Accuracy of throwing distance perception in Virtual Reality

Karolis Butkus
Department of Information Systems
Kaunas University of Technology
Kaunas, Lithuania
e-mail: k.butkus@ktu.edu

Tautvydas Čeponis
Department of Multimedia
Kaunas University of Technology
Kaunas, Lithuania
e-mail: tautvydas.ceponis@ktu.edu

***Abstract* — This article investigates how people perceive distances in virtual reality (VR) and use that information to execute a representation of a real life throwing motion. In order to measure accuracy, this research proposes a throwing motion testing framework, which acquires metrics data from both the real and virtual environments. The results show, that the examinees tend to throw more accurately at longer distances and use excessive amounts of force.**

Keywords—virtual reality, perception, accuracy, throwing motion

I. INTRODUCTION

During the last decade virtual reality technology has significantly improved and is used in different technological spheres. The visual representation is becoming more realistic and looks more natural. Although technology is evolving, it is hard to replicate human senses. Therefore, this study tries to analyze how accurately people perceive virtual world distances when executing a throw.

This study presents a throwing motion testing framework to determine the differences between the virtual and real world's environment perception capabilities. It will discuss similar studies in the field related to perception and motion tracking, explain the testing framework and methodology, the experiment's process, discussion about the results and drawbacks of this study and the conclusion, possible future.

A similar project [1] to determine the perception of virtual reality was carried out in 2008 by researchers from Aachen, Germany. In their experiment, they asked 23 participants to estimate distances to virtual reality objects in three different environments. Results show that people tend to underestimate distances and that visual surroundings did not affect results considerably.

Another article checked people's ability to locate themselves in a virtual environment. Their task was to point at themselves in a VR platform using a pointer. The experiments results stated that participants most commonly locate themselves at the upper region of their face and that draws a conclusion that people in a virtual environment are more head-centered. [2]

A more recent study [3] was carried out by researchers from Iowa State University. The group examined prior attempts at improving distance perception in a Virtual environment (VE) and proposed a more thorough methodology to measure the results by isolating unaccounted variables in past studies. The experiment tested the participant's size and distance perception in a VE replica of a real world room with half of the examinees having seen the room prior to the experiment and half participating blindly. The first tested method for improved distance perception was visual replication of a real world environment, the second was walking interaction, which allowed participants to move around the virtual environment prior to testing. The results concluded that walking interaction significantly increased the accuracy of distance perception and size perception to a lesser degree. Furthermore, it was more effective than visual replication in both scenarios.

A similar study to research [3] was carried out at Clemson University in 2011 [4]. In this experiment, researchers investigated near-field egocentric distance estimations in an Immersive Virtual Environment and compared it to real world distances. The experiment examined two methods: verbal and reach measurements. Participants had to report distances verbally and then show it with their reach. Results show that both verbal and reach methods tend to underestimate distance and that with an increase in distance deviation also increased. Another interesting fact was that the verbal method was less accurate than the reach method.

The study [5] made by three researchers from the Dresden University of Technology attempted to find out what factors mostly affect people's estimations for distance in the virtual world. They arranged the factors in four groups: measurement methods, technical, compositional and human factors. The research concluded that people tend to underestimate distance and that to improve human distance recognition skills - a rich, detailed environment and powerful technical hardware must be ensured. Such as high quality graphics, carefully adjusted camera settings and virtual environment with a regularly structured ground texture.

As mentioned a few times in other researches people tend to underestimate distances in virtual reality and according to Steven M. LaValle, the cause for that could be different gaps between pupils [6]. If pupils in the real world are closer than in the virtual world, the virtual environment looks larger to the user and the other way round if the pupils are further apart in the real world.

II. THROWING MOTION TESTING FRAMEWORK

To determine the differences in perception between reality and a virtual environment, we focused on the different aspects of throwing kinematics in reality and VR. Three main characteristics are taken into consideration: throwing distance in reality, throwing distance in virtual reality and the initial velocity of the hand tracker in a throwing motion.

To measure the above mentioned features a throwing simulation framework was created. During the testing procedure participants throw a 10 gram ball to three different distances (2 meters, 3 meters, 4 meters) and a tracker attached to their hand transmits VR data which is recorded digitally, while real life distance is measured with a ruler. Each participant has three attempts at three distances with the virtual reality headset being used and another with it mounted on top of their head for tracking accuracy.

The testing system is developed using *Unity Engine* and *HTC Vive Pro* VR headset and tracker. The framework's visual environment is a replica of the room where the simulation was performed so it would not cause distractions to the participants. Distances at which the ball is thrown and standing position are marked in both the real and virtual environments (Fig. 1 and Fig. 2).

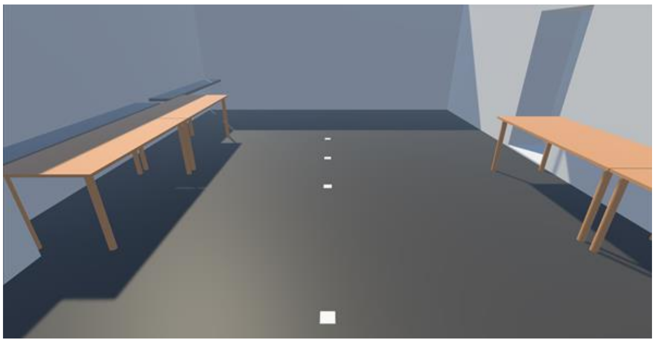

Fig. 1. *VR testing platform (user view)*

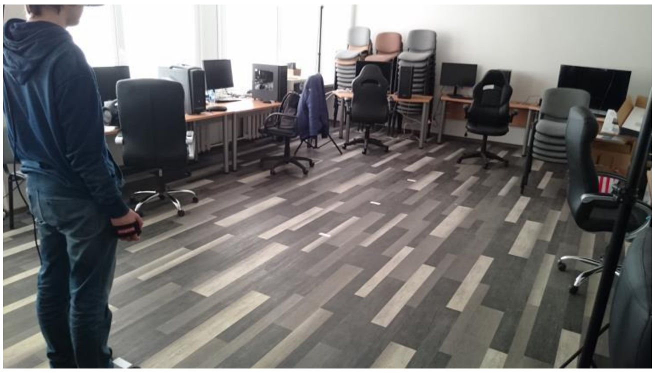

Fig. 2. *Real testing scene view*

In the experiment, *HTC Vive Pro* virtual reality headset and tracker are both connected to a personal computer with *Windows 10* operating system. The tracker's data collecting *Base stations 2.0* were placed at 5 meter distances from each other, at opposing corners of the room. The testing framework was built in *Unity 2018.3.5.f1* with an implemented *SteamVR* plugin. The original plugin's view for the ball throw scene was edited so that it would replicate the experiment room and the stock throw function was modified so that it didn't require any buttons to be pushed. The throw in the system is initiated when the tracker is swung and the velocity of the tracker starts to slow down after the constant increase in velocity at the start of the throw. The simulated environment replica consists of a 9 meter by 6 meter square room with an open top. The layout is positioned at the exact locations of real world objects.

To collect quite accurate motion data the tracker is attached to the palm of the participant and the ball is put on top of the device (Fig. 3). When the person executes a throw the tracker captures the initial velocity, and upon slowing down the system initiates a throw in virtual reality and sends the collected speed and data about the ball's collision with a ground surface to a text file. The real distance is measured with a ruler and all collected digital and non-digital data is saved in a spreadsheet.

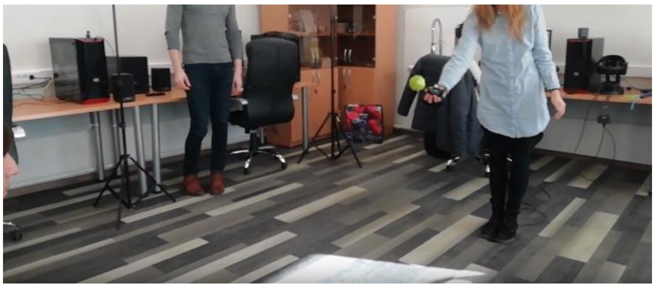

Fig. 3. *Ball throw in the experiment*

III. EXPERIMENT

The main goal of the experiment is to determine how accurate is a human's perception at determining distances using a virtual throwing mechanism compared to a real world throw.

The experiment participants were six people: 4 males and 2 females. The participants age ranged from 19 to 25 years (mean age 22.3), all of them were healthy and didn't suffer from VR sickness. At the beginning of the test, the participants were given time to practice throwing in virtual reality and get used to it. Then the examinees did three consecutive throws at specified distances without a headset and then they had three attempts with the virtual reality device. This process was repeated three times at three different shooting distances. During the experiment, participants were not allowed to move from the starting position. The collected distance and velocity data was saved in a spreadsheet.

The experiment's results are presented in Table I where every user's average thrown distance is shown in a centimeters format. Results of shots with virtual reality equipment and without it are separated and the total average of each baseline distance is calculated.

From Table I it is easy to see that people throw the ball most accurately at a distance of 3 or 4 meters when using the VR headset, whereas at the 2 meter mark there is a 10 centimeters deviation. However, with unobstructed vision people throw the ball more accurately at the first and third distances and in this case there is about a 10 centimeters deviation from the second distance. This data shows that with an increase in distance people's throws tend to become more accurate, whereas near distances are more difficult to judge.

TABLE I. AVERAGE THROWN DISTANCE WITH VR AND WITHOUT IT

USER	Reality			VR		
	200 cm	*300 cm*	*400 cm*	*200 cm*	*300 cm*	*400 cm*
1	189.667	298.000	378.000	215.000	326.000	414.000
2	207.333	301.000	389.000	204.667	307.000	398.333
3	212.000	295.333	382.667	198.000	301.667	375.000
4	167.667	268.667	389.000	164.000	277.667	478.500
5	183.000	286.000	415.667	178.333	301.667	407.000
6	217.333	278.667	428.667	182.000	301.667	347.667
AVG[a]	196.167	287.944	397.167	190.333	302.611	403.417
SD[b]	17.565	11.458	18.464	17.222	14.090	40.216

[a.] AVG – Average

[b.] SD – Standard deviation

In addition, from the bar chart shown in Fig. 4, which represents the average miss distance from a mark (negative value if it is shorter than the baseline distance and positive if the average value is greater), it is noticeable that the experiment participants tend to underestimate distances and throw the ball at a shorter distance. Only two columns show a slight ball overthrow and both belong to results achieved in virtual reality .

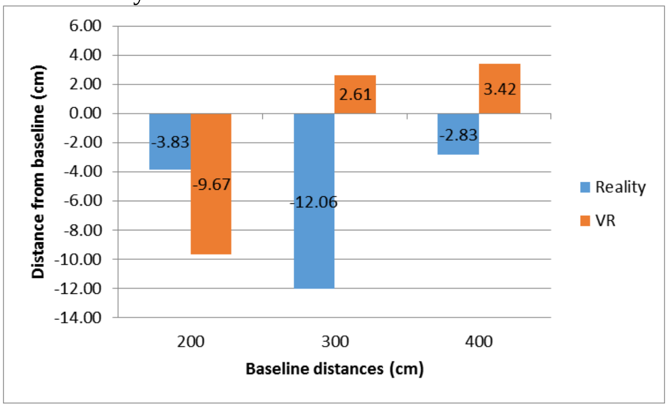

Fig. 4. *Average distance from baseline mark*

Table II shows every participant's standard deviation of three throws and average standard deviation which is about 17 centimeters. Therefore, it can be said that the experiment needs an increase in participants and throw attempts to make the experiment's data even more accurate.

TABLE II. THE STANDARD DEVIATION OF EACH PARTICIPANT THROWS

USER	Reality			VR		
	200 cm	*300 cm*	*400 cm*	*200 cm*	*300 cm*	*400 cm*
1	7.409	8.287	29.063	17.795	32.934	39.047
2	10.656	4.967	13.928	19.754	15.895	2.625
3	11.225	17.632	2.494	28.891	14.055	18.239
4	8.807	24.253	14.900	12.832	14.055	3.500
5	30.342	4.546	13.888	4.989	28.170	0.816
6	15.965	30.214	29.915	9.899	45.492	36.736

Data about the average initial velocity is presented in a clustered columns chart and a scatter graph (Fig. 5 and Fig. 6) where the baseline distances and different environments are separated. Besides average values, medians are given to make the data more accurate.

From Figures 5 and 6 it is noticeable that people tend to throw the ball with more power when they are in a virtual environment than when they are in the real world. This statement also is reaffirmed by the medians of all throws in real and virtual worlds.

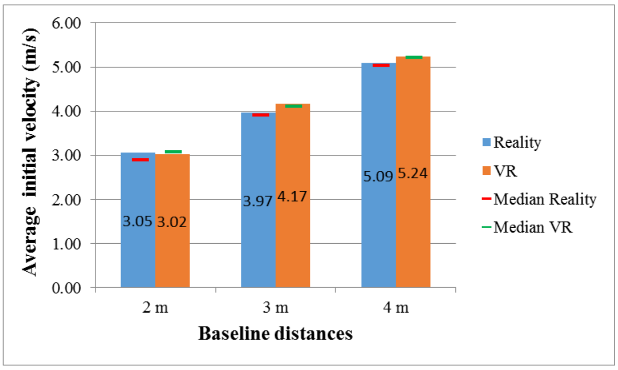

Fig. 5. *Average initial velocity and medians*

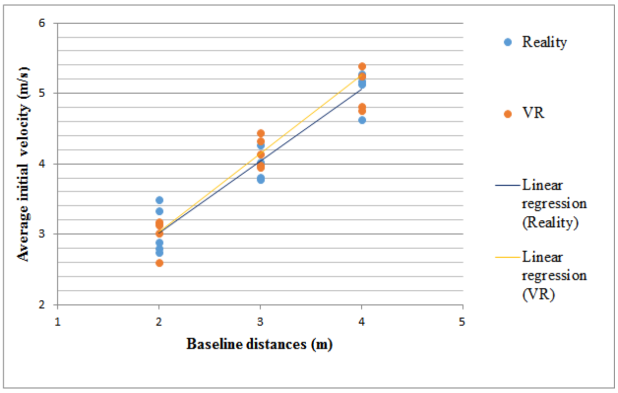

Fig. 6. *Average initial velocity linear regression*

IV. DISCUSSION

This study was conducted to find out how accurately people perceive the virtual environment and decide what amount of power is needed to throw the ball. To achieve this goal 6 participants took part in the experiment where they had to throw a ball at 3 distances with and without a VR headset.

After all tests, the collected data shows that people's accuracy with VR tends to increase with an increase in distance and that the average initial speed tends to be higher than pitching the ball without the headset. To explain the increase in velocity we could say that because people are more head-centered [2] in a virtual environment, they sense that distance is further than it actually is. Moreover, people are more likely to underthrow than overthrow the ball in real life and the increase in velocity when using VR allows their shots to be more precise. But when people are throwing close range shots the distances spread out and accuracy decreases.

These results show, that the described method can be used to calibrate hand strength in Virtual Environment fields, such as gaming [7], simulations [8], gesture recognition systems [9]. The motion force a person outputs in a fully immersed virtual system has to be decreased by 3 – 5 % to assure that the user's perception of his virtual strength matches the real world results and compensates their depth perception in a VE.

To acquire more accurate estimations we cannot forget that all velocity data is collected by a wireless tracker and the real ball that was put on the tracker could interfere with results and that could be a reason why the standard deviation for a few participant's throws was so high.

In addition, to help the person better comprehend the depth of a virtual world during the experiment it could be allowed for the participants to walk around the room as shown in research [3] and not undertake the whole experiment from a standing position while only having to trust their vision.

Furthermore, it was brought to the examinees attention, that to get more accurate results the participants had to do a bigger backswing while performing the throwing motion to get a more consistent velocity and more suitable throw initialization timings.

V. Conclusion and Future Works

In this study, we concluded, that people perceives 2 – 4 meter distances nearly the same as in real life. Moreover, people tend to use 3 to 5 % more power when throwing a ball in virtual reality than in real life. However, the used methodology needs improvement (some throws standard deviation is as high as 45 centimeters) to eliminate unnecessary factors, such as inaccuracy of manual real world measurements and signal integrity loss from ball position relative to the sensor. Furthermore, a larger pool of participants is needed to achieve precise data averages and calculations. There is also the possibility to attach a separate sensor to the ball that is being thrown by the participants, thus eliminating the need for real world measurements by allowing us to compare the data between both throws directly. Although the research is not perfect it has considerable potential to be used as a calibration tool for various virtual reality fields which involve hand motion and arm strength.

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