A Software Application Framework for Developing Immersive Virtual Reality Experiences in Health Domain

Yifan Wang, Kiran Ijaz, and Rafael A. Calvo, *Senior Member, IEEE*

***Abstract*—Producing immersive virtual reality (VR) experiences for health is time consuming and expensive. Software application frameworks that combine design patterns and components have shown to be a way to reduce development costs and improve quality. This paper introduces VR-Rides, an object-oriented application framework for creating VR experiences that combines exercise equipment and panorama images. The framework employs Unity as the engine to connect and handle communications between different components including multiple VR devices (HTC Vive and Oculus Rift), sensors and physical activity devices (e.g. exercise bike or a Fitbit sensor) effectively. Panorama images from Google street view which developers combine with game narratives are used to produce experiences. The framework reduces the time and effort of developing VR experiences such as exergames and cognitive assessment. Three VR experiences built with VR-Rides are described.**

I. Introduction

Virtual reality has been used in different areas in health care such as surgical procedures, medical therapy, patient education, medical training, skill development and rehabilitation for more than twenty years [1]. Immersive VR where users experience being in a different world, has been used in education, training and other health [2][3] and wellbeing areas [4]. Expectations for these systems from the general public, companies and health professionals have increased dramatically due to the availability of new low cost immersive VR devices like the HTC Vive [5] and Oculus Rift [6].

Some of these expectations originate in the new ways for supporting motivation and engagement through the sense of immersion. Users can interact using hand controllers and other devices that help them feel they are being transported to new worlds. In fact, the literature has provided evidence that exergames can motivate people to be physically active and provide direct physical benefits [7][8]. Researchers are using immersive VR systems with different platforms and hardware to develop exergames that promote exercise, or other serious games. For example [9] describes a virtual reality cycling exergame which consists of Oculus VR headset, Microsoft Kinect, a bicycle and a customized virtual scene.

Although consumer VR systems are now affordable, content creation still requires a significant investment. In the context of health, particularly health research, such cost can be a significant hindrance to outcomes.

Software engineering techniques can be used to significantly reduce such cost, particularly through the creation of object-oriented application frameworks (OOAF) that combine domain-specific design patterns with software components [10]. Such frameworks have shown to reduce cost and improve the quality of software in many domains [10].

Besides reducing cost, such technique can improve quality through better design. Design patterns provide a common vocabulary and a reusable solution for object-oriented design. It is a mechanism for expressing design structures which “identify, name and abstract common themes in object-oriented design” [11]. Interaction design patterns can also be used [12]. A framework is a half-finished application that can be reused and specialized to produce custom applications. [10]. OOAF is a kind of software technology defined as a “reusable design of all or part of a system that is represented by a set of abstract classes and the way their instances interact” [13]. Essentially, an OOAF is a customizable application that consists of design patterns and components, which benefits developers with its modularity, reusability, extensibility and inversion of control [10].

The literature on using application frameworks in VR is scarce. *OpenTracker* is a framework that simplifies the development and maintenance of hardware setups through object-oriented design, introduced as “a first attempt towards a ‘write once, input anywhere’ approach to virtual reality application development” [14]. *DIVERSE* is a highly modular collection of complementary software packages [15], with similar goals, to facilitate the creation of extensible and reconfigurable device independent virtual environments.

A few VR frameworks have focused in health care. *CyberMed* is a free framework for either new or expert programmers to develop VR based medical application for simulation [16]. *SOFA* is an open-source multi-modal framework, aimed at interactive computational medical simulations that facilitates collaborations of specialist from different domains through its independent components design and scene graph data structure [17]. In addition, with the help of PhysX-based framework, researchers in rehabilitation can use haptic elements and VR to customize experiments in the real world personalizing to the patient disability [18].

In this paper, we describe a new OOAF named VR-Rides that can help developers build VR experiences where people move in virtual worlds generated by panorama photos.

Our proposed framework allows developers to: (1) employ HTC Vive and Oculus Rift HMD easily in Unity [19], as well as responding VR controller operation; (2) use Google street view panorama images as virtual environment and customize their own locations through XML configuration files, without programming; (3) use different types of inputs for movement in game, such as DeskCycle [20], sensor attached to a

*Research supported by Charles Perkin’s Centre, University of Sydney.

Corresponding author: Yifan Wang (e-mail: yifan.wang@sydney.edu.au)

The authors are with the Wellbeing-supportive Technology Laboratory, School of Electrical and Information Engineering, The University of Sydney, NSW 2006 Australia (e-mail: yifan.wang@sydney.edu.au, kiran.ijaz@sydney.edu.au, rafael.calvo@sydney.edu.au).

RAC is funded by the Australian Research Council Future Fellowship FT140100824.

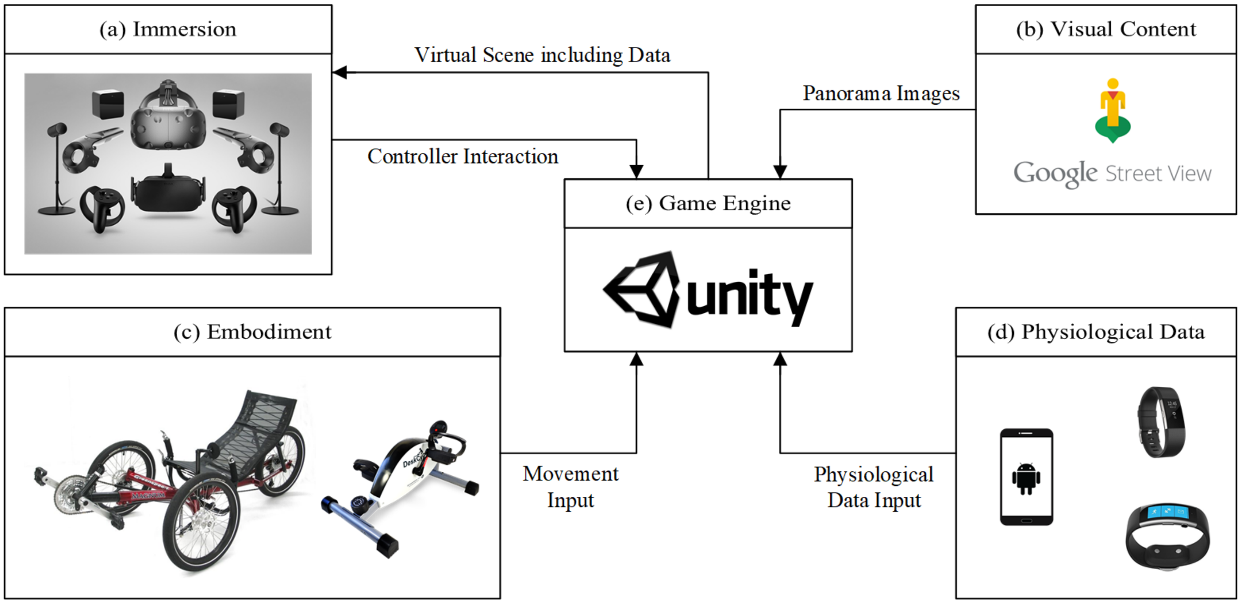

Fig. 1. An overview of VR-Rides architecture

recumbent trike [21], keyboard or even a controller, via different APIs we provide; (4) show physiological data in game and record as XML files after game finishes, through commonly used wrist bands like Fitbit [22] or Microsoft Band [23] without programming.

II. FRAMEWORK ARCHITECTURE

We implement our framework by separating the application in software components that act in different main roles, using the prototype pattern and component pattern introduced in "Game Programming Patterns" [24]. A VR-Ready computer running Microsoft Operating System (Windows 10) is used to connect the hardware and run the Unity game engine, while the game engine handles all the data and interaction from other components.

As shown in Figure 1 our proposed framework architecture, termed VR-Rides, consists of five major components: (a) VR platforms, namely HTC Vive and Oculus Rift, including the immersive VR headsets and hand controllers; (b) Google street view panorama images, used as virtual environment which is rendered to VR headsets; (c) recumbent trike or DeskCycle, which is used to control player's movement. It also could be a keyboard, a game controller, VR controllers or a joystick; (d) physiological data, captured through Fitbit or Microsoft Band and sent to computer through an android phone; (e) Unity, a game engine that connects all other components and deals with their communications.

A. *Immersion*

Our framework currently supports the latest commercial VR platforms: HTC Vive and Oculus Rift, which offers an immersive environment through headsets, as well as Oculus DK2. With the immersive VR headset, the user can experience a 360° view of his or her surroundings. The sense of immersion is achieved by tracking free head movements and enabling the user to move freely in multiple directions. This component facilitates the integration of controllers that provide new ways to interact with the VR environment and can increase the sense of immersion.

B. *Visual Content*

This component provides the *staging,* or visual content captured automatically from Google Street view panorama images and rendered to the VR headset by Unity. The staging provides the immersive stereoscopic views of uncountable geographic locations. The virtual scene (or 'stage') changes according to the user's current movement within the application. Google street view allows narratives to use an environment that is personalized or chosen by individual user.

C. *Embodiment*

VR-Rides provides the components to design games with a safe play environment that is suitable for different people. The physical interaction to the game environment is provided through a comfortable and stationary recumbent trike or other controllers. For example, a speed sensor and a smart phone are used to keep track of the player's pedaling in game. Besides, the trike can be replaced with a DeskCycle, as shown in Fig. 1. (c). Other interactions with game environment could be done with VR hand controllers.

D. *Physiological Data*

The proposed framework offers the functionality of showing and recording physiological data in a game, such as heartrate and calories burnt. Physiological data is captured through a Fitbit wristband or Microsoft Band. We developed an android application to pass the real-time data to Unity, so that developers can utilize these data to show physiological status in the VR application.

E. *Game Engine*

Our framework uses the Unity game engine, to connect all other components and process their interaction. According to the location we choose, Unity fetches panorama images from Google server and renders them to VR headsets, so that users

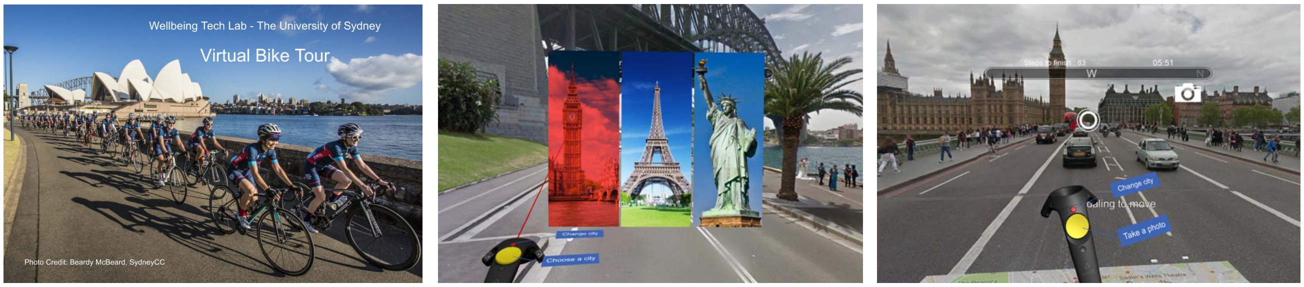

Fig. 2. Virtual Bike Tour game

can feel a 360° view of surrounding scene within VR. When user pedals the trike, data from speed sensor is passed to Unity, in which the user could move to the direction where he is looking at. Meanwhile, the user's real-time physiological data is kept passing to Unity and can be easily shown on a user interface (UI) component in VR headset and recorded into XML file. In addition, Unity will also respond to the VR controller according to developer's code.

III. Framework Implementation

We wrote the VR-Rides OOAF in C#, as a Unity asset package that can be easily imported to a Unity project. Our goal was to make it easy for developers to use. Thus, our components are modular and reusable. For most of them, we use a "drag and drop" method in our components, which means developers and researchers do not have to write code or scripts with these components.

Immersion, visual content, embodiment and physiological data, these four components are modularized into four Unity components, called prefabs in Unity, for reuse in different applications. To use a prefab in Unity, a developer drags it from the project folder and drop into a Unity scene. The process is the same as "copy and paste", without programming.

For the immersion component, the developer can use either HTC Vive or Oculus Rift headset with our prefab in Unity, without writing any code. Whereas when working with VR controllers, with our provided APIs, developers still need to add their own code to respond to customized controller button pressing. However, the amount of work has been reduced and the process has been simplified.

With respect to the visual content component, developers do not have to do anything with it since it works by default when they add our street view prefab into their Unity scene. In this way, they can have a 360° view of real-world imagery in VR easily. The only step left for developer is to add his or her customized location into an XML configuration file, or several locations that can be configured in the game.

To use the embodiment and physiological data components, VR-Rides provides android apps that receive data from speed sensor and wrist band, and also pass it to Unity so developers can process through their own code, or use the display and record function provided with our prefab by default.

In general, the developer can easily use our framework to build a VR platform where the virtual scene is generated by Google street view panorama images, with physical activity and physiological data integrated, meanwhile it requires little work to combine and work on those components. In the VR platform, if the developer chooses to use speed sensor or DeskCycle, he or she already has the functionality to move around in the virtual environment through our framework. Otherwise, we provide APIs to use with other controller as movement input. However, the main part of the application is to design developer's own game mechanism and narrative, as our framework saves time and effort on our components.

IV. Case Studies

The framework described above has been used to write the software in two VR riding games for health (competitive and affiliative) [25] and one psychological assessment. One of the goals was to evaluate our framework and the development of real VR experiences. In addition, we also tested the user engagement and motivation of our platform and software.

The first game experience implemented called "Virtual Bike Tour" was designed to be "affiliative" i.e., bring people together and is shown in Figure 2. In this game players use a recumbent trike to safely cycle in different cities with a guided tour that describes each location. During the game, VR controllers can be used to choose cities and take pictures of virtual scenes like the ones in Figure 2. Pictures can be shared with family or friends and used as conversation starters.

The second game environment was aimed to feel competitive. In this game players start in unfamiliar places initially. They need to navigate themselves close to landmarks to recognize those cites. A successful guess will lead players

Fig. 3. System setup using our framework

to the next level which is more difficult and they get scores based on time spent. Figure 3 describes the system setup built with our framework.

We evaluated the VR riding games with both young students in our university and older adults in a community centre (females = 21, males =20). The results showed that both our games were engaging ways to do exercise for different age groups. The use of a recumbent trike made it easy and comfortable for people to exercise, which in our case the participants aged ranging from 18 to 92. The employment of real-world imagery in VR engaged participants to keep pedaling to explore new places and positive response were showed in terms of psychological factors as well. Besides, real-world imagery recalled personal memories. Some seniors talked about their own experience and stories of a place when they saw it in VR. Results also suggested that most of the players were willing to register for future sessions.

The development of the two games in that study was done using VR-Rides. With VR-Rides researchers and developers could focus their efforts on game UI and narrative.

A third VR experience was psychological assessment for early cognitive impairment also at the community centre with healthy control group (n = 40, age = 50+). We are currently evaluating (in progress) a number of new game designs, all developed using VR-Rides. In this study VR-Rides has been used to develop a cognitive assessment for older adults, a possible mechanism for the early detection of dementia. Studies conducted were approved by The University of Sydney Human Research Ethics Committee (HREC) protocol number 2015/185 and 2016/629.

Through a combination of design patterns and software components VR-Rides provides a fast and simple development in adding different devices as inputs and real-world imagery as virtual scene, which reduces time and effort.

V. Conclusion

In this article, we introduced the idea of using a software application framework as a software engineering approach to VR development. The architecture of our framework VR-Rides, is modular with few components based on prototype pattern and component pattern. We aim to support and help developers to build their own interactive VR platforms and software with multiple devices through reducing their efforts in implementation. Feasibility is shown through the description of games developed using our framework for different HCI studies.

Furthermore, we envision several applications in the health domain using our framework. For instance, with the combination of real-world imagery and controllers, researchers in rehabilitation can create a VR application that helps user group such as disabilities to have tour of different places those are not accessible to them otherwise. In therapy area, e.g. therapy for legs or knees, developers could build a VR platform with DeskCycle or some therapy specific equipment for patients to have engaging experiences with real-time physiological status showed in-game. Moreover, psychologists may use our framework to develop a VR software that can help autistic children to recognize common public places and interact with the VR environment. Due to our framework's modular nature, it can be easily adapted and customized for new VR health applications.

Currently we are working on the release of our framework. In our future contribution of this framework, we will keep expanding its capabilities through adding more reusable devices, sensors and the functionality of allowing developers to build their own virtual environment according to different studies.

References

[1] J. Moline, "Virtual reality for health care: a survey," *Stud. Health Technol. Inform.*, vol. 44, pp. 3–34, 1997.

[2] M. Ott and L. Freina, "A literature review on immersive virtual reality in education: state of the art and perspectives," *Conf. Proc. eLearning Softw. Educ.*, no. 1, pp. 133–141, 2015.

[3] J. Dascal *et al.*, "Virtual reality and medical inpatients: A systematic review of randomized, controlled trials," *Innov. Clin. Neurosci.*, vol. 14, no. 1–2, pp. 14–21, 2017.

[4] R. A. Calvo and D. Peters, *Positive Computing: Technology for Wellbeing and Human Potential*. 2014.

[5] "HTC Vive." [Online]. Available: https://www.vive.com.

[6] "Oculus Rift." [Online]. Available: https://www.oculus.com.

[7] A. J. Daley, "Can Exergaming Contribute to Improving Physical Activity Levels and Health Outcomes in Children?," *Pediatrics*, vol. 124, no. 2, pp. 763–771, 2009.

[8] A. E. Staiano and S. L. Calvert, "Exergames for Physical Education Courses: Physical, Social, and Cognitive Benefits," *Child Dev. Perspect.*, vol. 5, no. 2, pp. 93–98, 2011.

[9] J. Bolton, D. Lirette, M. Lambert, and B. Unsworth, "PaperDude : A Virtual Reality Cycling Exergame," *CHI '14 Ext. Abstr. Hum. Factors Comput. Syst.*, pp. 475–478, 2014.

[10] M. Fayad and D. C. Schmidt, "Object-oriented application frameworks," *Commun. ACM*, vol. 40, no. 10, pp. 32–38, 1997.

[11] E. Gamma, R. Helm, R. Johnson, and J. Vlissides, "Design Patterns: Abstraction and Reuse of Object-Oriented Design," in *European Conference on Object-Oriented Programming*, 1993.

[12] J. Tidwell, *Designing Interfaces: Patterns for Effective Interaction Design*. 2010.

[13] R. E. Johnson, "Frameworks = (components + patterns)," *Commun. ACM*, vol. 40, no. 10, pp. 39–42, 1997.

[14] G. Reitmayr and D. Schmalstieg, "An open software architecture for virtual reality interaction," *ACM Symp. Virtual Real. Softw. Technol. Proceedings, VRST*, pp. 47–54, 2001.

[15] J. Kelso, V. Tech, S. G. Satter, L. E. Arsenault, P. M. Ketchan, and R. D. Kriz, "DIVERSE : A Framework for Building Extensible and Recon gurable Device- Independent Virtual Environments and Distributed," vol. 12, no. 1, pp. 19–36, 2003.

[16] L. S. Machado, R. M. Moraes, D. F. Souza, L. C. Souza, and I. L. L. Cunha, "A framework for development of virtual reality-based training simulators," *Stud. Health Technol. Inform.*, vol. 142, pp. 174–176, 2009.

[17] F. Faure *et al.*, *SOFA; a Multi-Model Framework for Interactive Physical Simulation*, vol. 11. 2012.

[18] A. D'Andrea, M. Reggiani, A. Turolla, D. Cattin, and R. Oboe, "A PhysX-based framework to develop rehabilitation using haptic and virtual reality," *IEEE Int. Symp. Ind. Electron.*, no. May, 2013.

[19] "Unity - Game Engine." [Online]. Available: https://unity3d.com/.

[20] "DeskCycle." [Online]. Available: http://www.deskcycle.com.

[21] "Greenspeed Magnum Recumbent Trike." [Online]. Available: http://www.greenspeed.com.au/magnum.html.

[22] "Fitbit Charge 2." [Online]. Available: https://www.fitbit.com.

[23] "Microsoft Band 2." [Online]. Available: https://www.microsoft.com/microsoft-band/en-au.

[24] R. Nystrom, *Game Programming Patterns*. Genever Benning, 2014.

[25] K. Ijaz, Y. Wang, D. Milne, and R. A. Calvo, "Competitive vs Affiliative Design of Immersive Exergames," in *Serious Games: Second Joint International Conference, JCSG 2016, Brisbane, Australia, September 26-27, 2016, Proceedings*, 2016, pp. 140–150.