# *WindWalker*: UsingWind as an Orientation Tool in Virtual Environments

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## Abstract

*Trans-sensory perception is the alternative use of one of our senses to perceive information which is generally perceived by another sense. Common examples exist among handicapped people, such as blind people who play soccer based on sound emitters placed on the ball and at the goals. The present study aims at using wind as an interface modality for interaction in virtual environments. More than that, in this study we propose to use the direction of the air in motion as an abstraction of the natural sense humans have from the wind. We give a new meaning to the wind direction with the purpose of self-orientation in virtual reality environments. We develop hardware and software interfaces for wind rendering and then analyze user performance on specific orientation tasks.*

## 1. Introduction

Human senses are channels, paths through which the information reaches us. Thus, one specific piece of information can reach us through different senses. One example easy to understand is rhythm. Rhythm can easily reach us through at least three senses: hearing, as a drum beat; vision, as a light blink; touch, as an object rhythmically tapping on one's skin. In the cinema, sound has long been used to add value to the image [4]. It is common sense that music and special effects communicate a number of feelings to the film viewer. In an analog way, wind, as a weather phenomenon, encompass rich information that people can sense in their real lives. While vision and hearing are the most

widespread senses explored in virtual reality (VR) and the media in general, wind still have not received the attention it deserves.



**Figure 1.** A user interacting in a virtual environment with wind rendering

Nevertheless, experiments and studies regarding the use of artificially generated wind in VR have been developed as early as in the fifties. Morton Heilig's Sensorama [6], the first VR system, already used fans as a form of sensorial feedback to simulate a motorcycle ride. However, more elaborated studies in the field of wind rendering only started to happen as late as in the last decade. Such studies generally research for a way to increase immersion and presence sensation in digital virtual environments (VE).

In this paper we propose to exploit the wind in a different role than its natural one: the role of aiding in user orientation. In a more concrete way, for example, wind can be used to indicate objects positions in a virtual environment, or

it can be used to represent directions or paths to be followed by a user, or still to be used to carry any other simple informative or orienting content as, for example, collisions with virtual walls.

To make this possible, we also propose in the present work the development of a system to individually render wind around a user's head (Figure 1). Such system is based on a head mounted wind generator. Although this design is not really a novelty [3], our wind display is made with off-the-shelf hardware and self-produced simple software. Moreover, the contribution of this work is not the wind display itself. It is rather the analysis we developed around it, including tests performed with the help of volunteer users and measurements taken during a controlled experiment.

In the remaining of this paper we will detail the design of the wind display device and the experiment used to assess its effectiveness and efficiency. Section 2 discusses the related work, while section 3 introduces the discussion on how to use the wind as a means of communication with the user. Following, the design and implementation of the device hardware and software are detailed in section 4. The experimental results are analyzed in section 5 and conclusions and future work are expressed in section 6.

## 2. Environ

Two previous works were the main sources of inspiration to develop this project, the Wind Cube [8] and the *Head Mounted Wind* [3]. These two projects were successful in the field of wind rendering and were useful as a basis to the exploration and development of our own ideas.

However, differently of our proposal, both these works focus on the wind realism, more specifically, on a way to render wind such that it is perceived as a real wind. *Wind Cube* [8] is a system aiming at improving a virtual reality environment with sensorial wind feedback. The device consists of a large set of fans attached to a cubic structure. The user is placed inside the cube in such a way that wind can be rendered from a number of directions around him.

The authors analyzed what would be the most suitable number, placement and direction of fans. Their hypothesis is that this can improve the immersion and presence experienced by the user.

The *Head Mounted Wind* [3], in turn, is more focused on presence. The authors propose to improve the feeling of presence for a remote pilot of a virtual or real ultralight aircraft. To accomplish this, they rely on information related to the wind influence that is eventually rendered to the remote pilot as wind direction and intensity by means of a head mounted device. The device is an octagonal frame attached to a head mounted display, where 8 computer case coolers are placed. Their ultimate goal, proposed as future work, is to reduce the error in remote piloting of such kind of aircrafts.

Besides, another work, the *VR Scooter* [5] explored a wind interface to assess how such interface makes the user experience more realistic and convincing when traveling through a large scale virtual environment. They unexpectedly also found that, combined with a tactile interface, such increase in the realism also improved user performance. It is not clear though whether the wind or the vibration is responsible for the performance increase.

The commercial use of wind rendering, in turn, is still just starting. The *Ambient Experience*, by Philips [1], focus on the computer games market. It is essentially a sound system which, besides the speakers, also offers a set of two directional fans. Compatible games could render wind effects to increase realism.

## 3. Wind as an orientation tool

Differently of the previous devices, which the goal was to improve presence in a virtual environment, we propose the *WindWalker* as a device to make an alternative use of the tactile feedback provided by the wind. We use the rendered wind as a non-conventional way to communicate spatial information. In such a way, users can use the wind as an orientation tool for navigation in virtual environments. Wind can be used to inform the presence of obstacles, or opposingly, to indicate a free path. Wind is thus applied as an additional information layer to complement the user experience, or can be itself the whole experience.

Using it this way, wind rendering plays a similar role as text layers and menus so often used in augmented reality. They are a completely non-natural way to communicate with users which can, nevertheless, stimulate their perception and

sensibility to such an extent that they become intuitive and improve user performance. A real life example of device playing the same role is the rear-view mirror. While the natural way of looking back is turning the head, all drivers get quickly used to the non-natural rear-view mirror and perform much better in their driving task than if they had to turn their head all the time they have to look back.

Let us now introduce a situation in which a person is left at the entry point of a maze and is invited to find the exiting point. When an easy maze is used, the person will not have much difficulty to find the exit using essentially the sense of sight, the vision. For a more complex maze, perhaps the influence of proprioceptive, tactile and auditive memories can be noticeable besides visual memory. This is more dramatic, and can be noticeable for easy mazes, if the person lacks of vision, as for example, when the maze is a completely dark environment or the person carries some type of sight deficiency. In such cases, wind can be used to inform of open passages.

In the scope of this paper, we use the orientation capability of wind as follows. We describe a maze as a set of nodes with passages to one or more of four possible directions: forward, backward, left and right. When a user is placed at a node, the system is able to produce wind blowing from any number of these four directions. For our case study, turning a fan on means setting it to its maximum power and turning it of means setting the power to zero. Wind blowing from one direction means that there is an open passage in that direction. Absence of wind means that the passage is blocked.
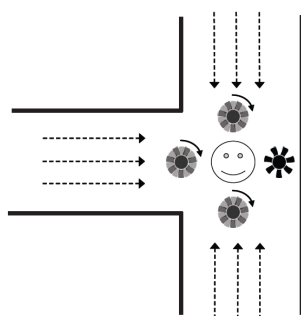


**Figure 2.** Within a maze, wind is generated wherever a passage is open. In this schema, the user can move to front (up), back (down) or left. Right passage is blocked, so no wind is produced coming from the right.

Figure 2 illustrates the role of the wind within a maze. In the following section we detail our wind interface and how the wind is used as a metaphor for orientation in a virtual maze.

## 4. Design and Implementation

### 4.1. Hardware design

Our hardware consists of a device with four PC cooler fans controlled by electric pulses sent through a computer's parallel port and a controller board. Figure 3 shows a schema of the hardware including the electronic circuit and connections.

We have built a controller board which receives signals from 8 parallel port pins. Each of them controls the mechanism of turning on and off the external power supply for one of the coolers. The controller board works in binary mode, controlling only the state of zero power or maximum power. Consequently, we needed a strategy to control intermediate cooler speeds. As implementing actual power level control would require a more complex integrated circuit which is not always available, we propose to simulate power graduation using pulse width modulation (PWM). Essentially, PWM turns on and off the fans quickly, in pulses. The duration of each pulse or the frequency of turning on and off determines the final constant speed of the fans. Figure 4 illustrates our controller board. Notice that only 4 of the 8 ports are currently connected.

The fans, in turn, are mounted on an aluminum structure which is placed on the user's head. Each fan is attached to the structure at a location immediately in front, in the back, in the left and in the right of the user head. The device looks like and is worn as a hat with wires, as shown in figures 1 and 5.
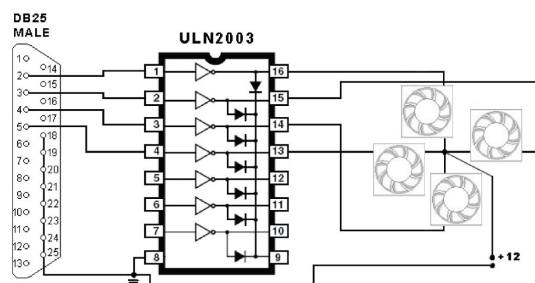


**Figure 3.** Electronic schema for the *WindWalker* hardware. It uses a ULN2003 integrated circuit to switch on and off 4 PC-coolers.
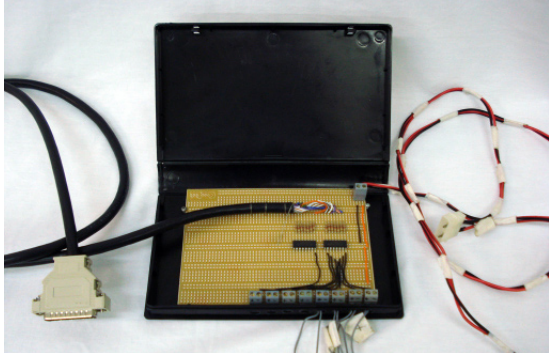
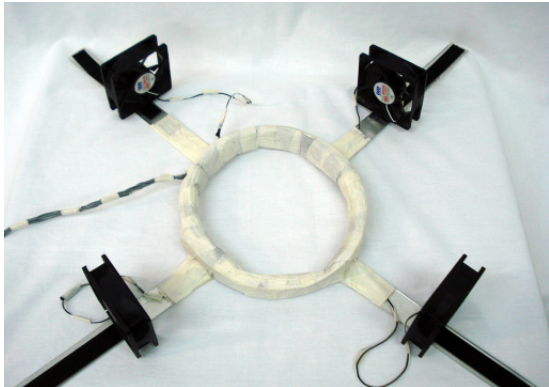**Figure 4.** Controller board. It turns on and off the fans through the parallel port.



**Figure 5.** Aluminum structure with the cooler fans attached

## 4.2. Software design

Besides the hardware, a software controller and application was developed to exploit and assess the use of the *WindWalker*. The software application is a game. The game consists of a maze represented as a 2D virtual environment (see maze examples in Figure 6). The user is initially placed at one of the maze cells and the goal is to find the only exit.

The game is designed in such a way that the user interacts using the keyboard to move in the maze. However, the feedback to the user can be given in three different output modalities:

**Map -** this modality is visual and spatial. The user sees the maze from the top and a white circle marks their position in the maze as they move.

**Text -** this modality is also visual but not spatial. Textual information is displayed indicating which directions are free to move and which are blocked. See the screen shot in Figure 7.

**Wind -** this modality is spatial but not visual. The user wears the *WindWalker* device and

has their eyes covered. Only wind guides them in the maze.

When wind is used, the application also controls the fans according to the user position in the maze. The three modalities can be used all together or individually. We exploit this flexibility in section 4.3 to evaluate the impact of wind in user perception.
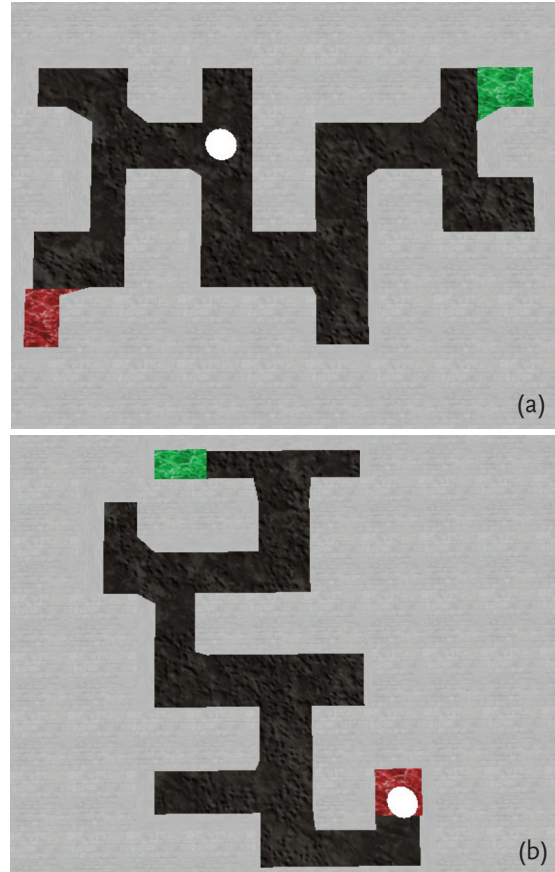


**Figure 6.** Two examples of maze maps used in our experiment. The red cell is the entrance point and the green cell is the exit point.
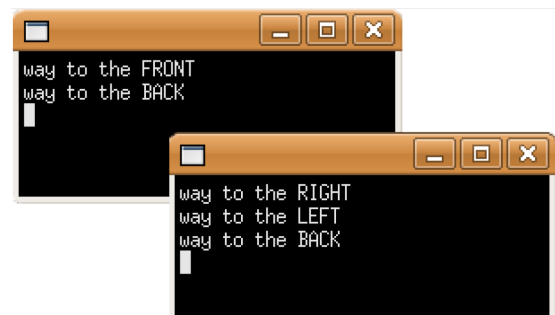


**Figure 7.** Screen shots of the game application in textual mode. Textual indications must be read and interpreted in order to an action to be taken, which increases the cognitive load.

## 4.3. Assessment

To assess our approach of using the wind as an orientation tool for virtual environments, we designed an experiment and invited 12 subjects to voluntarily participate. They are random people with ages between 17 and 32 years old, and are 3 female and 9 male.

Suppose a 2D labyrinth of corridors where the user is constrained to move step-by-step in one of the four directions (left, back, right, front) at a time. The motion is carried out by pressing the keys A, S, D and W, which is the standard in computer games and is widely known by computer users as a technique to move in virtual environments. The keys are set to each movement as follows:

A: move left;
S: move backwards (down);
D: move right;
W: move forward (up).

We hypothesize that the average user is able to orient himself in the environment using only the wind feedback provided by a device like the *WindWalker*. To verify the hypothesis, in this experiment we test the ability of users to perform the task of finding their way out of simple mazes using only wind feedback. As we have not stipulated a time limit to the task, every user will eventually find the exit as the time grows indefinitely. Thus, we measured the time spent for posterior comparison with the time spent to perform the same task with only the textual interface (Figure 7).

First of all, the participants are invited to practice with the system. In order to become familiar with the devices and the game rules, they are allowed to use the keys while looking at the map on the screen and wearing the *WindWalker*. They can also read textual information signalizing which directions are free to move an which are not. They are stimulated to close their eyes to train skin perception and also to take the *WindWalker* off to practice with only the textual interface at will.

After the initial practice, the actual experiment starts. It involves two tests: one using only the wind interface and another using only the textual interface. The tests order is switched among participants to avoid privileging either of them. When the wind interface test starts, each participant wears the wind rendering device, is placed in front of the keyboard, is blindfolded and wears earphones. These measures ensure that the only information the participant receives from the virtual maze is the wind. Then, the user is asked to move along and find the exit.

Analogously, the textual interface is tested with the user in front of the video monitor and keyboard while wearing earphones and without the *WindWalker*. Times are also logged.

Some other precautions are taken to ensure a fair comparison. As the common cooler fans take around one second to accelerate when they are turned on, we applied an equivalent delay before updating the textual interface. Also, to amplify the weight of perception in the experiment time and minimize the weight of the game itself, we decided to use cognitive overload in the tests. For both the wind and textual interfaces, the participants performed the tests while being simultaneously asked simple mathematical questions through the earphones. A new question is presented soon after each one is responded. All answers are recorded to verify the number of correct answers, the number of incorrect answers and how many times the participant has got distracted and asked to repeat the question. Question examples are shown in Table 1 so that the reader can estimate their difficulty level.

**Table 1.** Examples of mathematical questions used for cognitive overloading the interaction task.

| Addition | Multiplication | Subtraction | Division |
|---|---|---|---|
| $12 + 9 = 21$ | $6 * 5 = 30$ | $57 - 3 = 54$ | $34/2 = 17$ |
| $44 + 37 = 81$ | $7 * 8 = 56$ | $214 - 34 = 180$ | $32/8 = 4$ |
| $11 + 9 = 20$ | $12 * 4 = 48$ | $21 - 5 = 16$ | $78/6 = 13$ |
| $123 + 321 = 444$ | $52 * 7 = 364$ | $312 - 123 = 198$ | $55/5 = 11$ |
| $54 + 42 = 96$ | $43 * 3 = 129$ | $68 - 24 = 44$ | $45/5 = 9$ |
| $5 + 37 = 42$ | $24 * 3 = 72$ | $27 - 9 = 18$ | $400/10 = 40$ |
| $67 + 5 = 72$ | $8 * 11 = 88$ | $35 - 17 = 18$ | $18/9 = 2$ |
| $39 + 101 = 140$ | $7 * 15 = 105$ | $49 - 29 = 20$ | $35/7 = 5$ |
| $15 + 8 = 23$ | $7 * 6 = 42$ | $77 - 8 = 69$ | $49/7 = 7$ |
| $97 + 2 = 99$ | $13 * 6 = 78$ | $85 - 83 = 2$ | $72/9 = 8$ |

Notice that cognitive overload is a common practice for task-based evaluation in the field of human factors and ergonomics. In reference [10] the authors analyze the role of cognitive load in surgical skill acquisition.

Just after the tests, each user were asked to respond a questionnaire. Results and discussion of the experiment and questionnaire are presented in section 5 below.

## 5. Results and discussion

The *WindWalker* device has been tested and its ability as a mean of orientation has been assessed using a maze game application as already described in previous sections. The hypothesis that the device can be used as an isolated means of orientation to find the maze's exit has been confirmed. 12 out of 12 users could find their way out of the maze in an average time of 3 minutes and 35 seconds. For normalized comparison we also evaluate the time taken for the users to perform the same task using the textual interface in isolation as a means of orientation. The average time we computed was 2 minutes and 44 seconds. The chart in Figure 8 illustrates the comparative analysis of time to perform the task. As vision is still privileged by the average human as a means to acquire spatial information, some advantage in time of the textual interface was expected. Surprisingly, this advantage is small (31 percent) comparing to studies in cognitive science [7][9], which report that 50 to 65 percent of the cerebral cortex is dedicated to process vision information while the remaining cortex is shared by the touch with the other 3 human senses.

Moreover, despite the small advantage in time exhibited by the textual mode, when we turn our attention to the average time the participants spent to answer each of the mathematical questions, we see that in this criteria it is the wind interface which wins for a slight advantage. As shown in the chart of Figure 9, each participant spent an average of 9.6 s in each mathematical question asked when interacting with the textual interface, and 9.2 s when interacting with the wind interface.

More than the slight advantage, this small difference indicates that the effort required to perceive and interpret the rendered wind is not greater than the effort to interpret the textual interface. Furthermore, we also evaluated the

overall grading for the mathematical questions. We have noticed that the participants gave wrong answers or asked to repeat the question to an average of 4.4 questions during the textual interface test against only 1.3 question during the wind interface test. This considerable advantage, depicted in the chart of Figure 10,
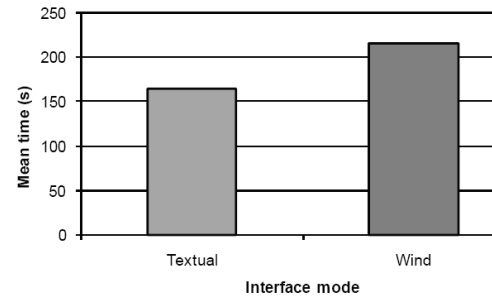


**Figure 8.** Time to complete the task. This chart compares the mean time spent by each of the 12 participants to find their way out of the maze using the textual and the wind interfaces isolated.
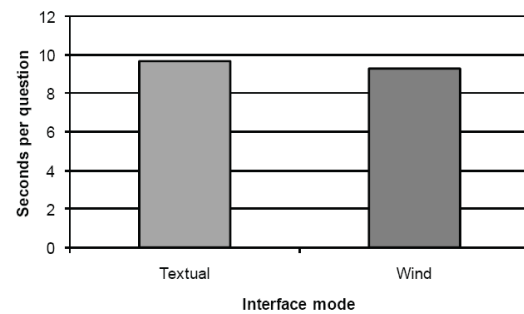


**Figure 9.** Seconds to respond one mathematical question. Comparison of the mean time each participant spent to give a response to each of the questions asked while moving in the maze using the textual and the wind interfaces isolated.
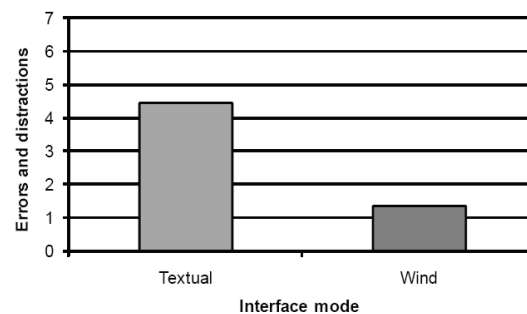


**Figure 10.** Cognitive errors while performing the task. Average number of wrong answers or distractions made by a participant while using the textual and the wind interfaces isolated. A distraction is computed whenever the user asks to repeat a question.

indicates that the orientation task based on wind is less demanding in terms of cognitive load than the orientation task based on text. This is even more surprising knowing that, as they responded the questionnaire, most of the volunteer users stated that they are familiar with textual displays and none of them had tried a wind interface before. The only reason these results are not even more influential is that the number of users tested, 12, is too small to allow a complete and significant statistical analysis. Further user tests are left for future work.

## 6. Conclusions

Perception is the ability to take in information via the senses, and process it in some way. Vision and hearing are two dominant senses that allow us to perceive the environment. As a natural consequence, they are the most explored in the fields of virtual reality and virtual environments. However, the study of haptic (tactile), olfactory, and gustatory stimuli also fall into the domain of perception. Such senses are also rich in information and recently started to be considered to increase the realism of virtual and mixed realities.

To explore the human tactile system as an interface to perceive wind, and to assess the impact of the wind as an orientation tool, we proposed a wind rendering system and an evaluation experiment. We compared user ability to orient in a maze using either visual stimuli through a textual interface or tactile stimuli through our wind interface. The experiment results indicate that even for the untrained user the wind interface is satisfactory, as all subjects actually solved the maze. They also uncovered the fact that in a bimodal task (performing math calculations while navigating) the wind interface is less cognition demanding than the textual interface.

Such findings are very encouraging as, according to research in cognitive sciences, people with certain disabilities amplify other senses adapting them to replace the missing sense. Taking this knowledge into account, we believe that similar techniques involving wind rendering might grow in popularity when they are implemented as an alternative interface for vision-impaired people in conventional computer games. However, further evaluation is required to understand the learning curve for alternative interfaces in applications like games

and to enable us to provide a better gaming experience for users. Some initiatives already exist using sound to communicate location of walls, doors and opponents in first person shooter games as AudioQuake [2]. In future initiatives, wind could be used together with sound and touch to improve the accessibility of computer games.

In our case study we detected some limitations that will guide us in designing better and more accurate devices for orientation in future works. One of them is that people wearing long hair misunderstood or could not detect wind rendered from the back. Another, which is particularly annoying in our approach of using the wind, is that opposite winds can be misleading. For example, wind blowing simultaneously from both sides of the head were sometimes interpreted as blowing also from ahead. As in nature wind blows generally only in one direction at a time, such misinterpretation can be explained as a difficulty for people to adapt their sensibility to the new situation. Future work could explore different uses for wind, for example, blowing when the user approaches a wall, meaning an imminent collision, and not blowing when there is an open way.

Another implementation left for future work is to combine position tracking of the user to avoid the use of the keyboard and amplify the feeling of presence.

Finally, we observed a cheerful interest of the people in trying the device. At least twenty other people, besides the experiment participants, already tested the device and gave us a rather positive feedback. Such curiosity indicates the existence of a potential to establish new interaction metaphors that may reveal new application possibilities.

## 7. Acknoledgements

## 8. References

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