# Frustum View Angle, Observer View Angle and VE Navigation

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***Abstract**. The issue of screen size is discussed with respect to the task of navigating in 3D computer graphics environments. Two variables are isolated, the observer's visual field of view (observer VA) subtended by a screen, and the viewing frustum angle (frustum VA) determined by the computer graphics geometry. It is possible to have these set to be identical, which according to one hypothesis should lead to a stronger sense of situational awareness in the virtual environment. Another plausible hypothesis is that a wide (frustum VA) field of view will be the most important factor in situational awareness with the correct viewpoint being largely irrelevant. Two experiments are reported that examine these issues with respect to different tasks requiring situation awareness. The task in the first experiment was to find targets by navigating over a digital terrain model. The result showed that frustum field of view (frustum VA) was the most important predictor of search time. In the second experiment subjects were asked to rotate left or right by 45, 90 or 180 deg. For this task we predicted that having the correct viewpoint would be important but the results showed (contrary to our hypothesis) that a medium (60 deg.) frustum width gave the most accurate performance with viewpoint being a minor factor. These results exemplify the "robustness of visual perspective" phenomenon that has been reported by vision researchers.*

**Keywords:** Virtual Reality, Navigation, Field of View.

## 1 Introduction

What size screen should we have? A small screen is convenient because it is compact. A large screen allows many people to see the same information, but are there other reasons why we should choose a large screen over a small one. It is frequently stated that a wide field of view will help users become "immersed" in a virtual space and because of this they may be able to navigate more easily [9,15]. The extreme example of this is the CAVE display [5], but more recently there has been considerable interest in large field of view screens such as Silicon Graphics Power Wall [TM] that provide a near immersion experience. However, given the cost of large displays, it is worth asking what tangible benefits may be obtained from them.

Besides giving a sense of "being there" perhaps the most compelling argument for a wide field of view is that it will help us become situated in a virtual space and therefore enable us to navigate better. The question is, it is necessary to fill-up the observer's visual field with a virtual image or can we simply define a wide field of

view in the computer graphics model of the virtual environment? Every computer generated image is defined by a center of perspective and optically correct perspective is obtained by placing the observer's eye at that point, but we can choose to view a screen from some other distance. For example, we can define a wide angle frustum but view the screen from a distance so that the screen only subtends a narrow angle in our visual field.

Having a large field of view may help us build a cognitive map of the environment [1,6]. Wells and Venturino [20] found that a large field of view helped in target acquisition task, but only when there were more targets. There was no significant effect of field of view on performance with three targets, but performance was significantly degraded when the fields of view was 60° or less when there were more targets.

There are also costs to spreading the available information over a large field of view. Assuming that we have a constant number of pixels available, it may be better to concentrate them in a smaller field as is done with a regular monitor rather than spread them over a wall sized display. A typical office environment has all kinds of useful visual information, such as books and papers that a wide field display would necessarily displace. In addition, because our ability to resolve detail falls off in the periphery of the visual field [2], having a wider screen does not necessarily increase the amount of information available to perception. In fact most displays do not provide sufficient detail at the center of the visual field and increasing display size makes this problem worse. Another cost to spreading information out over a larger visual field is that it takes more time and effort to search it. When we wish to look at something more than 10 deg. from the center of vision, we tend to move our heads also. Indeed for movements of greater than 20 deg. the head movement precedes the eye movement. [19].
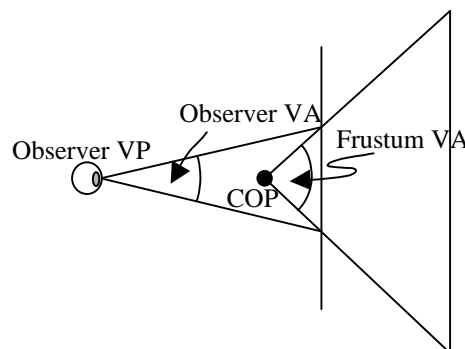


**Figure 1.  The observer visual angle (VA) and the observer viewpoint (VP) refer to the field of view of the observer of an image.  The Frustum VA and the COP are terms that refer to the geometry used to construct the image.**

Experience tells us that viewing displays from the wrong distance may not be disturbing. We look at television, movies and pictures in magazines without having any particular concern that we are not viewing from the geometrically correct point. The fact that we do not notice is called the robustness of visual perspective [12]. An incorrect viewpoint may even have benefits. There is evidence that viewing a screen

from a point closer than the correct center of perspective will result in less perceived distortion than viewing it from further away [8].

In many computer graphics texts the terms *viewpoint* and *center of perspective* are used interchangeably. To be clear, we need separate terms for the observer's field of view and the geometry of perspective applied in the computer graphics system. Thus, in the remainder of this paper we will always use "observer VP" for the viewpoint of the observer and COP for the computer graphics center of perspective. Similarly, we will use "observer VA" to refer to visual angle subtended by a screen from a particular observer VP and we will use "frustum VA" for the computer graphics defined viewing angle. Figure 1 illustrates these terms.

## 2 Related research

Both visual information and information from the vestibular system (semi-circular canals and otolith organs) in the inner ear provide us with information about changes in our heading and motion [13]. A number of researchers have investigated the relative importance of these factors. Under some circumstances purely visual information may be adequate; Riecke et al, [16] found that subjects were able to judge how far they had rotated in a cylindrical display with a 180 deg. field of view without vestibular information. However, studies of virtual space navigation with and without actual locomotion indicate that physically moving the body appears to be important when a complex series of movements is made [4,11]. Also, Pausch et al [14] found that search for missing target, was facilitated when subjects were able to change views by turning their heads and bodies in an immersive VR display.

Nevertheless, there is also evidence that smaller non-immersive desktop displays can be effective in spatial search tasks. Robertson et al [17] found that providing users with extra peripheral information on a desktop display substantially improved performance using the same task as that employed by Pausch et al. Moreover, the search times they measured were considerably faster.

In a study that bears directly on the screen size issue Tan et al [18] compared a large flat screen display (with 75 deg frustum VA) to a smaller monitor (with 33 deg frustum VA) for a 3D navigation task. Performance was better with the larger screen and they attributed this to users being able to see more of their environment at a given time and having "a greater sense of their movements". The observer VA was not specified, although presumably this was larger for the wide display and this may have been a factor. Also, the large display had twice as many pixels as the small display and this may have contributed to the improved performance. In more recent study Czerwinski et al [6] directly compared the relative effects of frustum VA and Observer VA for virtual space navigation task by varying both screen size and frustum VA. They found that having large frustum VA and large screen size improved performance on both measures, although curiously, having a large screen size resulted in subjects traveling longer distances.

# 3 Motivation

Our goal in the present study was to systematically investigate the effect of varying observer VA and frustum VA to discover how these factors interact in tasks requiring situation awareness in virtual environments using flat screen display.

## 3.1 Task 1.  Finding targets in a virtual environment

The first task required subjects to seek seven targets scattered over a digital terrain model. We predicted that a larger frustum VA would enable participants to see more of the environment at once and thereby carry out a more efficient search and interception strategy.  We were also interested in the possibility that having the observer VA match the frustum VA would give a better sense of situational awareness and might somewhat improve performance.

## 3.2 Task 2. Turning through a specified angle

For the second task subjects were required to turn their view direction by a specified angle. Based on the theory that we can use optic flow in order to judge degree of self rotation, we predicted that if the observer VP is the same as the COP we should be better at estimating how fast and far we are rotating in the virtual environment.

 We predicted that a wide view would be better for accurate turning than a narrow angle because it provides more information about the environment.  We also made predictions about what should occur when the observer VA is different from the frustum VA.  If there is a narrow observer VA but a wide frustum VA the angular velocity of optical flow will be larger and we predicted that subjects would turn less to compensate.  Conversely, if there is a wide observer VA but a narrow frustum VA the angular velocity of optical flow will be smaller and we predicted that subjects would turn more.

# 4 Experiment Design

Both experiments involved subjects viewing a digital elevation model back-projected onto a screen, with the subject seated in front of it so that his or her viewpoint was roughly aligned vertically and laterally with the center of the screen. The room was darkened.

## 4.1 The virtual environment

The terrain model was a square grid of 150x150 height values with each cell 3 m square given an overall size of 450 m square.  The terrains were constructed by randomly summing Gabor functions having random centers, sizes and orientations. (A Gabor function is the product of a sine wave and a gaussian and thus provides a smooth ridge-like piece of terrain; summing a number of Gabors produces a realistic looking smooth terrain.)  The result was a smoothly varying digital elevation map with heights from the peaks to the valleys being on average about 32 meters. Even though the terrain was a regularly gridded height field, it was not possible for a viewer to perceive the orientation of the grid and thereby gain information about

heading. The spatial period of the Gabors was randomly varied between 10 meters and 70 meters with amplitude scaled proportionately to the period. When observers were situated in the central region of the terrain, where the targets were placed for the first experiment, the edge of the terrain was never obviously visible. The terrains were textured with a pattern that was produced by another sum of a set of randomly oriented Gabors designed to produce a circularly uniform fine-grained texture. An example terrain is shown in Figure 2 with a 60 deg frustum VA. While navigating, an update rate of 30 frames/second was maintained.

## 4.2 Viewing conditions

To vary observer VA we varied the distance at which the observer sat relative to the screen. The width of the image on the display screen was 122 cm. Subjects were seated either 61 cm (near) or 277 cm (far) from the screen center giving observer VAs of 90 deg and 30 deg respectively. These angles roughly correspond to looking at conventional monitors and looking at a single wall of a CAVE display when standing in the center.

Frustum VAs of 30deg, 60deg, and 90deg were used. The combination of these with the wide and narrow observer VA resulted in 6 viewing conditions. The projector was a Plus DLP model with 1024x768 pixel resolution.

## 4.3 Navigation

Both experiments used a joystick controller for navigation. This had the advantage over a mouse that if subjects released it, it would automatically re-center and they would stop moving. Tilting the joystick forward and back resulted in changes in velocity forwards and backwards respectively. Tilting the joystick to the left and the right resulted in turning to the left and right with the rate of turn proportional to the displacement.

Subjects were prevented from traveling over the edge of this virtual environment. If they came within 25 meters of the edge of the environment, movement in that direction was halted, and they would tend to slide sideways along the boundary. Subjects were trained to detect this condition and turn around when it occurred

The observers viewpoint was always fixed at 1.7 meters above the terrain.

## 5 Experiment 1: Target Acquisition

The subject's task was to navigate over the terrain seeking out red cone shaped targets and drive through them each in turn. When a target was driven through in this way it turned blue. There were seven targets present at a given time and hitting all of them constituted a trial block. When all seven targets had been set to blue the viewing Frustum VA was changed and a new set of seven targets appeared.

This task requires situation awareness in that subjects had to search the space to find targets that were often hidden behind hills. Since they could sometimes perceive a number of targets simultaneously, if they could create a mental map of them, they would be able to plan an efficient strategy for hitting the targets.
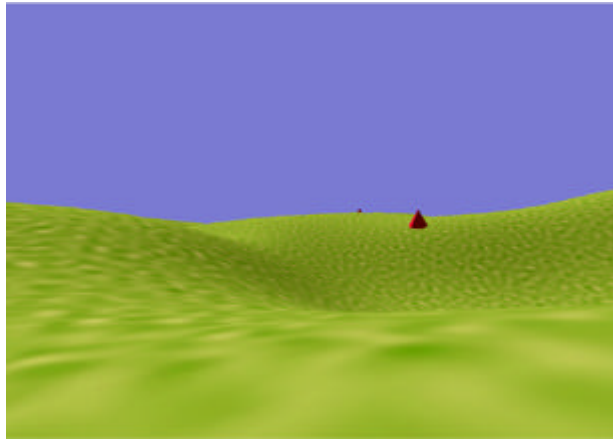
**Figure 2. An example of an artificial terrain. One target is clearly visible, another is just showing over the horizon.**

## 5.1 Targets

The targets were cones 5 meters in diameter at the base and with an apex 5 meters above the point on the surface where they were centered. The cones continue down into the terrain so that no gaps are seen underneath them. There were seven cone targets randomly positioned within a 150 meter square in the central region of the terrain model. Targets positions were constrained so that no two targets ever appeared closer than 25 meters.

## 5.2 Trials

A subject was seated either at the near or far viewing position. The subject then used the joystick controller to drive through all 7 targets as fast as he or she could. Targets all started as red but when each target was hit it turned blue so that the subject would not hit it again. While the subject was seated at one position (either near or far) all three Frustum VA conditions were used (7 targets for each), with the order randomly determined. The subject then moved to the other viewing position (far or near) and the process was repeated. This was followed by a complete replication. Half the subjects ran trial blocks Near, Far, Near, Far, and half the subjects were given Far, Near, Far, Near.

Before the experiment started subjects were given a training session consisting of two complete sets of 3 trial blocks while seated midway between the near and the far positions. Subjects were shown how to use the joystick and told to turn around when they hit the edge of the VE. Subjects were instructed to carry out the task as quickly as possible.

## 5.3 Subjects

There were 12 subjects. These were undergraduate students, graduate students, staff and faculty. The students were paid for participating.

| | Frustum Visual Angle | | |
|---|---|---|---|
| | 30 deg | 60 deg | 90 deg |
| Observer Visual Angle — 30 deg (far) | 4.29 | 3.19 | 2.76 |
| Observer Visual Angle — 90 deg (near) | 5.06 | 3.20 | 2.93 |

**Table 1. Summary of results from Experiment 1. Mean time per target in seconds (after the first).**

### 5.4 Results from Experiment 1

Subjects were able to complete the task under all viewing conditions. Because the data were highly skewed with outliers they were log transformed for analysis. The means were inverse transformed back to seconds for clarity of presentation. The results are summarized in Table 1. An analysis of variance revealed the only significant factor in the time it took to hit the targets was the Frustum VA. $F(1,11) = 37$ $p<0.0001$. Overall, time per target was 68 percent slower with the narrowest field of view than with the widest field of view. The two conditions where the observer VP matched the COP were not significantly better. In addition, there was no overall effect of wide versus narrow observer VA.

## 6. Experiment 2: Rotating the Viewpoint

The purpose of this task was to determine how easily people could turn themselves by a specified amount within a virtual environment displayed on a flat screen. We made two predictions.

1) Subjects would perform the task better if the frustum VA matched the observer VA.

2) Subjects would perform the task better with a wide angle display if the frustum VA matched the observer VA.

On each trial subjects were asked to turn in the virtual space by a designated angle: 45 deg, 90 deg or 180 deg. A message appeared on the screen for 2 seconds:

**Turn {Left|right} by {45|90|180} degrees**

Subjects made the turn using the joystick. Tilting the joystick to the left caused a left turn and tilting it to the right caused a right turn. For this condition forward motion was disabled and no targets appeared on the terrain. In order to prevent subjects from learning a strategy based on timing the turn assuming, for example, a full deflection produced a fixed constant turn rate, a random gain factor was applied to alter the sensitivity of the joystick on each trial.

On completion of each rotation subjects pushed a button on the base of the joystick causing a new, randomly determined digital elevation map to be generated for the next trial and a new turn message to appear. The digital elevation maps were generated in the same way as for the first experiment, but without the targets.

## 6.1 Trial blocks

The procedure was similar to experiment 1.

A subject was seated either at the near or far viewing position. They were given 18 trials in a block consisting of all combinations left/right turns by 45/90/180 deg. repeated three times. The ordering of these trials was random. When the 18 trials had been completed, the subject moved to the other viewing position (far or near) and the process was repeated. Half the subjects ran trial blocks Near, Far, Near, Far, and half the subjects were given Far, Near, Far, Near.

If we assume that clockwise and counter clockwise rotations are equivalent, this yields 3(turn angles) x 2(Observer VAs) x 3(frustum VAs) for a total of 18 conditions.

## 6.2 Results from Experiment 2

The main effects are summarized in Figure 3. There was a large effect of frustum VA. $F(2,11) = 108.3$ p< 0.0001. Overall the most accurate turns occurred with the 60 deg frustum. The mean error was a 29 deg undershoot with the narrow (30 deg) frustum; a 1.4 deg overshoot with the 60 deg frustum and a 20.8 deg overshoot of with the 90 deg frustum.
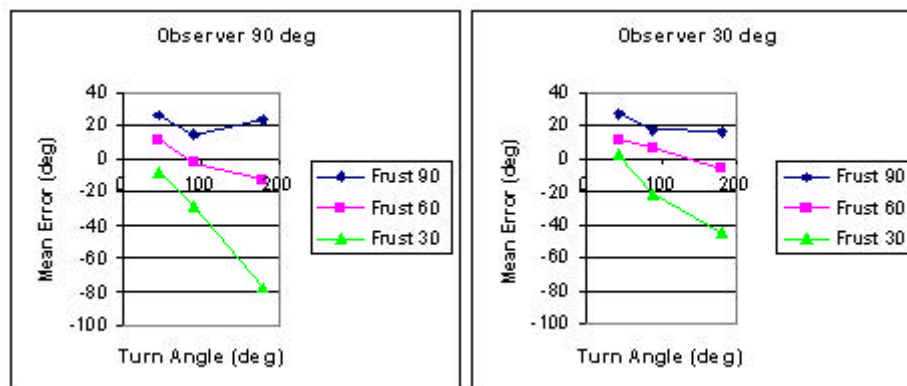


**Figure 3. The results from the turning experiment are summarized. There was a three way interaction between frustum VA, observer VA and turn angle.**

There was a small but still significant effect of observer VA. $F(1,11) = 12.4$ P < 0.005. Subjects on average overshot by 1.0 deg in the far viewing position (30 deg observer VA) and undershot by 5.8 deg in the near viewing position (90 deg obsever VA).

There was a significant effect of turn angle: Errors were larger with the larger turn angles $F(1,11) = 24.7$ P < 0.0001.

There was a three way interaction between frustum VA, observer VA and turn angle $F(4,44) = 2340$ P= 0.02. The main component of this was that for the 180 turn angle, the differences between 30 and 90 deg Frustum VA were exaggerated.

To get an idea of the overall level of accuracy that might be expected in the best case (with the 60 deg. frustum VA ) we analyzed the data to determine the mean absolute error in this condition. This turned out to be 15.5 deg (34%) for the 45 deg turn; 17.0 deg (19%) for the 90 deg turn and 23.8 deg (13%) for the 180 deg turn.

## 7 Discussion

Our results confirm the finding of Tan et al that a wide field of view makes it easier to navigate over an artificial terrain. However frustum VA rather than the observer VA was by far the most important factor. In the first experiment there was no effect of observer VA, and only a small one in the second experiment. The implication is that for similar search tasks a desktop monitor is likely to be as effective as a wide screen display if they both have comparable resolution. But it is necessary to increase the frustum VA and this undoubtedly gives a distorted view of the data. This may well cause problems for other tasks and may reduce the sense of presence that accompanies a wide observer VA [7,9,10].

The results from the self-rotation experiment can be described by two phenomena; robustness of visual perspective and optic flow. As discussed in the introduction, the robustness of perspective is a term used to describe the fact that we appear to be able to ignore distortions in images viewed from the wrong center of perceptive. A possible explanation for this is that most people have spent considerable amounts of time, beginning in early childhood, looking at dynamic screen images representing perspective views of 3D scenes. We view these images on television screens and at movie theatres but almost never from the correct center of perspective. Thus we may have developed ways of compensating. The results suggest that when we see a perspective image at either from very near or very far, we assume a kind of default intermediate viewing angle. The overturning that was observed with the wide frustum VA and underturning with a narrow frustum VA can be explained as an effect of optic flow. As the frustum VA increases the angular velocity of moving patterns decreases. To compensate we turn more. Apparently neither rigid body assumption nor experience with television and movies is sufficient to compensate.

Given the fact that the terrain was constructed only of smoothly varying hills, with no distinct features, the mean turn error 20 deg for the 60 deg frustum VA is surprisingly good. As a practical matter this suggests that the viewing angle should be carefully set in scenarios where virtual environments are used as a training tool for people who will later navigate a similar real environment. However although our subjects were most accurate with a 60 deg. frustum VA it might be the case that a different landscape – for example one with more distinct landmarks – would result in a different optimal frustum angle. This is a topic for future research, but in lieu of such research a frustum angle of 60 deg would appear to be a good compromise for tasks where situational awareness is an important concern.

## Acknowledgements

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