Factors Affecting Dynamic Moving Detectability in VR Space

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Abstract: The use of VR technology is growing in a number of fields, but there are still some problems that need solving. One of said problems is the improvement of interaction within the VR space and how user interfaces are displayed. In this study, research has been conducted on how users feel using a simple, solid figure. In order to investigate better user interfaces in VR space and more effective ways of displaying information. Tasks were conducted to recognize the trajectory of an object’s movements in virtual space using VR contents. This was used and an investigation was conducted into how much recognition was affected by the speed of an object’s movement, the range of the object’s motion, and how far an object is away. As a result, it was found that the appropriate distance needed to recognize a dynamic body’s movement, proved that there is a tendency for the rate of accurate recognition to rise the wider the range of motion is, and learned that recognition is not affected if the speed of movement is within the range where ocular following responses are possible. In addition, it was proved that a combination of distance and speed heavily influences recognition of a dynamic body.

Keywords: VR Space, Dynamic Moving Detectability, User Interface,

1. Foreword

In recent times, the use of VR technology is becoming more widespread in the fields of healthcare, education, and entertainment. However, there are still problems in using VR spaces, such as differences in how people feel the experiences and VR sickness, loss of attention, and improvements in how interaction is displayed. The traits of interaction within VR space include a wider variety of directions for movement compared to flat surface display and problems if multiple movements occur simultaneously. Due to this, traditional flat display design principles may not be applicable to VR spaces.

In Uemura’s research into the effects that a user interface has on dynamic movement recognition, it was found that a specific impression can be given to users through the usage of movements of a simple figure on a flat display [1]. By using this and investigating how users experience VR space with the use of simple solid figures, we thought that a better interface and effective ways to display information in VR space could be considered. Possibilities given for influence factors to measure in VR space included types of movement, distance and height, movement speed, and nearby environment, in addition to the combined influence of said factors.

In this study, we investigated the effects that the speed of an object’s movement, its range of motion, and the distance from an object have upon recognition in VR space, all using a simple solid figure. In addition, by comparing the accuracy using a combination of three influence factors, we also investigated the influence on the recognition of each factor.

2. Experiment Methodology

2.1 Experiment Outline

In this experiment, a head mounted display (hereafter, HMD) was used to detect the route of an object’s movement in virtual space and investigated the effects the speed of an object’s movement, its range of motion, and the distance from an object had on ease of recognition within the VR space. In this experiment, areas where there were large numbers of students or a high percentage of the generation that is interested in VR were considered. Thus, 30 men and women in their 20s were asked to participate. The HMD used was HTC Vive.

2.2 Experiment Environment

The subjects were asked to put on the HMD and sit on a chair. In this position, they were asked to conduct a task whereby they had to detect the route of a simple solid figure’s movement. The virtual space was created with unity with a red sphere 15cm in diameter to adjust the subject’s position and a 1000m-long center line displayed in a 2m x 2m space, as shown in figure 1. The reason for the length of the center line was to give it the
appearance of being near infinite in length.

Fig. 1: The background of the virtual space used in the experiment

2.3 Stimuli
The stimuli presented in the experiment were a sphere, chosen as a simple solid figure, and 18 varieties of movements adjusted by combinations of speed (fast: 8m/s, slow: 4m/s), distance (2m, 10m, 100m), and range of motion (1m x 1m, 2m x 2m, 3m x 3m). In order to ensure the distance moved for each of these varieties was the same when their range of motion was aligned, prototypes (table 1) were made of each different movement route (fig. 2). Six routes were designed from combinations of two straight lines and two diagonal lines. These were then rotated 90° and 180° for a total of 18 routes. A distance of 10m was used as base for the speed, with the slower speed set as 30°/s or less that subjects can follow with smooth pursuit eye movement, and the faster speed set at 60°/s or less and can be followed with intermittent saccades. Among these figures that were integers and multiples of another were chosen- 4m/s (at a distance of 10m and 4m in size, the angle is $360/\pi \times \arctan (4/10/2) =22.62^\circ<30.00^\circ$. That is to say that a speed of 4m/s can be followed with smooth pursuit eye movement) and 8m/s (at a distance of 10m and a size of 8m the angle is $360/\pi \times \arctan (8/10/2) =43.60^\circ<60.00^\circ$. That is to say that a speed of 8m/s can be followed with intermittent saccades) [2].

Table 1: All prototype combinations

| Prototype | Speed | Distance | Range of motion | Route |
|-----------|-------|----------|-----------------|-------|
| No.1      | Slow  | 10m      | 1m x 1m         | 1     |
| No.2      | Fast  | 100m     | 1m x 1m         | 2     |
| No.3      | Slow  | 2m       | 2m x 2m         | 3     |
| No.4      | Fast  | 100m     | 2m x 2m         | 4     |
| No.5      | Slow  | 10m      | 2m x 2m         | 5     |
| No.6      | Slow  | 2m       | 3m x 3m         | 6     |
| No.7      | Fast  | 2m       | 1m x 1m         | 7     |
| No.8      | Fast  | 10m      | 2m x 2m         | 8     |
| No.9      | Fast  | 2m       | 3m x 3m         | 9     |
| No.10     | Fast  | 10m      | 1m x 1m         | 10    |
| No.11     | Fast  | 10m      | 3m x 3m         | 11    |
| No.12     | Slow  | 100m     | 3m x 3m         | 12    |
| No.13     | Slow  | 100m     | 2m x 2m         | 13    |
| No.14     | Fast  | 100m     | 3m x 3m         | 14    |
| No.15     | Fast  | 2m       | 2m x 2m         | 15    |
| No.16     | Slow  | 10m      | 3m x 3m         | 16    |
| No.17     | Slow  | 100m     | 1m x 1m         | 17    |
| No.18     | Slow  | 2m       | 1m x 1m         | 18    |

Fig. 2: Breakdown of the 18 types of movement routes

2.4 Setting Options
Subjects were shown the movement of the sphere within the VR space and displayed six figures showing options for movement routes. Next, they were asked to choose a number corresponding to the option that was the same as the sphere’s movement (fig. 3). The options were based on the correct answer and set as follows: ① Movement 1 is the same and movement 4 is at the correct angle and direction, but in the wrong position, ② Movements 1 and 2 are the same, ③ Movements 1 and 4 are the same, ④ Movements 3 and 4 are the same, ⑤ Movement 4 is the same. These were selected based on the assumption that subjects mainly remember images 1 and 4 and judge based on them. These were arranged on panels in a random order.

Fig. 3: Example of option panel displayed during examination

2.5 Experiment Procedures
In preparation for the experiment, the subjects were asked to sit so that the red sphere touched their abdominal area and had them adjust so that the center of their body was in line with the center line. Following the preparation, the subjects were asked to watch two
examples to instruct them of the movements of the sphere. The experiment was begun once they had understood the procedures.

For the first trial, two seconds after the experimenter signaled, the movement of the sphere was displayed on the center line, with the subject asked to memorize the route of its movements. Two seconds after the sphere had stopped moving, six options were displayed on panels, with the subject having to verbally state the number which they believed to be the correct route of movement. Moreover, there were 18 prototypes for the movement of the sphere that were shown one at a time randomly for a total of 18 trials.

Furthermore, there were no specific restrictions in place during the experiment such as not allowing subjects to move their neck when trying to memorize the movements of the sphere. The reason for this was to simulate actual use of VR technology.

The reason for the second gap between displaying the options after the sphere had completed its movement was because visual information is retained for around two seconds after the stimulus is lost [3]. If displayed instantly, there is a chance one may answer even if they are not fully aware of it.

2.6 Questionnaire
Following the experiment, subjects answered a questionnaire. The first question asked subjects to place the factors of speed, distance, range of motion, and eyesight in order of how large an effect they believed they had on recognition difficulty. Question two asked them how many times they had experienced VR before, and question three asked them how good their eyesight was. Question one was selected in order to research the effects of influence factors on a subject’s subjective ease of recognition, while questions two and three were designed to remove erroneous data.

3. Experiment Results
3.1 Calculating average values and t-testing
The results of the experiment and the percentage of correct answers for all of the 18 trials are as is listed in table 2. In addition, a t-test was used to calculate the average values for the percentage of correct answers by speed, distance, and range of motion in order to research the effects of each factor. The average percentage of correct answers when the speed was high was 65.93%, compared to 61.11% when it was low, thus indicating minimal variation. For distance, the percentages were 61.11% for 2m, 78.33% for 10m, and 51.11% for 100m, thus showing a significant difference between 10m and 100m (p=0.022<0.05). For the range of motion, the percentages were 53.89% for 1m x 1m, 64.44% for 2m x 2m, and 72.22% for 3m x 3m, thus displaying no significant differences. Moreover, the combination that yielded the highest percentage of 93.33% correct answers was fast speed, 10m distance, and a range of motion of 3m x 3m. At the other end of the scale, the combination that yielded the lowest percentage of correct answers at 26.67% was slow speed, 100m distance, and a range of motion of 1m x 1m. A collection of these percentages is shown in figure 4.

Table 2: Percentage of correct answers in order of sample number

| Sample number | Speed | Distance | Range of motion | Percentage of correct answers |
|---------------|-------|----------|----------------|------------------------------|
| No.01         | Slow  | 10m      | 1m x 1m        | 83.33%                        |
| No.02         | Fast  | 100m     | 1m x 1m        | 43.33%                        |
| No.03         | Slow  | 2m       | 2m x 2m        | 50.00%                        |
| No.04         | Fast  | 100m     | 2m x 2m        | 73.33%                        |
| No.05         | Slow  | 10m      | 2m x 2m        | 86.67%                        |
| No.06         | Slow  | 2m       | 3m x 3m        | 73.33%                        |
| No.07         | Fast  | 2m       | 1m x 1m        | 73.33%                        |
| No.08         | Fast  | 10m      | 2m x 2m        | 83.33%                        |
| No.09         | Fast  | 2m       | 3m x 3m        | 63.33%                        |
| No.10         | Fast  | 10m      | 1m x 1m        | 46.67%                        |
| No.11         | Fast  | 10m      | 3m x 3m        | 93.33%                        |
| No.12         | Slow  | 100m     | 3m x 3m        | 66.67%                        |
| No.13         | Slow  | 100m     | 2m x 2m        | 36.67%                        |
| No.14         | Fast  | 100m     | 3m x 3m        | 60.00%                        |
| No.15         | Fast  | 2m       | 2m x 2m        | 56.67%                        |
| No.16         | Slow  | 10m      | 3m x 3m        | 76.67%                        |
| No.17         | Slow  | 100m     | 1m x 1m        | 26.67%                        |
| No.18         | Slow  | 2m       | 1m x 1m        | 50.00%                        |

Fig.4: Average percentage of correct answers by influence factor

3.2 Questionnaire Results
Question one saw subjects rank factors that they felt affected the difficulty of detecting movements. The results of which saw the subjects rank speed and distance joint highest, followed by range of motion, then eyesight. Moreover, upon tallying the responses for question two, it was found that there was no increase in the percentage of correct answers with number of times experienced. Similarly, with question three, there was no fall in the percentage of correct answers depending on one’s eyesight.
4. Observations
The results have indicated that differences in distance have the greatest influence on the percentage of correct answers. There was a significant difference shown between distances of 100m and 10m, which matched the questionnaire results where subjects stated that distance had a large influence. In addition, the fact that the percentage of correct answers for distances of both 100m and 2m were lower than that of 10m means that one can conclude that a distance range from an object that is suitable for recognition does exist.

With regards to range of motion, there were no significant differences, but the percentage of correct answers did show a tendency to rise with the ranges of motion as 1m x 1m yielded 53.89%, 2m x 2m yielded 64.44%, and 3m x 3m resulted in a 72.22% percentage of correct answers. One can deduce that this means that it is easier to recognize movements the wider the range of the angle is to do so. Moreover, as is shown in table 3, this tendency can also be found to a degree with a distance of 2m, which can go out of our field of vision. Thus, one can conclude that even with movements that exceed the field of vision, subjects look to interpolate said movement into their recognition. However, there would appear to be a limit to this and a possibility that recognition would become more difficult if the range of motion were too wide. As this research was conducted with the assumption of movements in interfaces, research was not conducted into ranges of motion that exceed reasonable limits for interfaces. However, one may infer that there is a need to research the limits of which one can interpolate a range of motion.

With regards to speed, the difference in the average value of the percentage of correct answers was small and examining speed as a sole factor did not result in a noticeable influence. However, according to the questionnaire results, the subjects felt that speed of movement had a great influence on their recognition. The speeds set for this experiment were based on a distance of 10m and were both set as speeds that were within a recognizable range. In addition, while there were relative fast and slow speeds, one can say the difference was such that it would have little effect on recognition if the subject was focused.

However, the combined average values for distances of 2m and 10m were 69.44% for fast and 70.00% for slow compared to average values of 58.99% for fast and 43.33% for slow when the distance was 100m, thus showing a large difference in the average values. Furthermore, under the conditions of a distance of 100m and slow speed, both the lowest (1m x 1m, 26.67%) and second lowest (2m x 2m, 36.67%) percentage of correct answers were found concentrated together, with lower percentages of correct answers being shown for the slower speed in the set ranges on this occasion. One can infer that it is the combination of this with distance that affects how easy it is for one to remember movements. Therefore, one can say that if the distance from an object exceeds a certain range, distance has a great influence on the effects of speed.

Table 3: Differences in percentage of correct answers for ranges of motion at 2m distance

| Distance | Average percentage of correct answers when the distance is 2m |
|----------|--------------------------------------------------------------|
| 1m x 1m  | 61.67%                                                       |
| 2m x 2m  | 53.33%                                                       |
| 3m x 3m  | 68.33%                                                       |

5. Conclusion
As a result of the investigation into dynamic movement recognition in VR space through experiments, we learned that there are appropriate distances for dynamic movement recognition and proved that there is a tendency for the rate of accurate recognition to rise the wider the range of motion is. With regard to the speed of an object’s movement, it was found that recognition is not affected if the speed of movement is within the range where ocular following responses are possible. However, it was proved that a combination of distance and speed heavily influences recognition of a dynamic body. In addition, it was proved that the distance of an object has a greater influence on recognition in VR spaces when compared with interfaces on flat displays. In future, it is considered that is necessary to research the range for the optimal distance and movement in the depth direction in further detail. Furthermore, we also would like to research users’ impressions, including that of ways of movements, and explore the possibility of creating a better UI/UX in VR space that is less easily influenced by movement recognition.

6. References
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