Towards Usable Underwater Virtual Reality Systems

Raphael Costa*
University of Texas at San Antonio, USA

Rongkai Guo†
Kennesaw State University, USA

John Quarles‡
University of Texas at San Antonio, USA

ABSTRACT

The objective of this research is to compare the effectiveness of different tracking devices underwater. There have been few works in aquatic virtual reality (VR) - i.e., VR systems that can be used in a real underwater environment. Moreover, the works that have been done have noted limitations on tracking accuracy. Our initial test results suggest that inertial measurement units work well underwater for orientation tracking but a different approach is needed for position tracking. Towards this goal, we have waterproofed and evaluated several consumer tracking systems intended for gaming to determine the most effective approaches. First, we informally tested infrared systems and fiducial marker based systems, which demonstrated significant limitations of optical approaches. Next, we quantitatively compared inertial measurement units (IMU) and a magnetic tracking system both above water (as a baseline) and underwater. By comparing the devices rotation data, we have discovered that the magnetic tracking system implemented by the Razer Hydra is more accurate underwater as compared to a phone-based IMU. This suggests that magnetic tracking systems should be further explored for underwater VR applications.

Keywords: Virtual Reality, Underwater, Tracking, Rehabilitation, Games

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information SystemsArtificial—augmented and virtual realities;

1 INTRODUCTION

If VR systems could be used effectively in real underwater environments, there are many potential beneficial applications, such as entertainment, SCUBA diver training, and aquatic rehabilitation. Aquatic rehabilitation [4] is a recommended rehabilitation approach for many injuries and disabilities because it keeps patients cool, results in low stress on patients' joints, and offers additional resistance to improve exercise effectiveness. The increasing use of aquatic rehabilitation and the benefits of land-based virtual rehabilitation heighten the need for usable and accessible VR systems that work underwater. However, there are very few VR systems that have been developed for use in real underwater environments. The first instances of adapting a VR or augmented reality (AR) system for underwater use was Blum et al. [2] and Morales et al. [5] underwater AR system, in which the users had a waterproof video-see-through head mounted display that enabled them to swim in a real pool with virtual fish or visualize commercial diving assembly tasks, respectively. Since then, research has been conducted to develop systems for AR enhanced underwater vehicle tele-operation[3]. More recently, underwater VR/AR systems - DOLPHYN[1] and AREEF[6] - demonstrate that underwater VR/AR games are possible. However, the usability issues are not well understood and technical challenges are complex. Moreover, little is known about usability of underwater VR/AR for persons with disabilities in aquatic rehabilitation games. The primary objective in this paper is to provide a better understanding of tracking performance for underwater VR rehabilitation games.

Based on the limitations of previous works, we evaluated and compared several off the shelf orientation tracking approaches including optical, magnetic, and inertial. This paper presents these results and offers suggestions on how to design aquatic VR systems in the future.

2 OPTICAL TRACKING FOR UNDERWATER VR - PRELIMINARY EXPERIMENTS

To investigate the best approaches for optical tracking underwater, we performed several informal experiments with a Microsoft Kinect 360, a Naturalpoint OptiTrack motion capture system, and fiducial marker tracking (i.e. Vuforia) in a swimming pool.

To test these approaches underwater, we used a small aquarium to keep the devices dry and sank half of the aquarium into the swimming pool. We attempted to minimize the distance between the glass of the aquarium and cameras of the devices to have minimum reflections from the glass. We firstly tested the Microsoft Kinect 360, because our ultimate goal is to explore a full-body tracking system for underwater VR. We pointed the Kinect to the front and bottom of the tank, with the bottom giving marginally better results. Although we could identify the shape of the objects seen from the Kinect camera within about one and a half meters, we still could not get the skeleton identified or calibrated.

Then we tried an infrared approach with an OptiTrack Naturalpoint Camera. We expected that the OptiTrack would yield better results underwater than the kinect as the intensity of the infrared of the OptiTrack camera could be adjusted. However, using a trackable object with three passive retro-reflective balls, the observation range was about half a meter from both the front and bottom directions. Lowering the infrared intensity of the camera and using another trackable object with 3 active infrared LED lights, the observation range extended to approximately 1.5 meters from both the front and bottom sides.

Lastly, we experimented with a fiducial marker tracking system on board a waterproof phone - Vuforia. Similar to previous reports by Oppermann et al. [6], we found that the visible light optical tracking did indeed work. However, it was slightly less effective than fiducial marker tracking above water and was subject to the same line of sight and environmental lighting limitations.

3 QUANTITATIVE COMPARISON OF MAGNETIC AND IMU UNDERWATER TRACKING APPROACHES

Due to the limitations of optical and IMU tracking, we aimed to evaluate magnetically tracked interfaces in an underwater environment. Based on previous studies, IMUs seemed to work effectively for orientation tracking underwater. Thus, we compared magnetic orientation tracking (i.e., a waterproofed Razer Hydra) to waterproof phone IMUs as a reference both above and below water.

3.1 Apparatus

The apparatus to test the tracking accuracy of the two approaches consists of a rod, Razer Hydra, Samsung Galaxy S4, and Sony Xperia ZR (Figure 1). A laptop is used to log data from the Razer

---

*e-mail: cicraphael@gmail.com
†e-mail: rguo70@gmail.com
‡e-mail: John.Quarles@utsa.edu

2017 IEEE Virtual Reality (VR)
March 18-22, 2017, Los Angeles, CA, USA
978-1-5090-6647-6/17/$31.00

Hydra while the phones log their own data. The Razer Hydra controllers are covered in silicone putty for waterproofing purposes. The Galaxy S4 is in a waterproof case and the Xperia ZR is waterproof by itself.

Figure 1: The apparatus has a Razer Hydra controller on each end with the Sony Xperia ZR on the right and and the Samsung Galaxy S4 on the left.

3.2 Procedure

In order to compare the accuracy of the different devices both in and out of the water, the devices were securely attached to the rod. When the experiment is performed, the logging system is then turned on and the apparatus is rotated around manually as one Hydra controller and one phone are underwater and the other Hydra controller and phone are above water. In our experiment movement was recorded for approximately 15 seconds.

3.3 Analysis

To analyze the data, we followed the methodology described in Sessa et al. [7]. First, the axes data were manually aligned due to the differing default alignments of the devices. Then, a base offset was computed and applied to align the orientations. Once the alignments were done, the phone axes were dynamically time warped in relation to the hydra using the statistics package R. The time warp aligns the data points so that any differences based on network or capture time latency minimally affect the error comparison calculations (Figure 2). Finally, we computed the root mean square (RMS) to analyze the differences in rotation between the devices.

3.4 Results

The differences in the rotation of the devices are calculated with a RMS and are shown in Figure 2 and Figure 3. In the underwater experiment, the hydra above water (HAW) to hydra underwater (HUW) comparison are the most consistent, never going above .1 error. The phone above water (PAW) to phone underwater (PUW) also shows consistency. The above water experiment show more consistent and slightly lower error than the underwater experiment, however, the Y axis shows far larger error.

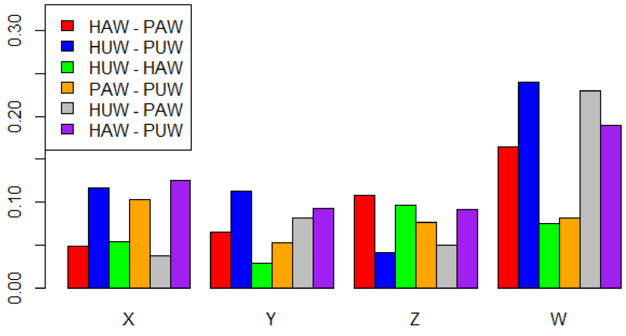

Figure 2: Underwater RMS Data

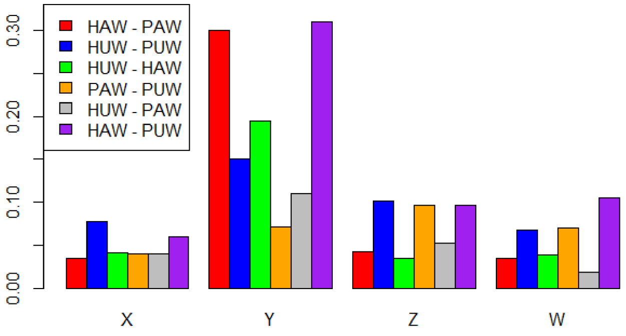

Figure 3: Above Water RMS Data

4 DISCUSSION AND CONCLUSION

The Underwater RMS data suggests that being in the water increases the error in tracking. The two hydra controllers compared to each other are generally on the lower end of error, which we attribute to the fact that they are wired to the same device. In both the underwater and above water studies, the comparisons with the PUW in general tend to be higher than the others. This suggests that the Galaxy S4's IMU is not as accurate as the Xperia's or the magnetic tracking of the hydra. The cause of the large error in the Y axis of the above water and the W of the underwater is not clear.

In this paper, we presented our studies on finding the most effective tracking system underwater. Fiducial marker systems work slightly worse than they do on land, but still need special preparations to obtain good results. The magnetic tracking system works well and has the least limitations.

For our current studies, we were limited to a short range of motion due to the Razer Hydra requiring a wired connection. Our future goals are to evaluate other systems such as acoustic tracking and eventually develop rehabilitation games that can accurately obtain position and orientation data.

ACKNOWLEDGEMENTS

This work was supported in part by grants from NSF.

REFERENCES

[1] A. Bellarbi, C. Domingues, S. Otmane, S. Benbelkacem, and A. Dinis. Augmented reality for underwater activities with the use of the dolphyn. In *Networking, Sensing and Control (ICNSC), 2013 10th IEEE International Conference on*, pages 409–412. IEEE, 2013.

[2] L. Blum, W. Broll, and S. Mller. Augmented reality under water. In *SIGGRAPH'09: Posters*, page 97. ACM, 2009.

[3] M. Chouiten, C. Domingues, J.-Y. Didier, S. Otmane, and M. Mallem. Distributed mixed reality for remote underwater telerobotics exploration. In *Proceedings of the 2012 Virtual Reality International Conference*, page 1. ACM, 2012.

[4] G. M. Gehlsen, S. A. Grigsby, and D. M. Winant. Effects of an aquatic fitness program on the muscular strength and endurance of patients with multiple sclerosis. *Physical Therapy*, 64(5):653–657, 1984.

[5] R. Morales, P. Keitler, P. Maier, and G. Klinker. An underwater augmented reality system for commercial diving operations. In *OCEANS 2009, MTS/IEEE Biloxi-Marine Technology for Our Future: Global and Local Challenges*, pages 1–8. IEEE, 2009.

[6] L. Oppermann, L. Blum, J.-Y. Lee, and J.-H. Seo. Areef multi-player underwater augmented reality experience. In *Games Innovation Conference (IGIC), 2013 IEEE International*, pages 199–202. IEEE, 2013.

[7] S. Sessa, M. Zecca, Z. Lin, L. Bartolomeo, H. Ishii, and A. Takanishi. A methodology for the performance evaluation of inertial measurement units. *Journal of Intelligent & Robotic Systems*, 71(2):143–157, 2013.