VOS – Designing a Visual Orientation System

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Abstract
While humans possess a well-developed sense of direction and can easily walk to a visible target, that ability is drastically reduced when lacking visual cues. In situations where people cannot depend on sight, orientation might become a critical issue, as when escaping a room filled with smoke, swimming in open waters, hiking in the fog or crossing the woods at night. In this paper, we present the design and implementation of VOS - a Visual Orientation System for providing an augmented sense of direction. Our system uses LEDs to offer cues on how to correct the current heading. Our findings consist of demonstrating the viability of such system, as well as its usability. We discuss the implications for designing technology that enables people to orient themselves and navigate places with little or no visual cues.

Author Keywords
Swimming; augmented senses; HCI for sports; Sense enhancement.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction

Orientation, and the general sense of direction, is a complex mental mechanism. It involves the vestibular sense (responsible for sensing angular momentum and linear acceleration [8]), the senses of sight and hearing, and the mental mapping of the surroundings [5].

Exposing the senses to unusual conditions may limit our capability to orient ourselves correctly, and deprivation of visual and auditory cues hinders the mapping process. Many different situations present this problem, such as swimming or escaping a building on fire, where smoke and blackouts make navigation impossible. In the case of swimming in open waters, for example, swimmers have no visual references while swimming. This results in the impossibility to swim in a straight line and forces swimmers to stop periodically to look for visual cues (if possible at all) or consult a compass or GPS device [6], which causes exhaustion and sub-optimal routes.

Current consumer-grade technology has the potential to tackle this problem. Our contribution in this work is an exploration on how to effectively and unobtrusively communicate direction to people through visual cues. Further, our findings suggest that different situations can be better approached with different signalling methods and we propose interaction concepts and experiment designs to assess them.

Related work

A corpus of work investigates visual feedback methods for general navigation tasks. Poppinga et al. created AmbiGlasses, a device that provides visual feedback for navigation with a dozen LEDs positioned around the eyes [7]. Their study suggests the validity of conveying information in the periphery of the visual field.

In the same line of work, Tseng et al. used point-light movement as peripheral visual guidance for vehicle navigation [9]. Although they do not evaluate their design in the wild, their results show how people are able to recognize different types of signals presented in the periphery of their field of view.

For the particular case of devices intended for swimmers, Förster, Bächlin and Tröster presented a comparative evaluation of three non-interrupting user interfaces: audio, visual and haptic-feedback [3]. Their findings indicate that audio feedback is not an appropriate modality for conveying information to swimmers. The same authors created SwimMaster, a system that provides feedback to swimmers about their performance [1]. Using wearable accelerometers to measure the movements of the swimmer, their design provides off-line feedback about technique and performance. Chei et al. created an *exergaming* system [2] for swimmers based on a water-proof smartphone, which they used to collect metrics of the swimmers' performance. Their design provided tools for coordinated interaction among swimmers, that resulted in higher motivation and a richer experience.

These findings help create a framework to study the use of unobtrusive visual feedback to aid orientation in low visibility conditions, but leaves open the question about what method and modality is adequate for use cases such as swimming in open waters or finding the way out of a building on fire.

Concept

We propose a device for enhancing the sense of direction. We consider use case scenarios in which visibility is low or naught, such as what experience people swimming in open waters or navigating a room filled with smoke. For this

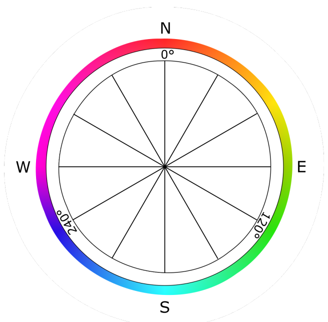

Figure 1: Colour mapping: the RGB colour space is mapped to the four cardinal directions, resulting in pure red for the North, pure green for 120° respect the North and pure blue for 240°.

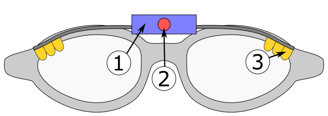

Figure 2: Mock device that provides only partial functionality: (1) microcontroller, (2) selector button and (3) RGB LEDs

reason, we base our design upon visual feedback, since the cognitive load for this sense will be likely at a minimum.

To emphasize the unobtrusiveness of our design, we take a minimalistic approach to the interface, which consists of two LEDs, positioned on the outer field of view of each eye. During our design process, we came to the conclusion that different use case scenarios need different signalling approaches. To address this question, we devised two different signalling modalities, intended for different scenarios:

Relative discreet orientation
The system indicates a deviation from a given direction. When the goal of the user is to keep a heading, this system provides cues to the user, showing towards which direction she needs to correct her heading.

In this case, the cues consist of a single LED lighting up on the side towards which the user must turn to. The LED shines in yellow, ensure visibility in a large scope of situations but has not the strong culturally attached negative implications of red.

Absolute continuous orientation
The system indicates all the time the absolute direction using a colour. We map the colour values of RGB LEDs to the angular deviation respect North in degrees (see Figure 1), starting with pure red for North, pure green at 120° (roughly SSE) and pure blue for 240° (roughly SSW). The intermediate colour values are mapped linearly between the two pure colours delimiting the interval for each value.

This way, all directions have a unique colour, with a granularity limited only by the accuracy of the sensors and the colour spectrum that 24bit RGB colour coding can provide.

Study

We ran a pre study with a mock device (see Figure 2) to assess the method for conveying the cues in the relative discreet method. The mock device consisted of generic swimming goggles, with three RGB LEDs fixed to each side, in a way that when turned on, could be clearly perceived in the outer field of view for each eye. These two sets of LEDs were controlled by an Arduino board which, by clicking on a button, allowed to browse through different combinations of signalling patterns (continuous signals with one or multiple LEDs, blinking signals at different intervals, waving patterns, etc.). The device was connected to a magnetometer and worked like a compass, turn on the light signals on the side that resulted on a smaller angular deviation respect to the magnetic North. We set a threshold of 3 degrees deviation to each side, to generate a *roughly right direction* zone, within which both LEDs were off (see Figure 3).

We invited six participants (3 males and 3 females with ages between 26 and 38) to test the device while sitting on an office chair and collected their impressions during a semi structured interview. Five participants preferred a single continuous light, stating all other approaches are more distracting. Two of them stated that the use of more than one LED on each side produced too much light intensity, which they found unpleasant. One of the participants preferred the blinking lights, since she said it reminded her of the turn signals from cars. All participants expressed that they perceive the device as useful and would consider using it in the suggested application scenarios.

Implementation

We implemented a prototype capable of providing both forms of feedback. We base the *relative continuous* signalling method on the insights we gained during the pre study.

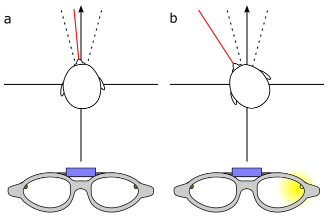

Figure 3: (a) The user heads towards a direction within the threshold, so no LED is actuated. (b) The user heads towards a direction outside the threshold, so an LED on the opposite side (from the wearer's perspective) is actuated.

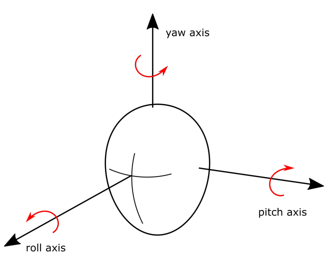

Figure 4: Aeronautical denomination of the Tait-Bryan angles: the roll axis points forward to where the user faces, the pitch to the sides and the yaw upwards. Thus, the yaw angle is equivalent to the heading.

Since the enhanced orientation is provided by a compass, and thus respect the magnetic North, the device only provides feedback about direction on the horizontal plane [4], requiring compensation of any movement and tilt of the user's head. We achieve this with a triple-axis accelerometer, which we use to calculate the horizontal plane respect the orientation of the sensor using the gravitational pull as a reference.

The program running in the Arduino constantly polls the current values provided by the accelerometer and magnetometer. We used a combined sensor, the LSM303 [1] that provides both measurements. Using the Tait-Bryan angles to model our coordinate system (see Figure 4), we calculate the roll and pitch of the head of the user using the values provided by the accelerometer:

$$pitch = \arctan \frac{A_y}{\sqrt{A_x^2 + A_z^2}} \quad (1)$$

$$roll = \arctan \frac{A_x}{\sqrt{A_y^2 + A_z^2}} \quad (2)$$

where A_x, A_y and A_z are the normalized values of acceleration for the three respective Cartesian axes. The calculated $pitch$ and $roll$ are angles in radians, respect to the horizontal plane. The magnetic readings M_x, M_y and M_z are also normalized and projected on the calculated plane:

$$H_x = M_x \cdot \cos roll - M_z \cdot \sin roll \quad (3)$$

[1] www.st.com/resource/en/datasheet/DM00027543.pdf

$$H_y = M_y \cdot \cos pitch + M_y \cdot \sin roll \cdot \sin pitch + M_z \cdot \cos roll \cdot \sin pitch \quad (4)$$

$$yaw = \arctan \frac{H_x}{H_y} \quad (5)$$

The obtained yaw is then the angle of the magnetic North respect the heading of the user, projected on the horizontal plane. This value is smoothed using a low-pass filter, minimizing the noise of the device and the effect of the movements of the user.

The device has a single control button. When the device is turned on while the button is pressed, the program for *relative discrete* direction feedback is loaded, if not, the system boots in the *absolute continuous* direction mode. For the first case, the button also serves to set the current direction as the goal. The feedback is provided using two RGB LEDs fixed to the sides of swimming goggles. The RGB value in the absolute direction mode is calculated as with simple linear functions (see Figure 6). For the relative direction mode, the LEDs are set to yellow.

The device is powered using a coin cell battery, a safer alternative to LiPo battery packs in case the system is exposed to water. All electronics of the device are made water proof using vacuum sealed bags, enabling its use for swimming (see Figure 5). Both signalling modes are implemented as described in the design. The relative direction mode has a tolerance threshold of 3 degrees to each side before indicating a deviation from the desired heading. When setting a new goal direction by pressing the button, both LEDs blink three times to confirm the selection.

Figure 5: VOS prototype. The electronics are vacuum-sealed in a waterproof bag and attached to standard swimming goggles.

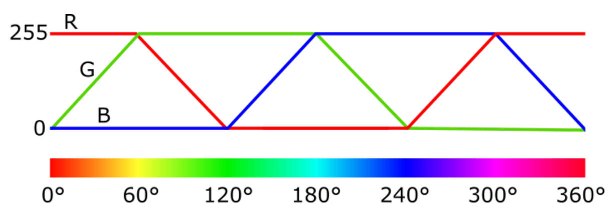

Figure 6: Colour mapping for the absolute direction signal. Using the RGB colour coding, each angular direction is mapped to a linear combination of red, green and blue, resulting in the tones displayed in the bottom bar.

Evaluation plan

We want to evaluate which feedback method is better in the two main use case scenarios: swimming in open waters and navigating a room with low visibility. In the first scenario, the device must aid a user to keep a heading consistently, thus guaranteeing the swimmer to keep a straight line. Here the challenges are the accuracy of the feedback, the ability to compensate the movements of the swimmer and the user experience of the swimmer.

The second case scenario, navigation on dry land without visual cues, presents a different set of challenges. The user still relies on vision to dodge obstacles that turn visible at close range, so the unobtrusiveness of the feedback is critical. The exact desired direction is not known, but usually a general heading is enough to make it out of a room or building (more complex situation can be divided in shorter stages).

For the first case, we plan an experiment in a small lake. A group of experienced swimmers participating on an annual amateur competition will cross a lake and return, trying on each stage one of three conditions: absolute direction feedback, relative direction feedback and no feedback. Conditions will be balanced among participants, thus making the TCT for each stage a valid indicator of the performance increment the system provides. We expect that semi structured interviews will provide useful insights to further improve the application.

For the second, the believe that exposing participants to stressful real-like situations (such as navigating a room filled with smoke) are unnecessary and plan to run the experiment in a corn-maze instead. This fulfils the requirement of an absence of visual navigation cues and we plan to perform the experiment in the evening, to avoid the use of the direction of sunlight for orientation. In this experiment we will collect the TCT of each participant, which will cross the maze in one of the three conditions mentioned (absolute, relative or no feedback).

Preliminary conclusions and future work

We have created a device capable of providing visual feedback that enhances the sense of orientation in the lack of visual cues. During our preliminary evaluation we concluded that there are at least two possible ways of communication directions, both providing benefits and disadvantages for different use case scenarios. An additional finding is that people expressed interest in the concept and considered it useful.

Our evaluation showed also some limitations of our current prototype: the device succeeded in compensating movements and tilt of the head, but if the user tilts the head 90Âř to the side ((rolls) the head), the visual cues are on a line orthogonal to the horizontal plane, thus making the signals confusing. Another limitation of the device is the use of the magnetic North as orientation reference. For open waters swimmers this might not pose a problem, but the presence of competing strong magnetic fields cannot be excluded in other scenarios.

We plan to add Bluetooth and a GPS sensor to the device. This way, it will be possible to pair the device to a handheld device or computer and input desired coordinates, enabling the orientation system to aid its user in more complex situations.

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