Towards Cross-Platform and Multi-Transport Real Time XR-Experiences

KATHARINA PÖHLMANN, University of Glasgow, United Kingdom
GRAHAM WILSON, University of Glasgow, United Kingdom
MARK MCGILL, University of Glasgow, United Kingdom
DANIEL PIRES DE SA MEDEIROS, University of Glasgow, United Kingdom
GANG LI, University of Glasgow, United Kingdom
STEPHEN BREWSTER, University of Glasgow, United Kingdom

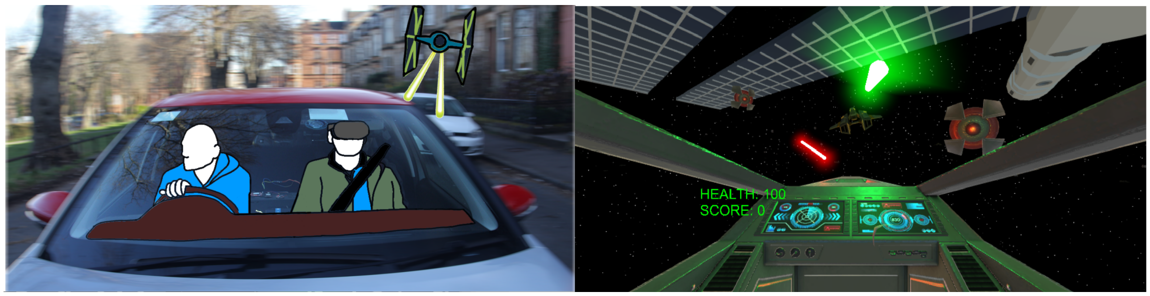

Fig. 1. PassengerXR allows users to experience various XR applications integrating the motion of the vehicle

We have developed *PassengXR*, an open-source in-vehicle motion platform and sensing toolkit for creating multi-user, location-based passenger eXtended Reality (XR) experiences on various types of transport. It senses the orientation (IMU), velocity (On-Board Diagnostic) and location (GNSS) of a vehicle and passes this data wirelessly to XR headsets in the vehicle, to render immersive experiences based on - or ignoring - vehicle movement. The public spend considerable lengths of time commuting and travelling, and immersive XR devices could help passengers pass the time more enjoyably or productively [6, 9, 11] through infinitely configurable virtual play/work spaces, or by incorporating the travel environment into more engaging experiences [7, 18, 19]. Automated vehicles are particularly promising, due to the potential addition of LiDAR, cameras, on-board navigation and low-level vehicle data streams. This kind of rich sensing environment is being used by Holoride [7] a closed, licensed platform limited to only specific high-end vehicles. As an open-source and off-the-shelf tool, *PassengXR* will allow any researcher or practitioner to create vehicular XR experiences. However, there are challenges in maintaining high-fidelity experiences on standalone devices in environments like vehicles. High frame rates and sensor sample rates need to be achieved to avoid motion sickness and maintain accurate real-time knowledge of current - and future - vehicle motion. Constrained processing power on standalone devices may mean that experiences need to balance visual fidelity, interaction complexity, and high performance in different ways, depending on the purpose of the application. This paper aims to promote discussions about how to use rich vehicular sensor data for creating passenger experiences, and how to balance the technical and experiential requirements of high-fidelity applications.

Additional Key Words and Phrases: XR, Virtual Reality, Augmented Reality, Automated vehicles, transport

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1 INTRODUCTION

With the rise of automated vehicles, research and industry are increasingly interested in making use of, or counteract, the real motion (speed, orientation, etc.) and location of the vehicle for the redesign of the interior of the car and to design novel experiences for passengers that can use the travel time for leisure, entertainment or productivity [4–7, 20]. Research into in-vehicle eXtended Reality (XR) designs comes with particular challenges: high cost (e.g., driving simulators, buying/hiring real cars, expensive sensors), maintaining stable and accurate tracking, developing the necessary functionality, limited access to real driving data, etc.

This research area is readily growing with toolkits or platforms being developed providing templates and open-source codebases for detecting utilising data about the vehicle movements as well as the passenger within. One of the crucial challenges to overcome being the separation of head motion sensed by the Head-Mounted Display (HMD) and vehicle motion, so that car motion does not affect the passengers experience in VR [12, 14].

PassengXR uses an Inertial Measurement Unit (IMU) to track the vehicle orientation, combined with a GPS/GNSS sensor and On-Board Diagnostic (OBD-II) port connection for polling vehicle velocity [4–6, 20]. The data can now be used to match the motion of a virtual vehicle in Unity to the movements of the real car, while allowing for separate tracking of the passenger's HMDs. This allows the passenger to move their head around and view the virtual environment without the car orientation affecting this.

PassengXR to our knowledge is one of the first platforms that allows the use of standalone HMDs, thereby minimising the hardware necessary in the car eliminating the need for expensive and power-hungry laptop/PC VR setups. Our platform has been tested with various types of commercially available headsets (Meta Quest 2, Pico Neo 3 Pro, Pico G2 4k Enterprise and HTC Vive Focus 3) to investigate the gyroscopic yaw (y-axis) drift over time which can occur based on the IMU-sensors in the vehicular set up, particularly in a vehicle that is frequently turning. We found that some headsets are more suitable for the use in in-car XR experiences (e.g., Pico Neo 3 Pro) while others seem to struggle with higher levels of yaw drift (e.g., Meta Quest 2). This, however, does not mean that these headsets can not be used for in- vehicle experiences with our set up. The motion platform allows for the realignment of the headset drift by using reference points in the in-car environment (e.g., VR controllers) this is done at certain time points throughout a route and might be noticeable to the user.Additionally, the Unity application part of *PassengXR* can based on the orientation, velocity and world position data of the vehicle and the orientation and position data provided by the headset and controllers apply alignment and drift correction that should go unnoticed by the user.

Again, to our knowledge *PassengXR* is also the first platforms that provides tools to play back vehicle telemetry in the lab allowing researchers to test XR designs in various driving environments. The data recorded during a *drive* can be played back within Unity in real time recreating the same movements and events as experienced in the real car journey. This feature also allows researchers that do not have access to a vehicle to design virtual interfaces to test real car movements in virtual scenes.

In this paper we present some of the use cases for *PassengXR* investigated by our team and future challenges for passenger XR. We are hoping that this workshop will give us the opportunity to further discuss the challenges of balancing visual fidelity, interaction complexity, and high performance.

2 OUR WORK SO FAR

Our group (ViAjeRo; https://viajero-project.org/) has been working on various XR applications using PassengerXR.

2.1 *PassengXR* Motion Platform

PassengXR is an open platform for enacting passenger XR experiences in-car, with a reference hardware implementation and a Unity-based toolkit. The hardware consists of a SparkFun ESP32 Thing Plus Arduino microcontroller in a car connected to a SparkFun 9DoF IMU (for orientation), SparkFun OBD-II (for velocity), and SparkFun GPS-RTK Dead Reckoning (for GNSS/location). The Thing Plus broadcasts this data wirelessly to other Thing Plus boards in the vehicle, which then pass the data over USB serial connection to our Unity toolkit running on the XR headset. We use and recommend the Pico Neo 3 line of headsets, as they exhibit minimal IMU orientation drift when being used in-car. The Unity toolkit parses sensor data (via Protobuf) into scene-independent ScriptableObject (SO) assets that expose multiple custom data providers, such as Orientation, Velocity and WorldPosition. Using Unity XR plugins, all headset and controller input is similarly used to populate an XR Device SO exposing it's own Orientation and Position data providers. These providers are then fed into a Motion Platform Configuration SO, which enacts alignment, drift correction, XR input and vehicle reference frame movements within the Unity scene based on this data. This provides highly flexible access to all sensor/data types to be used in a Unity scene in any way the designer sees fit.

2.2 Motion Sickness Mitigation

Motion sickness in VR headsets as well as in vehicles is primarily believed to be caused by a conflict between self-motion information coming from the visual and vestibular systems[16, 17]. When passengers are engaged in non- driving related activities in the car, such as reading a book, watching a movie or working, their view of the external world is often limited, meaning they receive self-motion information from the vestibular system while not perceiving any matching visual input resulting in motion sickness. The real-time motion capture capability of *PassengXR* giving information about the vehicles motion profile and orientation allows us to integrate visual motion stimuli in the virtual environment displayed in an XR headset that matches the motion information perceived by the vestibular system (see Figure 1). Integrating virtually presented visual motion information in line with vestibularly perceived motion has been shown by our group to have beneficial effects on motion sickness in an in lab study using a rotating chair and has been found to be a potential motion sickness mitigation technique in other research using motion simulators as well as cars [2, 3, 8, 10, 13].

PassengXR also allows for easy integration of additional sensors. In the context of motion sickness research we have integrated three additional physiological sensors that serve as objective measures of motion sickness. The platform records now also heart rate, fingertip temperature and pupil diameter measured by Bluetooth devices, the HMDs and cable based sensors. In future settings these measures could be used in an online feedback loop. When an increase in motion sickness is detected the platform could adapt what is visually presented to the user to reduce adverse symptoms experienced.

2.3 Productivity

XR offers significant benefits for productivity, the passenger's workspace is no longer restricted by the physical dimensions of the space or displays. Our group has already conducted research into the effective, comfortable and socially acceptable design of virtual workspaces in XR [11] with other groups investigating their usability in transport (e.g., cars or planes [9, 15]). XR allows passengers to interact with an unlimited number of virtual windows from a seated position and in a limited physical space, see Figure 2. Motion platforms, such as *PassengXR* , can not only provide a more productive workspace but also allow for the integration of motion sickness mitigation strategies (visual motion cues) that can be presented in a fashion that lead to no or minimal distraction from the primary productivity task while ensuring the comfort of the passenger [2],

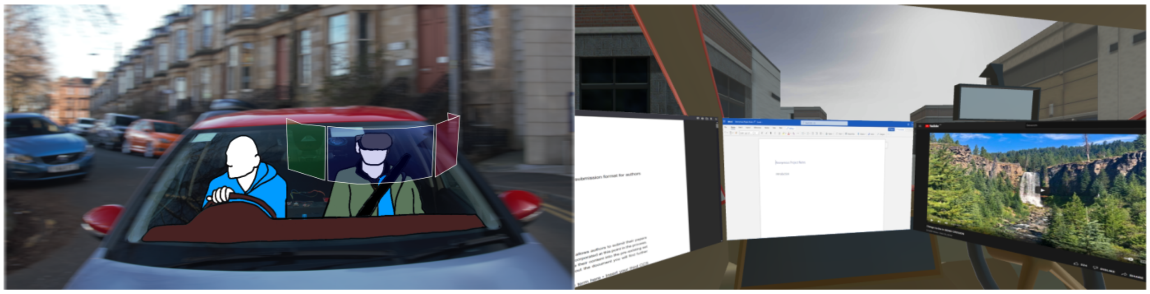

Fig. 2. Example of a Productivity Use Case

2.4 Entertainment - Integrating Vehicle Motion into Games

The car motion can not only be used in the background to mitigate motion sickness, but we have also started integrating it directly into the virtual experience, using the vehicle motion in game. Our group is currently designing a space shooter game (see Figure 1) that integrates the car orientation by rotating the virtual vehicle (spaceship) and the car motion (velocity, acceleration, deceleration) by moving the ship through space. Passengers can now spend their time traveling fighting aliens/space enemies. Integrating the vehicle telemetry into the game is not only entertaining for the passenger but has also beneficial effects on motion sickness. Holoride advertises a similar experience on their website [7] they, in turn also seem to integrate the car's surroundings (pedestrians, other cars, etc.) into the virtual experience. This is something our group is currently working on in an AR context. Integrating the world outside the car window into a virtual game, for example using the objects outside the window (trees, houses, other vehicles) as platforms in a sort of 2D platform game, allowing the passenger to control a virtual player through this world jumping from one platform to the next.

2.5 Location-Based and Shared XR Experiences

PassengXR also allows for Location-based experiences using GNSS positioning. This can be used for various passenger XR scenarios, such as location based gaming (as mentioned above) [19] or augmented tourism [1]. Applications could also integrate live Google (maps) data informing the passenger about events happening around them or giving them information about businesses around them, for example displaying reviews for restaurants or how busy the restaurants are.

PassengXR also allows for multiple passenger usage, supporting up to 10 users at a time. Multiple headsets in the same vehicle can receive the vehicle telemetry data without having to add more sensors or change the set up. Each passenger could for example play through the same game (e.g. the space shooter game mentioned above) or they could choose an individual experience more suitable to their current needs and mood.

The platform also allows for shared multi-user experiences in the car for the first time. The users can see the others' actions and movements in the shared virtual space. This provides new opportunities for in-car XR, such as watching a movie together, collaborating on a task, playing multiplayer games and much more. This setup could also be used on other forms of transport such as trains, planes or busses. Here we give the example of a tour bus (see Figure 3), giving a group of passengers a shared location-based experience. These people are viewing the same virtual experience and can see each other in this shared space. The bus could drive through a city and the motion platform would provide location-based AR overlays on historical buildings. When the bus passes by such a historical building, location-based triggers cause AR-like overlays to appear, and the users can interact with this overlay and can interact with the other passenger to for example draw their partner's attention to it.

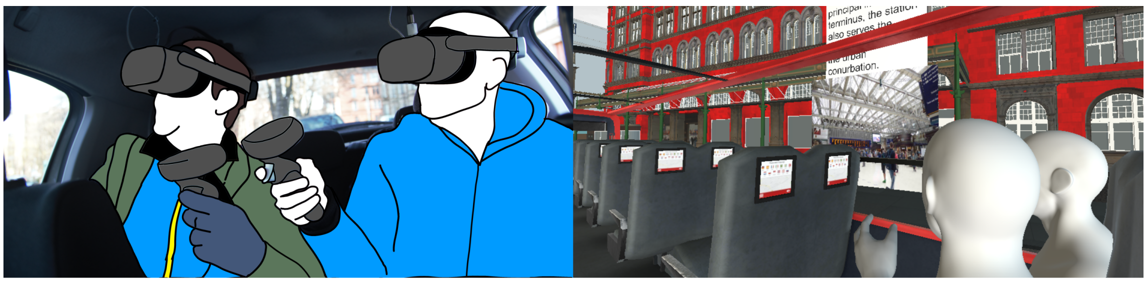

Fig. 3. Example of a Productivity Use Case

3 FUTURE OF PASSENGER XR

One big challenges still to overcome is the integration of such a platform on public transport. For all passengers to perceive an accurate experience that is representative of the experienced motion we ideally need telemetry delivered from the vehicle to all passengers. This, however, requires open standards/protocols and integrated sensing. Public transport also introduces additional needs, around contextual knowledge - from awareness of where you are on your journey, to when drinks are being served, to when other passengers or staff need to interact with the XR user. To support passenger XR in these even more challenging mobile contexts, we need both research and effort towards standardisation for cross-platform, multi-transit rules for sharing such contextual information. We have created a new toolkit that makes in-car XR possible supporting new mobile usage and contexts. This, however, is just the start of the challenge when it comes to real-time XR experiences in transport. To take full advantage of XR for the passenger experiences we need devices that can operate correctly and seamlessly across different modes of transport, integrating different motion profiles and accommodate for both functional issues, such as balancing high visual fidelity, interaction complexity and high performance, and social context, such as bystanders and social comfort.

4 CONTRIBUTION TO WORKSHOP THEMES AND GOALS

We created *PassengXR* as an open-source motion platform toolkit allowing researchers, game developers and the entire MobileHCI community to create in-car XR experiences. These can directly integrate the vehicle motion into the virtual environment by separating the car motion and rotations from HMDs. There are a few similar toolkits and platforms in the research and commercial spheres, however, they either focused on different use cases, require expensive hardware, have fewer features, or have restrictions in terms of who can access/use them. This work shows that the integration of IMU, OBD and GPS data through *PassengXR* can enhance the passenger experience in cars, by mitigating motion sickness, by allowing for a more productive work place set-ups (multiple screens), by allowing for interactive game play and by integrating location based and shared experiences.

We believe that this platform will allow for ground-breaking research by our team and due to its open-source nature by any other team interested in its use. As mentioned before there are however still many challenges to overcome, which we hope to discuss in this workshop. More information about our motion platform, the hardware needed and the unity-based toolkit needed to develop your own XR applications will be discussed in a future paper.

5 AUTHOR BIOGRAPHIES

Katharina Pöhlmann is a Post-doctoral Researcher in the School of Computing Science at the University of Glasgow (UofG) working on the ViAjeRo project (https://viajero-project.org/). She earned her PhD in Psychology at the University of Lincoln investigating the relationship of vection and cybersickness in VR. Her research focuses on using XR as a tool for motion sickness mitigation in moving vehicles focusing on multi-sensory cue integration.

Mark McGill (www.markmcgill.co.uk) is a lecturer (assistant professor) in the School of Computing Science at the University of Glasgow. His research explores the future of XR productivity (e.g. virtual workspaces, ergonomics, augmented peripherals) and XR-enabled passenger experiences.

Graham Wilson is a Post-doctoral Research Fellow in the School of Computing Science at the University of Glasgow, where he obtained his PhD in Computing Science. His research interests are in the beneficial and problematic use of Virtual and Augmented Reality technologies - particularly in terms of health and wellbeing - and it is currently designing novel VR/AR interfaces to improve immersive experiences in passenger transport. He previously worked on the design of multimodal, non-visual interface designs, including haptic, thermal and auditory feedback.

Daniel Pires de sa Medeiros is a Postdoctoral Research Associate at the University of Glasgow, focusing on the design of novel 3d user interfaces to overcome the physical limitations of restricted spaces in different forms of transportation. He obtained his PhD in Information Systems and Computer Engineering from IST, University of Lisbon. During his MSc in Informatics at PUC-Rio, Brazil he was part of the Virtual Reality and Digital Entertainment Group at Tecgraf/PUC-Rio, with a focus on developing VR-based novel interfaces for the Oil and Gas industry. Current research interests include Mixed Reality, Human Computer Interaction and 3D User Interfaces.

Gang Li is a Post-doctoral Researcher in the School of Psychology at the UofG also as part of the ViAjeRo project. He is committed to pioneering the integration of multimodal biosensing approaches with non-invasive brain stimulation techniques together to understand the neural mechanisms of VR-induced motion sickness so as to improve people's cognitive control abilities and improve the utility of consumer VR. This work involves the creation of illusory self-motion-inducing VR content, the development of wearable biomedical sensor systems for neural and physiological monitoring as well as the integration of non-invasive Brainwave Entertainment techniques.

Stephen Brewster is Professor of HCI in the School of Computing Science at the University of Glasgow. His research focuses on multimodal interaction, particularly haptics and audio. He specialises on in-car interaction for drivers and passengers, AR and VR and novel haptic displays. He was a General Chair of ACM CHI2019 and is a Member of the SIGCHI Academy.

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