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An orientation experiment using auditory artificial horizon

M. Gröhn, T. Lokki, and T. Takala

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AN ORIENTATION EXPERIMENT USING AUDITORY ARTIFICIAL HORIZON

Matti Gröhn

CSC - Scientific Computing Ltd
P.O.Box 405, FIN-02101 Espoo, Finland
matti.grohn@csc.fi

Tapio Lokki, Tapio Takala

Telecommunications Software and
Multimedia Laboratory
Helsinki University of Technology
P.O.Box 5400, FIN-02015 HUT, Finland

ABSTRACT

An orientation experiment was carried out in a spatially immersive virtual environment. The task of subjects was to navigate with 6 degrees of freedom flying method through a predefined route guided by visual cues. Simultaneously they should keep the model oriented in upright position as well as possible. In the experiment we had three different implementations of auditory artificial horizon, and for the reference the subjects accomplish the task also without the auditory support. According to the results the auditory artificial horizon helps subjects to keep the model oriented during the task.

1. INTRODUCTION

Visualization is one of the biggest application area of the virtual reality. Scientific visualization as well as architectural walk-throughs are very popular demonstrations in the CAVEs [1]. The main task of the user in these visualization demos is to navigate in the virtual world. The navigation device is usually a 6 degree-of-freedom wand or fly-stick. Although, such a wand is intuitive to use the spatial orientation during the walk-through is hard to control. The user often finds him/herself at the situation where the virtual world is disoriented or upside down. The situation is similar as the pilot has in the cockpit of the aircraft. For example, when flying inside a cloud it is hard to keep orientation without seeing the horizon. For this situation an artificial horizon has been developed.

In aircrafts the artificial horizon is implemented with a visual display, which shows the information provided by a gyroscope. A similar type of visual artificial horizon can be applied in virtual reality. However, in visualization application all additional visual objects might disturb the user. Therefore, it is worth of trying to provide information about disorientation to other senses. A tactile display has been proposed earlier [2] and in this paper we introduce a novel artificial horizon with auditory display.

In a virtual environment it is possible to limit users degrees of freedom, e.g. moving is allowed only in horizontal planes. For some tasks this is the most convenient solution, however, in this paper we concentrated on a 6 degree-of-freedom i.e. free flying situation.

1.1. Design of the artificial auditory horizon

An obvious way to use 3D audio for orientation information is to mark the x and y axes with auditory beacons in front and on side, respectively. When both beacon sounds are heard on the ear level both roll and pitch angles are close to zero. However, since elevation perception is not very accurate this was found impractical in our informal tests. In addition, as Benson [3] discusses, a sound source, fixed with respect to the observer, does not give an intuitive feeling of orientation.

A better way to indicate disorientation was found by applying a ”ball on a plate” metaphor; when the plate is tilted i.e. deviated from upright position, the ball starts to roll to the direction pointing downwards. This metaphor is applied to 3D auditory display so that sound is heard from the direction tilting downwards. In fact, with this metaphor the elevation information (spatial disorientation) is mapped to the azimuth angle. From the point of view of human spatial hearing, this mapping is more optimal since the azimuth perception is more accurate than the elevation perception [4].

1.2. Test environment

Orientation experiments were accomplished in the cave-like virtual room[1] of the Helsinki University of Technology. We are using 14 Genelec 1029A loudspeakers for sound reproduction. For the multichannel sound reproduction we use vector base amplitude panning (VBAP) [5]. More about implementation details of our audio environment are covered in another article [6].

2. ORIENTATION EXPERIMENT

2.1. Task

The task of a subject was to move along a predefined route inside an architectural model. The route was a typical walk-through, used in our virtual environment demos. All the time the subject should keep the model as upright oriented as possible.

Subjects control direction and velocity of movements by pointing with the wand. The gesture of pushing a wand button and moving the wand in space defines a vector, the length and direction of which are translated into motion speed and direction in a virtual space. In addition, rotations can be handled correspondingly by turning the wand.

The architectural model was a model of a new lecture hall of the Helsinki University of Technology. This model was explored before the hall was built in a project called Visualization of Building Services in Virtual Environment [7, 8]. This model has a lot of vertical and horizontal lines (as seen in figures 1-3) which the subject could use as visual cues for pitch and roll angle orientation.

[1] http://eve.hut.fi

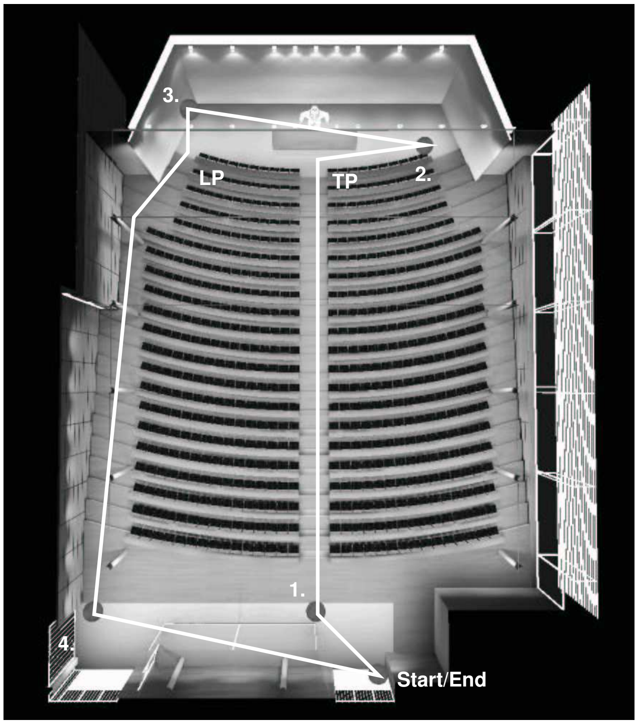

Figure 1: Top view of the lecture hall model. The route is drawn with the white line. Label TP indicates the turning point and label LP the landing point. Start/End point as well as order of the checkpoints are also labeled.

2.1.1. Route

The route is a loop as shown in the figure 1. Each time the route is started from the point labeled Start/End. During the task, a visible red ball was used to remind the subject for the route. The ball was visible in the checkpoint, and when the subject reached the ball, the ball was moved to the next point. From the checkpoint 1 to the checkpoint 2 the subjects were asked to use the middle aisle of the lecture hall. After they had reached the front of the hall they were asked to make a 180 degrees turn at the turning point (label TP). From the turning point they had to move sideways to the checkpoint 2 keeping their view direction to the hall.

From the checkpoint 2 (near the floor level) they had to fly to the checkpoint 3 (near the ceiling) keeping their gaze direction to the hall. After the checkpoint 3 they had to hover down to the landing point (label LP), and then use the side aisle to reach the checkpoint 4. From the checkpoint 4 they moved back to the Start/End point.

2.2. Subjects

We had eight male non-paid volunteers for this experiment. Each of them reported to have normal hearing, although this was not verified with audiometric tests. There was also ninth subject, but she gave up in middle of the first training round due to a simulator sickness. None of the other subjects reported any problems during the tests.

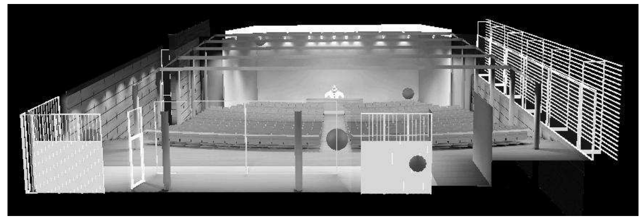

Figure 2: Back view of the lecture hall model.

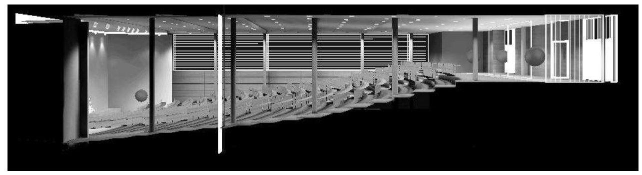

Figure 3: Side view of the lecture hall model. In this figure the ascending floor structure is easily seen.

2.3. Auditory stimuli

We applied three different auditory stimuli for the auditory artificial horizon in this experiment. All auditory stimuli were based on pink noise bursts. In the first stimulus the amount of tilt was used as a gain factor. When the model was oriented the stimulus was inaudible.

In the second stimulus the pulse rate of the noise burst was varied according to amount of the tilting. If the model was upright oriented the rate was 0.7 Hz. The maximum rate was 8 Hz

In the third stimulus a narrow band-pass noise was added to the stimulus. The center frequency of the noise varied from 50 Hz (when oriented) to 2 kHz.

These three auditory stimuli provided the three auditory conditions called gain, rate, and pitch. In a gain and pitch condition the rate of the stimulus was 2.4 Hz.

2.4. Procedure

In the experiment there were four types of conditions: visual, gain, rate, and pitch. In the visual condition a subject went through the route using only the visual cues to keep the model as oriented as possible. In this experiment we compared the orientation accuracy in different conditions.

Every subject had as many training rounds as he liked. Minimum number of training rounds was four. First training task was without the auditory artificial horizon to get the subject familiar with the route. After this initial round the subject had each of the three auditory conditions at least once. There were two subjects without previous experiment of our navigation system. They both accomplish more training rounds than other more experienced subjects. The time was not limited in this experiment. The subjects were informed to use a speed, which they considered to be suitable for a visualization demo situations.

After the training, the test consisted of two test sets. Each condition was used once for each subject in both test sets. Order of the conditions were randomized in each test set separately for each subject. For the analysis, the location and orientation of the

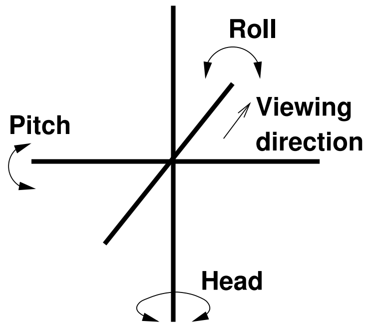

Figure 4: Definition of head, pitch, and roll angles

	Visual	**Gain**	**Rate**	**Pitch**
Pitch angle	4.27	2.90	2.78	2.83
Pitch std	1.80	1.48	1.26	1.40
Roll angle	2.66	2.19	1.98	1.75
Roll std	1.71	0.87	1.18	1.30

Table 1: Medians and standard deviations of absolute value of pitch and roll angle error (in degrees) for each condition in both sets.

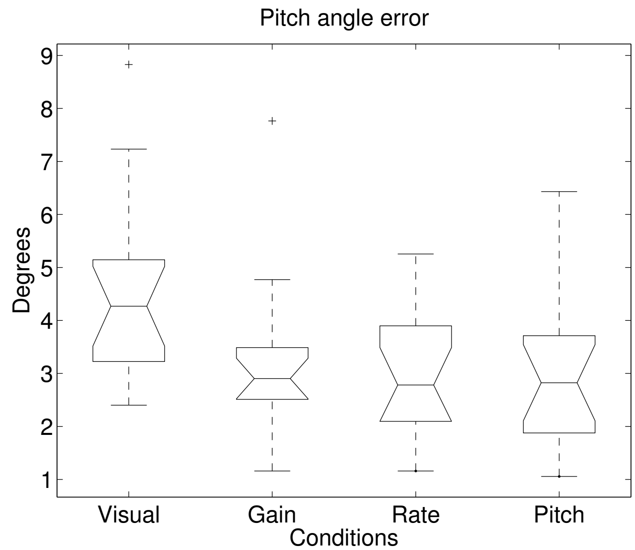

Figure 5: Boxplot of absolute value of pitch angle error for each condition in both sets. The box indicates the lower quartile, median, and upper quartile values.

subject were recorded with 10 Hz sampling rate. The orientation was recorded using head (yaw), pitch, and roll angles as defined in figure 4.

3. RESULTS

The amount of disorientation is measured and analyzed using absolute values of recorded pitch and roll angles. In the analysis, we used the medians of the absolute values of angles throughout the route (number of recorded values for one round was time dependent, and it varied from 981 up to 2598 recorded values). First we analyze results including both sets.

As seen in figure 5, in the visual condition the pitch angle error is larger than in auditory conditions. This difference is statistically significant (p-value = 0.009 in ANOVA). On the other hand there is no significant difference between the three auditory conditions.

With the roll angle error the situation looks similar although the difference between the visual condition and auditory conditions is smaller (figure 6). This time the difference is statistically not significant (p-value = 0.15). For each condition the pitch angle error was larger than roll angle error as seen in table 1.

Times to accomplish the task are not condition dependent (p-value = 0.73) and in table 2 it is seen that differences between time medians are much smaller than their standard deviation.

	Visual	**Gain**	**Rate**	**Pitch**
Time	138.1	137.8	150.6	154.6
Time std	40.3	30.3	31.3	33.6

Table 2: Median and standard deviation of times (in seconds) for each condition in both sets.

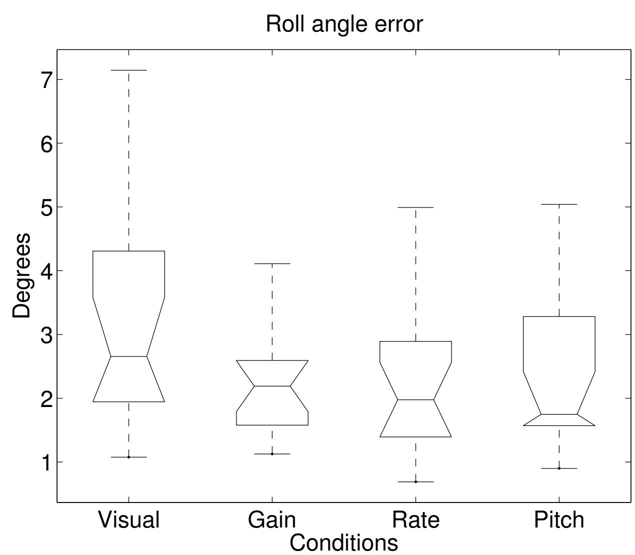

Figure 6: Boxplot of absolute value of roll angle error for each condition in both sets.

		Visual	Gain	Rate	Pitch
First test set	Pitch angle	4.30	2.92	3.01	3.15
	Pitch std	2.08	1.88	1.47	1.62
	Roll angle	2.50	2.59	1.98	2.52
	Roll std	1.58	1.04	1.51	1.61
Second test set	Pitch angle	4.27	2.90	2.58	2.56
	Pitch std	1.60	1.05	1.02	1.04
	Roll angle	2.84	1.84	1.84	1.69
	Roll std	1.92	0.46	0.75	0.71

Table 3: Medians and standard deviations of absolute value of pitch and roll angle error (in degrees) for each condition for the first and the second test set.

For further analysis we compared the results of the first and the second test set. In table 3 are the medians and standard deviations for both test sets. In the visual condition the median pitch angle error is almost the same in both test sets and median roll angle error is larger in the second test set. In auditory conditions the pitch angle error has been decreased in rate and pitch conditions and the roll angle error has been decreased for the gain and pitch conditions.

The boxplot for the pitch angle error in the second test set is seen in figure 7. The difference between the visual condition and auditory conditions is statistically significant (p-value = 0.003) also in the second test.

More interesting in the second test set is the the roll angle error. The difference between the visual condition and auditory conditions is smaller (figure 8) than with pitch angle error, but the difference is this time statistically significant (p-value = 0.04). With the roll angle error the gain condition has less deviation than other auditory conditions (table 3).

In figure 9 the absolute values of pitch and roll angle errors in the second test set are depicted for each subject and condition. In addition, times to accomplish the route are displayed. The pitch angle error is larger in visual condition than in auditory conditions for each subject. With roll angle error the situation is not as clear, and one subject even had more error in gain condition than in visual condition.

There were a big differences between the subjects. With roll angle error the most accurate subject (number 8 in figure 9) was more accurate with his worst condition than the least accurate subjects (numbers 1 and 3 in figure 9) with their most accurate conditions. Especially there is a lot of variation in the visual condition.

For further analysis we plotted the error angles during the route for one accurate and one inaccurate subject (subjects number 8 and 3 in figure 9) for each condition in the second test set in figures 10 and 11. The subject 8 (figure 10) has kept his orientation much better, and there are only few occasions were he had been slightly disoriented. On the other hand subject 3 (figure 11) has had almost continuous swinging when traveling through the route.

After the test, subjects were asked to put the auditory conditions in subjective order. In this evaluation all the eight subjects put conditions in the same order: gain (best), pitch, and rate.

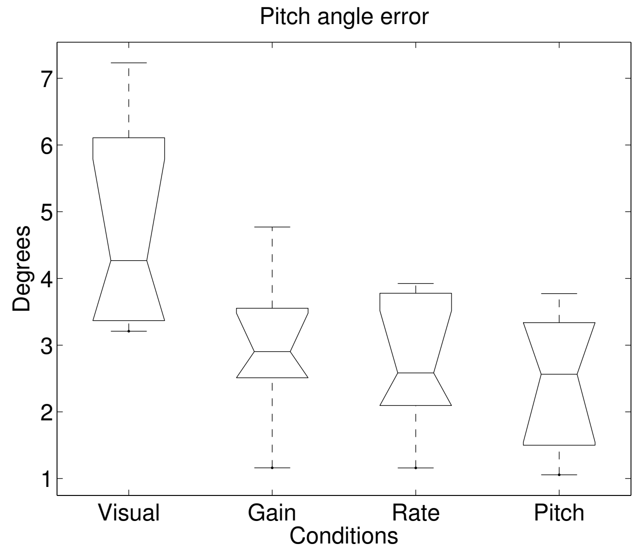

Figure 7: Boxplot of absolute value pitch angle error for each condition in the second test set

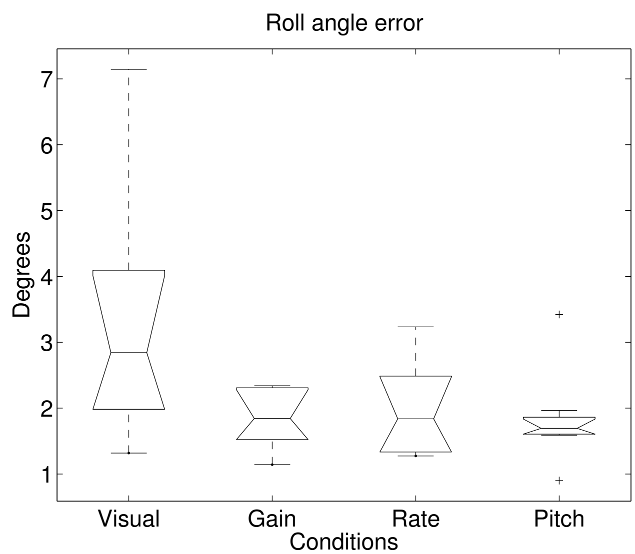

Figure 8: Boxplot of absolute value of roll angle error for each condition in the second test set.

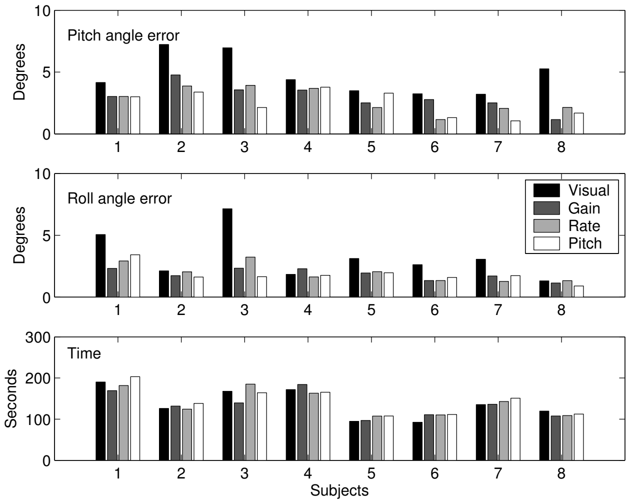

Figure 9: Bar graphs of absolute values of pitch and roll angle errors, and times for each subject and conditions in the second test set.

4. DISCUSSION

All the subjects understood auditory artificial horizon immediately, and they found it intuitive to use. Most of the subjects needed only one training round for each auditory condition, before they started the experiment test sets. No significant difference was found in performance times under different conditions. This suggests, that auditory cues didn't much increase the cognitive load of the subjects.

The amount of disorientation was larger in pitch angle than in roll angle for each condition. The difference varies from 0.7 degrees (gain condition) up to 1.6 degrees (visual condition) (table 1). This difference suggest, that subjects utilize the horizontal visual cues in front of them to keep roll angle oriented. The pitch angle was harder to keep oriented, especially when subjects were moving up or down the aisles. For example in figure 10 the plot for visual case indicates, that this subject has been disoriented in pitch, while he was moving up on the side aisle (time from 90 to 110 seconds).

Orientation accuracy did not change between the two test sets in visual condition. In auditory conditions subjects performed better in the second test set than in the first test set. This suggests that subjects had learned to use auditory artificial horizon during the experiment.

In subjective ranking the gain condition was preferred. Although pitch condition was subjectively ranked second best, two of the subjects reported that it was annoying. Rate condition was found least useful, because it had not as clear reference value for the perfect orientation as other two auditory conditions. This result suggests, that providing reference value information, is an important part of designing auditory stimulus.

5. CONCLUSIONS AND FUTURE RESEARCH

The auditory artificial horizon was intuitive and it helps users to keep the virtual world oriented. In subjective evaluation the sub-

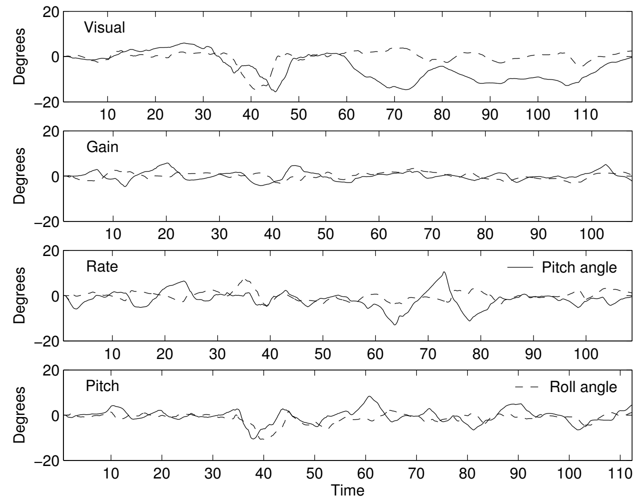

Figure 10: The pitch and roll angle values during a route for each condition in the second test set for the accurate subject. Pitch angle values are plotted using a solid line and roll angle values using a dashed line.

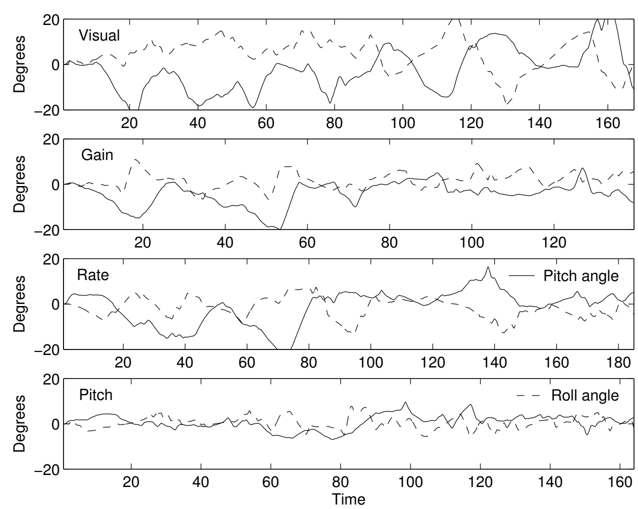

Figure 11: The pitch and roll angle values during a route for each condition in the second test set for the inaccurate subject.

jects preferred the auditory conditions with a clear reference value (gain and pitch). The gain condition was preferred, because it was silent when the model was fully oriented.

In this experiment we did not find any statistically significant differences between the auditory conditions. More experiments should be accomplished to explore that issue.

This experiment was accomplished with short training period and two test sets. Future research is needed to find out, if a longer period of usage will increase the orientation accuracy.

6. ACKNOWLEDGEMENTS

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