The magnitude of the changes between the chapel's original state and how it stands today means that augmented reality would not in fact be able to present a faithful image of how the

Fig. 2. Views of the outside of St Salvator's Chapel, present day and digital reconstruction circa 1460.

chapel originally looked, but would need to be combined with substantial application of diminished reality to remove present day features that were not there in the past.

The chapel was of the greatest significance for the new architectural ideas that it introduced into Scotland, at a time when Scotland was particularly open to external artistic influences. However, although the shell of the chapel survives and remains in use, it has lost its vault, its window tracery and its liturgical furnishings, and it now requires specialist skills to appreciate the quality of its original state. The virtual St Salvator's chapel is a product of a collaboration between architectural, art history and computer science scholarship. On the combined evidence of a highly detailed late medieval inventory and of the architecture itself, it has been possible to show how the chapel was furnished internally with altars, choir stalls, lecterns, screens, stained glass and wall paintings. The architectural, liturgical and spatial analysis allows our understanding of the history of the Chapel as a living building to be enormously enhanced by experiencing the building in its original context.

III. Mirrorshades Design and Implementation

The high level design of the Mirrorshades platform is shown by Fig. III (left). The hardware components of the system that are carried by the user comprise: an Oculus Rift DK1 HMD modified by the addition of a stereo camera video see-through solution comprising 2x Logitech C310 webcams modified with S-mount lens mounts and 2.1mm lenses to provide approximately 81.2 degree horizontal FOV of the RW environment (shown by Fig. III (right)), a 12,000mAh USB battery pack capable of outputting 2.1A at 5V to power the DK1, a Clevo W110ER laptop computer with an Intel i7-3632QM four-core/eight-thread processor, Nvidia GT 650M graphics card, 16GiB system memory and a SSD to allow safe operation while moving, a Google Nexus 5 smartphone running Android 4.4.4 and an Xbox 360 wireless controller with USB receiver.

The software components of the system comprise: an Android application that runs on the Nexus 5 smartphone, determines the location of the smartphone within the building that it is in using the IndoorAtlas IPS and submits these location data via PHP to a database server (the source code of this application is available online[2]), a PHP page on the database server that allows IndoorAtlas position data to be submitted to MySQL, a MySQL database server that stores location data for the phone and allows these data to be accessed by any SQL capable client, Web visualizations of position data held within the MySQL database for St Salvtor's chapel and a Unity application that runs on the laptop, combining a virtual model of the building, experienced with the DK1's head tracking, with RW camera streams, controlled via Xbox controller actions and the IndoorAtlas position data polled from the MySQL database server (the source code of this application is available online[3]).

The Unity application hosts the VR representation of the chapel and takes in feeds from both cameras, the DK1 head tracker and the Xbox controller. It also polls the MySQL server for the most recent position data. These inputs are combined together to form the visual output for the DK1 to display to the user. As the user moves their head the visuals that are presented to them upon the DK1's display change accordingly; the RW visuals change due to the cameras being physically fixed to the DK1 and the VR visuals change due to data from the head tracker being used to change the orientation of the Unity 'cameras' accordingly.

Alignment between RW and VR is achieved simply by placing the DK1 in the appropriate orientation before starting the Unity application; the Unity prefab that encapsulates the avatar functionality has a known virtual origin orientation and knowing this allows the DK1 to be oriented to match it to align the RW and VR visuals.

As the user changes their position by walking, the visuals that are presented to them upon the DK1's display also change accordingly; again the RW visuals change due to the cameras' physical attachment to the DK1 whilst the VR visuals change due to the user's position, as reported by the smartphone and IndoorAtlas, being used to move the position of the Unity cameras to the equivalent position within the VR representation. As the user presses buttons or pulls the trigger upon the Xbox controller, the visuals that are presented to them upon the DK1's display transition between RW and VR in different styles depending upon which button/trigger was activated.

[2]https://github.com/CJ-Davies/IndoorAtlas_SQL_uploader

[3]https://github.com/CJ-Davies/Mirrorshades

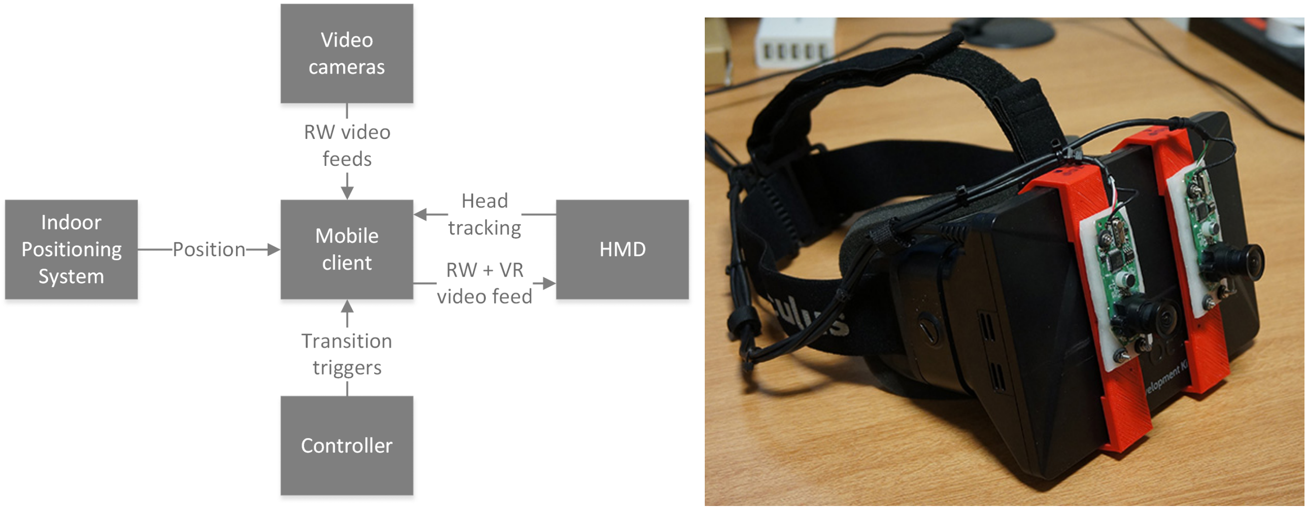

Fig. 3. Overview of the Mirrorshades platform.

IV. Between the Real and the Virtual

The novel aspect of parallel reality is the ability it imparts upon its user to switch their locus of attention between equivalent vantage points in real and virtual environments. In order to achieve the highest quality of experience with this style of interaction it is vital to determine how best to implement these transitions; that is, to mitigate the increased cognitive load (manifesting as increased conceptual reasoning and reduced perceptual processing) required to comprehend each transition, as this will detract from engagement with the environments and reduce the user's willingness to perform subsequent transitions.

Whilst some researchers support the notion that where more than one environment competes for attention there is an 'all or nothing' Gestalt switch between awareness of one environment and the other [2], the proposition explored here is that switching locus of attention does not completely overrule the user's awareness of the former, that both environments can be perceived at the same time [3] and that a user's focus can be *shared* between the real and the virtual [4], leading to a notion of 'distributed' presence. This is particularly so for situations where real and virtual environments share the same fundamental layout and dimensions (spatial equivalence).

The notion of experience of presence as continually changing [5], [6] lends confidence to the successful mitigation of the cognitive load associated with these transitions to manageable levels. One might even liken this 'switching' between real and virtual to the 'cycling through' behaviour observed in users of virtual communities, which stemmed from the 'window' concept of modern computer operating systems [7] and accelerated with mobile devices to the point where for many users today rapid cycling stabilizes them into a sense of 'continual copresence', where even just a mobile phone brings them into a world of continual partial attention to any particular subject or environment [8].

Five styles of transition control were investigated for the Mirrorshades platform: three that are triggered by the user via the controller, one that occurs automatically at timed intervals and one that changes the default visual stimuli from wholly RW to a mix of RW and VR.

V. System Performance and User Experience

Mirrorshades was evaluated in three stages. In the first system performance was measured. The second assessed the utility of Mirrorshades as a mobile parallel reality platform in comparison to existing seated VR techniques used within a digital heritage context. The third investigated participants' preferences and reactions toward different transition styles. A combination of qualitative and quantitative data were collected, as the nature of the platform is such that purely quantitative data are not sufficient to gain true insight into its experiential aspect, but are nonetheless useful to corroborate or rebut qualitative responses and observations. In total 17 participants, 10x male and 7x female, with a mean age of 23.1 years and a standard deviation of 4.9 years, took part in these user studies, each lasting 20-30 minutes.

The overhead of capturing, processing and rendering camera streams resulted in a marginally lower framerate throughout the parallel reality scenarios than the seated VR scenario, as shown by Fig. 5. The seated VR scenario averaged 52.4 fps compared to 39.2 fps for the parallel reality scenario, representing a 25.2% difference. Note that the referesh rate of the DK1 is 60Hz and the Mirrorshades Unity application was run with vsync enabled (vsync limits framerate to the refresh rate of the display to avoid screen tearing) so any values shown above 60 fps in Fig. 5 is due to the method used to estimate fps. Measurement of the end-to-end latency of the C310 solution was performed by placing the DK1, with the lens cups removed, in front of a LCD monitor displaying a timer. The end-to-end latency refers to the time taken for a visible change in the scene in front of the DK1 (in this instance, the incrementing digits upon the monitor) to be reflected by a comparable change upon the DK1's display. This figure accounts for latency introduced by the C310 cameras themselves, by the Unity engine and by the DK1's display. Out of 11 pairs of frames compared, 7 pairs showed 181-198ms latency, while 4 showed 198-215ms latency.

Through questionnaire data and interview transcripts participants reported that overall they found the parallel reality scenario to be both more enjoyable and more rewarding than the seated VR scenario, despite the decreased usability and

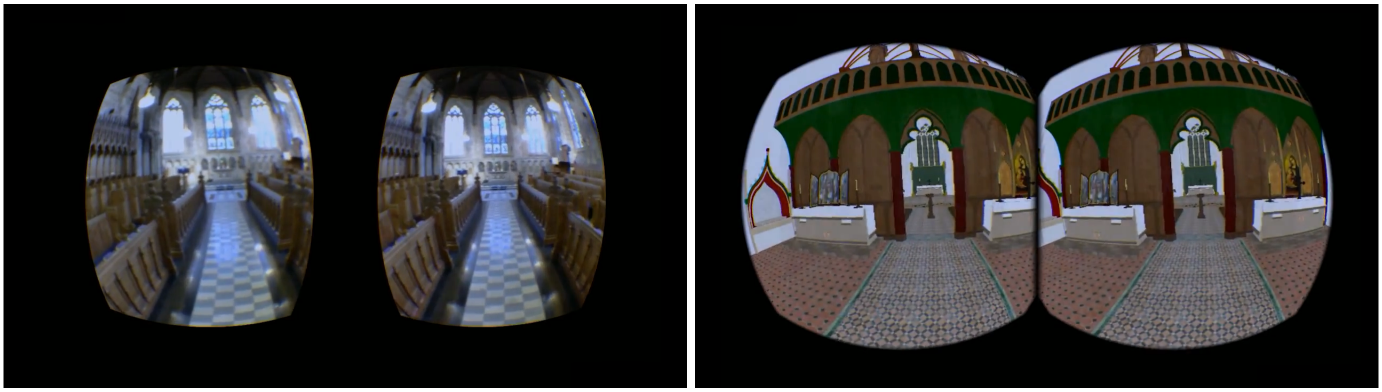

Fig. 4. Equivalent vantage into real and virtual St Salvator's chapel.

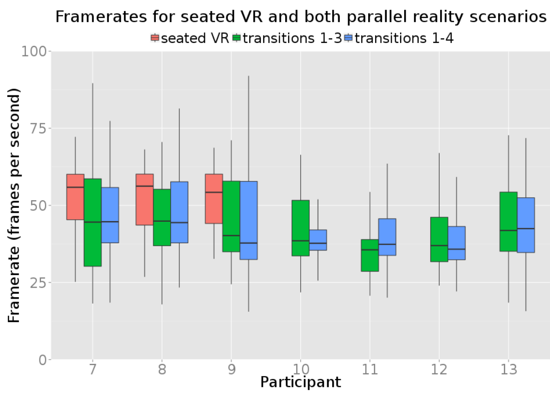

Fig. 5. Oculus Rift frame rate during use in St Salvator's chapel.

comfort effected by the requirement to don and carry a satchel of hardware and hold devices in both hands. The parallel reality scenario was reported as allowing easier comparison and contrast between RW and VR environments, leading participants to recognise more differences between the two environments and leading to greater learning and understanding of the chapel than with the seated VR scenario. The visual acuity afforded by the cameras and both the accuracy and lag of the IPS surfaced as the major detractors to the experience of the parallel reality scenario.

The third stage provided an insight into best practices for implementing future parallel reality experiences, by investigating preferences and reactions toward different implementations for performing transitions between RW and VR visual stimuli. Systems were compared where the user could switch between preset VR and RW mixes and where the mix was controlled by the degree to which the trigger was pulled. The latter proved the preferred system. It puts the user in control and enables them to superimpose VR visual stimuli upon default visual stimuli at any level that they wish.

VI. Conclusion

This paper has introduced an application which demonstrates how the parallel reality concept works as a new modality of interaction with complete real and virtual environments in tandem. It has presented and evaluated the Mirrorshades platform as an application of parallel reality in the field of digital heritage. The Mirrorshades platform has shown itself to be a rewarding new modality for experiencing VR content in a cultural heritage context. It improves upon seated VR techniques employed for the presentation of the same content as it allows immediate comparison and contrast between corresponding vantage points in both the RW and VR environments, successfully addressing the hindrance of on-site comparison of real and virtual environments with stationary virtual experiences.

Through questionnaire data and interview transcripts participants in user studies reported that overall they found the parallel reality scenario to be both more enjoyable and more rewarding than the seated VR scenario. The parallel reality scenario was reported as allowing easier comparison and contrast between RW and VR environments, leading participants to recognise more differences between the two environments and leading to greater learning and understanding of the chapel than with the seated VR scenario.

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