Design of a Wearable Tactile Interface to Convey Gravitational Information

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Abstract. This research aims to correct tilted body positions in pitch and roll, making the user's body axis becoming parallel with the gravitational acceleration vector through the use of tactile cues. A device is designed for the purpose and consists of a corset-like vest equipped with some sensors and four vibrotactile motors: two on the torso and one per each shoulder. The actuators deliver tactile feedbacks proportional to the angular error between the body axis of the user and the gravitational direction: the larger the error, the higher the frequency.

1 Introduction

The gravitational field has always affected human evolution becoming an intrinsic model [1, 6], so much that the "up" direction - considered the direction from where the gravitational acceleration pulls - easily allows objects identification and correct reading of signs [3]. In everyday life, multimodal and multisensory inputs are needed to identify the "up" direction: visual, vestibular and proprioceptive cues and the idiotropic vector [2]. In some environments, these inputs are not always clear and univocal.

Disorientation during deep-sea diving or micro-gravity experiences can occur for different reasons: losses of vestibular information due to unexpected sea currents, "space adaptation syndrome" due to the misalignment between the body's axis and the "expected" vertical direction, the misreading of proprioceptive cues induced by water density and visual reorientation illusions due to the absence of reference systems. Maintaining a vertical position allows to countermeasure these uncontrollabe reactions in our perception.

The aim of this research work is to try to correct tilted positions in pitch and roll dimensions, letting the body axis to be parallel with the gravitational acceleration direction, by providing properly designed tactile cues.

2 Design of the wearable tactile interface

The idea is based on the identification of human body parts as four cardinal directions. Given that human sensitivity on the torso sides is quite low [8], shoulders were used as punctual locations along with chest and back. Being provided with free movement in space, hands, and forearms were not considered the same signal could lead to multiple directional information depending on limbs orientation [7].The signal perceived by the user changes according to the error of pitch and roll angles with respect to the gravitational acceleration vector. If multiple tactile stimuli are conveyed to the user at the same time, their perception may guide the user to an intermediate position feedback [4, 5], allowing a fast correction of the tilted posture. The tapping on a shoulder could be associated to a "pushing" force moving the user towards the opposite shoulder such that a disturbing signal on the right shoulder would cue a clockwise rotation. Further experiments should be performed to confirm this result. According to Van Erp guidelines [9], a pulsed vibration increasing in frequency was selected as the driving stimulus, making the user not to get used to the tactile cues; additionally, a specific vibrational pattern signals the achievement of the vertical orientation in space.

Harware The prototype developed consists of a corset-like vest. Four vibrotactile motors were mounted on the torso (two, one on the front and one on the back for pitch dimension), and one per each shoulder for roll dimension. As shown in Figure 1, the Vibrating Mini Motor Discs are placed in tight pockets on the corset-like vest, which is regulated by Velcro straps and elastic bands. The vibrational amplitude is sufficiently large to be clearly perceived by the user [9]. A 9.6 V battery pack was introduced to power the circuit.

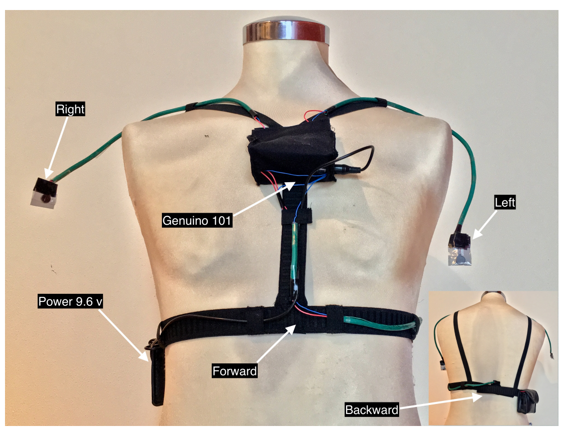

Fig. 1. The assembled prototype

The four actuators are controlled by a Genuino 101 board, and provide the user with a tactile feedback proportional to the angular error between his body axis and the gravitational direction: the larger the error, the higher the frequency.

The choice of the accelerometer varies according to the environment. In Table 1, possible solutions for land, deep-sea and microgravity conditions are listed.

Table 1. Accelerometers properties

Environment	Land	Deep-Sea	Microgravity
Sensors	Genuino 101 sensors	SA6200UW	MESA
Work Range	± 4 g	± 50 g	± 2 g
Resolution	10^{-2} g	10^{-3} g	10^{-6} g

Software The software consists of an Arduino IDE script controlling the actuators. A 100 Hz sampling frequency was adopted for both sensors. However, data acquired by IMU are likely to have high levels of noise; for example, accelerations due to translational motion can influence the measured direction of gravity. Signal distortions must be avoided through the implementation of a filter. After computing pitch and roll angles on the basis of Tait-Bryan formalism, a pulsing signal is sent to the actuators with a frequency proportional to the magnitude of the measured angles as shown in Figure 2 It is worth noting that modeling of angles changes according to each specific application.

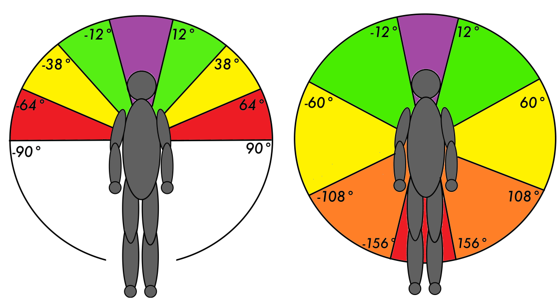

Fig. 2. Schematic representation of angles ranges for land navigation (left) and deep-sea navigation (right)

Land Navigation. If the computed angles are lower than 12 deg (absolute angle), no signal is sent to the actuators.

$12° < \alpha < 38°$ and $-38° < \alpha < -12°$ corresponds to frequency 1 Hz

$38° < \alpha < 64°$ and $-64° < \alpha < -38°$ corresponds to frequency 1.5 Hz

$64° < \alpha < 90°$ and $-90° < \alpha < -64°$ corresponds to frequency 2 Hz

Micro-Gravity and Deep Sea Navigation. Merfed et al. observed that in altered gravity conditions disorientation due to visual disturbances occurs, even if the user is correctly aligned with gravity direction [6]. For this reason, if the computed angles are lower than 12 deg in modulus, in these applications a 3 Hz signal is simultaneously sent to each actuator for one second every eight seconds. In deep-sea applications, since verticality is not the typical condition, the vibrational pattern does not run continuously but only when the wearer needs to emerge.

$12° < \alpha < 60°$ and $-60° < \alpha < -12°$	corresponds to frequency 0.75 Hz
$60° < \alpha < 108°$ and $-108° < \alpha < -60°$	corresponds to frequency 1 Hz
$108° < \alpha < 156°$ and $-156° < \alpha < -108°$	corresponds to frequency 1.5 Hz
$156° < \alpha < 180°$ and $-180° < \alpha < -156°$	corresponds to frequency 2 Hz

3 Conclusions

The result is a prototype which will be used in future testing activities to observe users' response to tactile cues and to verify the effectiveness of the system for different environments. The design hypotheses are based on data available in the literature. The solution can be easily adapted to be used in wet or space suits or simple shirts.

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