ACW2 CASE STUDY

Spatial perception distortion in a virtual environment result in a difficulty estimating distances over 1 meter within the varying overall graphical quality of a virtual environment.

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Design of Experiment and Plan of Implementation

Software to be developed

A virtual environment created within Unity. The virtual environment will have 3 variations in graphical quality. The first environment variation will be low fidelity and simple graphical details, such as no shadows, low textures. The second variation will have a higher fidelity with simple shadows and simple textures. The third variation will have an even higher fidelity with advanced shadows, high textures, and overall high tier graphics.

Hardware to be used

The hardware used for this experiment will be a standard desktop computer with a graphics card and an Oculus Rift VR headset. The PC will be used to create the Virtual Environment as well as power the Rift headset to view it.

Experiment

8 subjects (4 males, 4 females) will be chosen to partake in the experiment. The recruitment of the subjects will be based on a few factors. The first is their eyesight ability in the real world. Ideally, subjects will have normal, 20/20 vision and be able to judge distances rationally without the aid of glasses or contact lenses. Their ability to judge distances must be rather accurate and close to what the normal human can estimate.

The main experiment will consist of the user having to judge the distance between them and a specific object in their virtual environment. There will be three locations that the object can be within the environment, each of which the subject will estimate the distance between them and the object. The location of the object that the user must estimate is one of the independent variables of this experiment. Another independent variable is the overall quality of graphics within the scene. There will be three levels of overall graphic quality for the virtual environment consisting of: low, medium, and high.

The act of judging the distance of the object in each location will be repeated for each quality of environment, per subject. Overall, each subject will judge the distance of the object 9 times, 3 times in each environment variation. Each of which their estimated distance will be recorded which can be compared to the real distance.

The hardware used in this study would be using Unity to create the environment and its graphical variations and an Oculus Rift for the subjects to view them and complete the experiment

Data analysis to be used

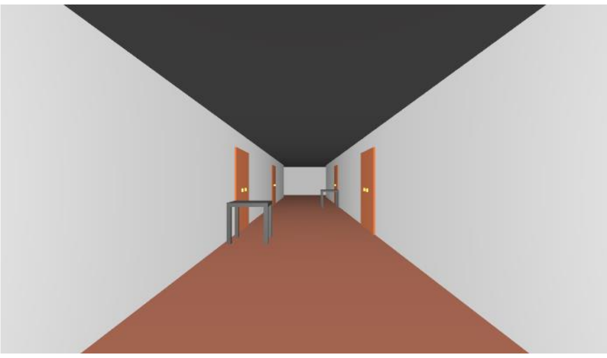
The data analysis will be done after the experiment has been completed. This will include, getting the mean of each location per graphics quality. Also, for each, the T-test will be used to gauge the variability of the data of each graphics and location to determine the difference between each participant's results in comparison to their peers. As well as this, the standard deviation will be taken for each graphic type and each location of object per location. This will express how much the data differs from the mean value.

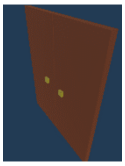
Implementation of Test Environment

The software produced for the experiment that will be carried out has been produced on the Unity Game Engine.

The software contains 3 graphical variations of the same environment: low, medium, and high.

The low environment consists of low poly assets, only one light source and basic textures





Low poly Assets

The medium environment has introduced shadows and multiple light sources, higher detail materials, and better-quality assets

Assets with light emitting materials

Assets with reflective materials

The high environment has improved lighting with better materials, higher details with height and occlusion maps for enhanced depth information

High poly assets

High detail textures with height and occlusion maps

The idea behind this is that the higher the overall graphical quality of the scene. The more depth information a user can pull from the scene and have a greater understanding of the depth from within.

Within the environment is a ball object, which will be placed at 3 different locations within each of the environments. The participant will have to estimate the distance between them and the object. This will be repeated for each environment, overall gaining 9 distance estimations per user.

Collecting Test Data

The collection of the test data occurred after the design and construction of the software that is used for the experiment. During the experiment, users were placed within the Virtual Environment and asked to estimate the distances between themselves, and objects placed in random locations per environment variation. Overall, there were 9 different locations that the user had to estimate the distance to. The process of taking the test data was in a linear, consistent pattern across all subjects. The subjects started off on the low-quality environment and then continued to the medium, then the high. Each environment started off with the closest object first, finishing off with the furthest away. The test subjects were in a seated position for the experiment.

Some things that we had to consider was the subject's use of subconscious bias when it came to estimating the location of the objects. If the objects were in the same location for each environment variation, the subject may re-use their previous estimations as they are aware the objects haven't changed locations. To combat this, we randomised the positioning of the objects, ensuring they weren't in the same place twice.

Overall, we used a total of 8 subjects to gather test data. An example of a subject's test data can be seen below. For each user we calculated the difference between the estimated distance and the real distance. This allows us to gauge how accurate the subjects' estimations were per distance as well as per environment variation.

Subject name	Estimated Distance (m)									
	Low graphics			Medium graphics			High graphics			
	Location 1 (m)	Location 2 (m)	Location 3 (m)	Location 1	Location 2	Location 3	Location 1	Location 2	Location 3	
Louis	1	2	7	0.5	4	10	1	3	6	
	Difference (m)									Overall difference
Difference	0	-1	-3	0	-1	-5	0.25	-1	-2	-12.75

Data Analysis

The independent variables of our experiment are the location of objects around a scene as well as the environment they reside in. The dependent variable is the distance that the subjects estimate.

The data holds each subject's estimated distance for each object in every environment. To calculate a score there and then, we calculated the difference between the estimated value and the real value for each estimation. The person's 'score' was considered the sum of the difference in estimations from the actual value. So, if the user estimated 5 meters and the real distance was 6 meters for a single object. They would have a score of -1. We determined the rankings of the subjects by comparing how close to 0 they were. The closer to 0 the overall score, the more "accurate" their estimations were.

Users estimations of distances per object within each environment									
	Low quality			Medium quality			High quality		
Subject	Location 1 estimati	Location 2 estim	Location 3 estim	Location 1 estima	Location 2 estim	Location 3 estim	Location 1 estim	Location 2 estim	Location 3 estimations
Louis	1	2	7	0.5	4	10	1	3	6
Dylan	0.5	2	5	0.3	3	7	0.5	2.5	5
Sam	0.5	2	6	0.3	3	8	0.5	3	4.5
Keeley	1	2.5	8	0.5	4	10	0.5	3.5	7
Wesley	0.75	3	8	0.2	4	11	0.5	3	7
Jackson	1	3	8	0.2	4	15	0.5	3	7
Fred	0.4	2.5	6	0.3	4	8	0.5	3	7
Kane	0.5	3	7	0.25	4	9	0.5	3	6

Estimations of distances for each user, per object, per environment variation

	Difference (m)									Overall difference
Difference	-0.5	-1	-4	-0.2	-2	-7	-0.25	-1	-3.5	-19.45
Overall error margin	-5.5			-9.2			-4.75			
Average estimation error margin	-1.83			-3.07			-1.58			

Example of the calculations used to determine the difference between estimated distance in relation to the real distance.

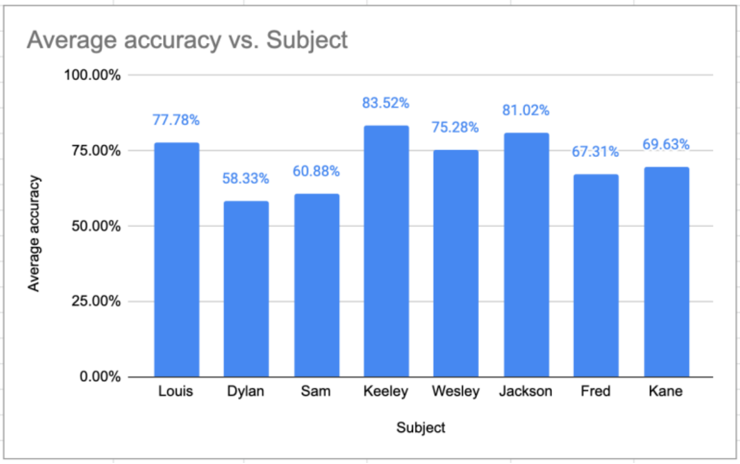
During analysis of the data, we found that using differences to estimate accuracy was inaccurate. For example, if you had a user that estimated a distance that was 50% inaccurate for both 1 meter and 10 meters. The 1-meter estimation could be -+ 0.5m, however the 10-meter estimation could be -+ 5 meters. This disparity in the accuracy meant that the users would score lower with the closer objects than with the objects further away. Because of this we shifted the determination of the accuracy to percentage difference in relation to the real distance. This was done by calculating the difference divided by the real distance, all deducted from 1. This gave us a percentage of accuracy.

Percentage of accuracy per users estimations of distances per object within each environment

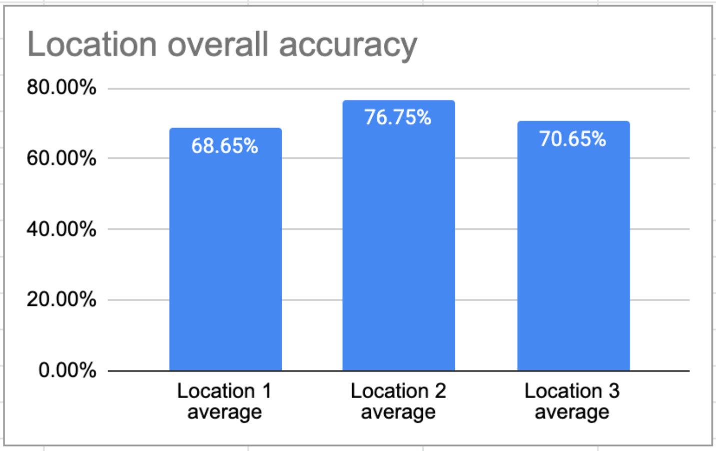
	Low quality			Medium quality			High quality			
Subject	Location 1 estimati	Location 2 estim	Location 3 estim	Location 1 estima	Location 2 estim	Location 3 estim	Location 1 estim	Location 2 estim	Location 3 estim	Average accuracy
Louis	100.00%	66.67%	70.00%	100.00%	80.00%	66.67%	66.67%	75.00%	75.00%	77.78%
Dylan	50.00%	66.67%	50.00%	60.00%	60.00%	46.67%	66.67%	62.50%	62.50%	58.33%
Sam	50.00%	66.67%	60.00%	60.00%	60.00%	53.33%	66.67%	75.00%	56.25%	60.88%
Keeley	100.00%	83.33%	80.00%	100.00%	80.00%	66.67%	66.67%	87.50%	87.50%	83.52%
Wesley	75.00%	100.00%	80.00%	40.00%	80.00%	73.33%	66.67%	75.00%	87.50%	75.28%
Jackson	100.00%	100.00%	80.00%	40.00%	80.00%	100.00%	66.67%	75.00%	87.50%	81.02%
Fred	40.00%	83.33%	60.00%	60.00%	80.00%	53.33%	66.67%	75.00%	87.50%	67.31%
Kane	50.00%	100.00%	70.00%	50.00%	80.00%	60.00%	66.67%	75.00%	75.00%	69.63%
	73.57%	**80.95%**	**68.57%**	**65.71%**	**74.29%**	**65.71%**	**66.67%**	**75.00%**	**77.68%**	72.02%
	74.37%			**68.57%**			**73.12%**			

Percentage of accuracy per subject estimation

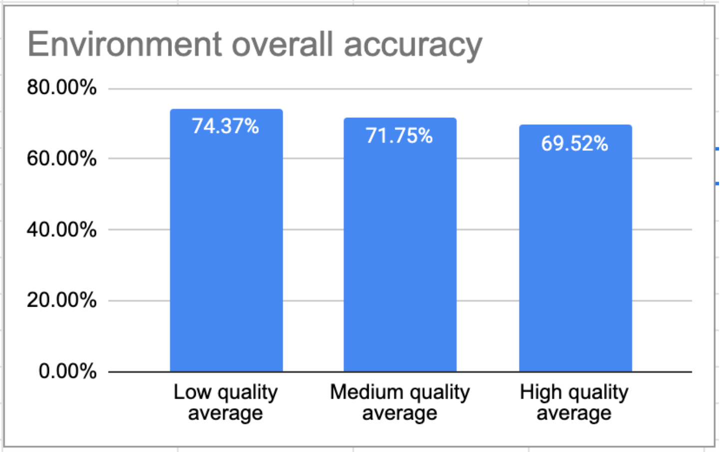
Upon switching the method of determining accuracy we found that the subject who 'scored' the lowest in terms of overall difference was not necessarily the most accurate at estimating the distances. From this data, we were able to produce charts to visualise the data as well as determine the average accuracy per location as well as per environment variation.



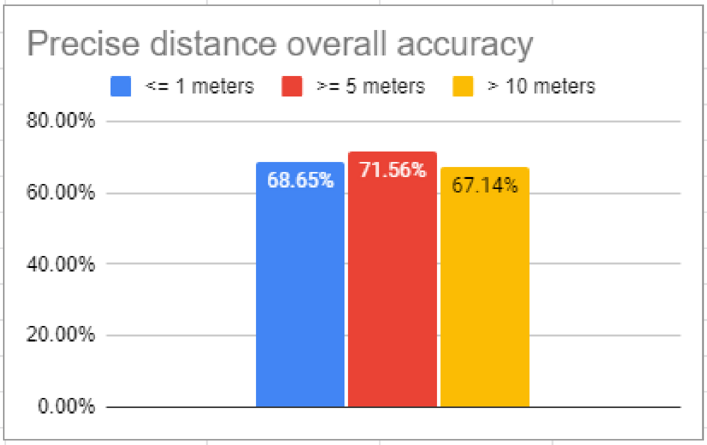
Average accuracy of each subject



Average accuracy of each location



Average overall accuracy per environment



Average accuracy of estimations across different distances

T-Testing

In order find out if the data collected is of significance, the t-test has been used to determine if there is a correlation between the quality of virtual environments and ability of depth perception. The null hypothesis for these tests is that higher quality virtual environments allow for better ability in depth perception, and the alternative hypothesis is that quality of environment has no effect on ability of depth perception. There have been 4 types of t-testing on the data acquired during the experiment. They are all paired samples, and the first 2 types were testing similarity in the estimates of the objects, one testing for similarity of two locations of the object in the same environment, and the other was testing same location of the object but in 2 different environments. The last 2 types of testing were for the accuracy of the estimation of the object, one for two locations of the object in the same environment, the other was testing same location of the object but in 2 different environments. For all tests, difference and noise are calculated to obtain a t-value, which we can use to see the real difference of the means between the two paired samples of data. Also calculated are the degrees of freedom, which is 14 because we had 8 samples, comparing two data sets of 8 then taking away 2 gives 14. Then finally is the t-test, which gives us a p-value, which shows the probability of obtaining our previously calculated t-value in its absolute form, if the null hypothesis is not rejected.

Similarity

The data shows that closer objects had a lower mean than further objects (Location 1 is closer to participant, Location 3 is furthest away). This trend is seen across all environments as seen in the data below. Standard deviation and varience also followed a simliar pattern. We could infer that closer objects are easier to gauge distance in a virtual environment than further away objects.

T -TESTING Similarity in estimates	Quality of Environments								
Paired samples	Low			Med			High		
	Location1	Location2	Location3	Location1	Location2	Location3	Location1	Location2	Location3
	1	2	7	0.5	4	10	1	3	6
	0.5	2	5	0.3	3	7	0.5	2.5	5
	0.5	2	6	0.3	3	8	0.5	3	4.5
	1	2.5	8	0.5	4	10	0.5	3.5	7
	0.75	3	8	0.2	4	11	0.5	3	7
	1	3	8	0.2	4	15	0.5	3	7
	0.4	2.5	6	0.3	4	8	0.5	3	7
	0.5	3	7	0.25	4	9	0.5	3	6
Mean	0.70625	2.5	6.875	0.31875	3.75	9.75	0.5625	3	6.1875
StandardDev	0.2624574795	0.4629100499	1.125991626	0.1193359603	0.4629100499	2.49284691	0.1767766953	0.2672612419	0.9977653603
Varience	0.06888392857	0.2142857143	1.267857143	0.01424107143	0.2142857143	6.214285714	0.03125	0.07142857143	0.9955357143
Number of samples	8	8	8	8	8	8	8	8	8

Location pairs (same environment)

As we can see from the data, the p-values are lower than 0.05 degrees of freedom, meaning that we reject the null hypothesis.

	Low			Medium			High		
Location Pairs	Loc1-Loc2	Loc2-3	Loc1-3	Loc1-Loc2	Loc2-3	Loc1-3	Loc1-Loc2	Loc2-3	Loc1-3
Difference(signal)	1.79375	4.375	6.16875	3.43125	6	9.43125	2.4375	3.1875	5.625
Noise	0.1881387928	0.4304275283	0.4087696588	0.1690143432	0.896421457	0.8823637845	0.1132908709	0.3651993096	0.3582571901
T-Value	9.534184701	10.16431272	15.09101732	20.30153142	6.693280212	10.68861865	21.51541409	8.728110696	15.70101077
Degrees of Freedom	14	14	14	14	14	14	14	14	14
T-Test(P value)	0.00001878502554	0.000000076309	0.000000019467	0	0.000010216074	0.000000678435	0	0.000000489801	0.000000011060

Environment pairs (same location)

In this set of data, we see similar results and can see that all are below 0.05 degrees of freedom, except for one set of data testing the closest placement of the object compared to low- and high-quality environments. This shows that the comparison of the environments with the highest disparity in quality and the closest objects may show that quality of virtual environment may play a role in determining the distance of an object that is below 1m.

Environment Pairs(sameLocations)	Low-Med(Loc1)	Low-Med(Loc2)	Low-Med(Loc2)	Med-High(Loc1)	Med-High(Loc2)	Med-High(Loc3)	Low-High(Loc1)	Low-High(Loc2)	Low-High(Loc3)
Difference(signal)	0.3875	1.25	2.875	0.24375	0.75	3.5625	0.14375	0.5	0.6875
Noise	0.1019344152	0.2314550249	0.967092476	0.0754081158	0.1889822365	0.949330121	0.1118782422	0.1889822365	0.5319061075
T-Value	3.801463905	5.400617249	2.972828423	3.232410695	3.968626967	3.752646125	1.284878965	2.645751311	1.29252135
Degrees of Freedom	14	14	14	14	14	14	14	14	14
T-Test(P value)	0.002422688139	0.000033165041	0.002185698988	0.001704471125	0.000805367429	0.00177268017	0.1357008539	0.01845152851	0.04517212617

Accuracy

The data shows that in further away objects, the mean get higher, showing further objects may be harder to estimate distances. However, in the higher quality environment, we can see that the difference in the means between the locations of the objects are much closer than in other environments, this could possibly mean that higher quality of environments gives better depth cues and therefore offer better distance estimations. Also, we can see that the means are all negative, meaning that that most participants underestimated values in a virtual environment.

T -TESTING accuracy	Quality of Environments								
Paired samples	Low			Med			High		
	Location1	Location2	Location3	Location1	Location2	Location3	Location1	Location2	Location3
	0	-1	-3	0	-1	-5	0.25	-1	-2
	-0.5	-1	-5	-0.2	-2	-8	-0.25	-1.5	-3
	-0.5	-1	-4	-0.2	-2	-7	-0.25	-1	-3.5
	0	-0.5	-2	0	-1	-5	-0.25	-0.5	-1
	-0.25	0	-2	-0.3	-1	-4	-0.25	-1	-1
	0	0	-2	-0.3	-1	0	-0.25	-1	-1
	-0.6	-0.5	-4	-0.2	-1	-7	-0.25	-1	-1
	-0.5	0	-3	-0.25	-1	-6	0.25	-1	-2
Mean	-0.29375	-0.5	-3.125	-0.18125	-1.25	-5.25	-0.125	-1	-1.8125
StandardDev	0.2624574795	0.4629100499	1.125991626	0.1193359603	0.4629100499	2.49284691	0.2314550249	0.2672612419	0.9977653603
Varience	0.06888392857	0.2142857143	1.267857143	0.01424107143	0.2142857143	6.214285714	0.05357142857	0.07142857143	0.9955357143
Number of samples	8	8	8	8	8	8	8	8	8

Location pairs (same environment)

In this set of data, we can see that in the low-quality environment, the first and second location for the object has a p-value that is above the 0.05 degrees of freedom, meaning that we could infer that in distances between 0-1m and above 1m, accuracy of the depth perception of an object is affected due to the quality of the environment. All other p-values are lower than 0.05, making the first p-value an outlier compared to the other t-tests which may mean that the reliability of this claim is also affected.

	Low			Medium			High		
Location Pairs	Loc1-Loc2	Loc2-3	Loc1-3	Loc1-Loc2	Loc2-3	Loc1-3	Loc1-Loc2	Loc2-3	Loc1-3
Difference(signal)	0.20625	2.625	2.83125	1.06875	4	5.06875	0.875	0.8125	1.6875
Noise	0.1881387928	0.4304275283	0.4087696588	0.1690143432	0.896421457	0.8823637845	0.125	0.3651993096	0.3621303534
T-Value	1.09626514	6.09858763	6.926272387	6.323427821	4.462186808	5.744512738	7	2.22481253	4.659924207
Degrees of Freedom	14	14	14	14	14	14	14	14	14
T-Test(P value)	0.2792699375	0.00002749157	0.00005173563	0.000018800526	0.00053670073	0.00035616300	0.00000624795	0.04304773692	0.00212112370

Environment pairs (same location)

In this set of data, we can see that there are multiple instances of where the p-value is higher than the 0.05 degree of freedom. The Low-Med (Loc1), the Med-High (Loc1), the Med-High (Loc2), and the Low-High (Loc1) sets of data all receive a p-value that's above the degree of freedom.

Environment Pairs(sameLocations)	Low-Med(Loc1)	Low-Med(Loc2)	Low-Med(Loc2)	Med-High(Loc1)	Med-High(Loc2)	Med-High(Loc3)	Low-High(Loc1)	Low-High(Loc2)	Low-High(Loc3)
Difference(signal)	0.1125	0.75	2.125	0.05625	0.25	3.4375	0.16875	0.5	1.3125
Noise	0.1019344152	0.2314550249	0.967092476	0.09206824914	0.1889822365	0.949330121	0.1237211366	0.1889822365	0.5319061075
T-Value	1.103650811	3.240370349	2.197307965	0.61095981	1.322875656	3.620974331	1.363954492	2.645751311	2.467540759
Degrees of Freedom	14	14	14	14	14	14	14	14	14
T-Test(P value)	0.2216014191	0.00080536742	0.01025954956	0.5068471931	0.1035517103	0.00216084716	0.1932155176	0.01845152851	0.00235229602

Conclusion

From the findings of the data analysis, we found that the results were interesting in relation to the proposal of this study. We hypothesised that the lower the environmental graphics, the less accurate subjects would be able to estimate distances of objects. However, the results show that the low-quality environment scored highest overall in terms of subject estimation accuracy with 74.37%. This is surprising due to the lack of depth information the environment provides, which is ordinarily the main aid in perceiving the space around an individual. The high-quality environment scored the lowest in terms of overall accuracy with 69.52% which conflicts with our expectations. Due to this, we propose another study be taken place to explore the reasons why this occurred.

Although the accuracy of the estimations was the lowest, subjects scored the lowest overall margin of error in this environment, on average scoring '-1'. Medium scored '-2.23' and low scored '-1.31'. These results fit the hypothesis of the study as the high-quality environment scored the lowest error margin of estimations. As this is not accuracy in relation to the real distance however, it's not being counted as accuracy of estimation, only margin of error.

Another interesting find was the distance that was most accurately estimated. We proposed in our hypothesis that the closer an object is to a subject, the more accurately they would be able to estimate the distance. We theorised that binocular disparity would play the biggest part in this as the disparity becomes less noticeable the further away an object is. However, from the findings we found that distances greater than or equal to 5 meters, subjects estimated with a higher accuracy than less than or equal to 1 meter (see chart above, labelled 'Precise distance overall accuracy').

Although in terms of accuracy of estimations for distances lower than 1 meter did not perform the best, it did in fact render the lowest margin of error per subject. On average, the objects in locations less than or equal to 1 meter, on average, were estimated with only a -0.22m margin of error. This means that each subject on average estimated the distance within 0.22m of the real distance, which supports the hypothesis of this study that subjects can estimate distances more accurately at distances less than 1 meter. Objects further than 1 meter scored -2.16m on average, which means that subjects estimated distances -2.2m less than the real distance on average

Another finding was that every subject underestimated the distance of the objects. This was not surprising due to the spatial compression and reinforces the proposals of other studies that it relates to. Although not important to our study, the findings were still interesting.

Overall, depending on how you look at the results, the analysis of the data shows that the hypothesis of this study was true and can be reinforced by the data found in the experiment. Overall subjects estimated objects at 1 meter or less to a 0.22m accuracy, whereas distances over 1 meter were estimated as -2.2m on average. However, if you look at the results and turn each estimation into a percentage of accuracy based on the real distance. It shows that the objects within 1 meter scored an overall accuracy of 67% as well as distances over 10 meters. But medium distances that were greater than 5 meters scored 72% accuracy. As the results of these are not definitive and there is no distinct boundary between accuracy. We are counting these results as every subject scored around 70% accuracy on each distance they estimated.

Similarly, we also found the results to reinforce the proposal that the greater the overall quality of the environment, the more accurately subjects can estimate distances. This is reinforced by the fact that subjects on average were only off by -1m for the high quality, -2.23m for the medium quality and -1.31m for the low quality. However, again, if you switch the definition of accuracy to the accuracy of the estimation based on the real distance, the low-quality environment actually-scored the highest with an accuracy of 74% and high quality with an accuracy of 70%.

Evaluation

A major difference that would impact the study next time would be the use of more subjects. As we only tested 8 subjects, the variation is not great enough to consider the study accurate More subjects would allow us to conduct a more accurate and thorough experiment and anomalies would be easily identified among the results.

Another improvement that could be made is the experiment software. The subject in the VR environment had no avatar. This means that they would not be able to use the size of themselves to gauge the space around them. We also placed no marker on the floor for them to gain reference from. The estimations were simply from their eye level to the object; however, it would have been better if the estimations were only on a single plane. Using floor markers would allow us to have the subjects estimate distances purely across the floor of the environment, rather than leaving it up to their decision.

One major improvement would be the use of a real-life control environment. We could not do this for this study as the virtual environment we created held no reference to a real-life location. Using a real-life environment as a control to do the experiment would allow us to identify possible anomalies in subject estimations as well as allow us to compare the difference between the environments in a purely analysis fashion. Subjects may also find it easier to estimate distances in the VR environment as they would also have real-life reference to make estimations on.