High-Resolution Feedback using Tactile Semaphores

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Abstract

In this paper, a novel tactile communication device for the neck is presented. This device relies on a one-dimensional array of actuators and uses tactile semaphores to convey information received wirelessly from a mobile device, computer, or game console to the subject wearing the device. Tactile semaphores are tactile patterns generated by multiple actuators on the neck. The neck is unique in that it offers an intuitive one-to-one tactile correspondence between directions in the horizontal plane and locations on its periphery. This device is capable of conveying bearings with an angular resolution better than 20° and ranges with nearly 10 levels of distance, making it accurate enough for most gaming and navigation applications. Tactile semaphores may be used to mimic real-world experiences and to enhance immersion in a gaming or simulation environment. In-world experiences such as acceleration, fall, impact, or game-related sensation such as boost, gradual loss of health, win, and loss may also be conveyed through the use of dynamic semaphores called marquee patterns. Other applications of this device are also presented.

Background

The five senses provide an individual with cues about distance, location, velocity, and properties of surrounding items. In simulated or virtual worlds such as electronic videogames, the senses are restricted by the size of the video screen, limited speaker sound quality, and the very limited tactile feedback provided by the vibration of a hand-held controller.

Vibrating game controllers have been devised (Nishiumi, Koshima and Ohta, 2006) and used to create in the player a sense of interaction with the physical world. For instance, in a racing game, as the vehicle leaves the pavement, the hand-held game controller vibrates. In first-person shooter games, the player is informed of having been hit through the vibration of the game controller. With the advent of controller-less game systems that enable interaction with a game without the use of controllers, such as Microsoft's Kinect system, even this basic tactile feedback is no longer available.

Tactile communication methods, systems, and devices have been devised to provide an individual with the ability to understand text and commands, or to augment his or her situational awareness. These methods primarily relate to artificial vision for the blind (MIT Touchlab, 2005) and to remote communication with individuals (Gilson & Christopher, 2007; Rupert & Kolev, 2008; Zelek & Holbein, 2008). Tactile communication devices have also been proposed to transmit parameters describing the state of a remote unmanned vehicle to various areas of a human controller's skin (King, 2009).

The Tactile Situation Awareness System (TSAS) is a wearable tactile display intended to provide spatial orientation cues (Zelek & Holbein, 2008; Rupert & Kolev, 2008). A belt equipped with transducers and worn around the waist (Gilson & Christopher, 2007) was devised to provide orientation cues to soldiers. This approach uses tactile stimulus at various positions around the torso and the belt area to pass on information on the location of an incoming threat to the subject.

Tactile displays, as the visual-to-tactile information translation devices are often called, have been investigated by research organizations such as the MIT Touch Lab (MIT Touchlab, 2005). Work on tactile displays is generally concentrated around passing tactile information to the skin and investigating the mechanical and physiological parameters that govern the complexity and bandwidth of transmitted information; this, with no particular attention paid to the neck skin.

In general, it can be noted that tactile devices designed to convey complex information utilize a relatively large area of the body and do not offer an intuitive or accurate relationship between the information conveyed and the tactile feeling sensed by the subject.

A novel tactile feedback device

The proposed device is built around an exoskeleton in the form of a pair of headphones (Figure 3) connected by flexible and spring-loaded metal strips resting around the neck of a user. The exoskeleton maintains an extensible holster that carries a number of tactile actuators taught and snug around the neck of the subject. This design (Figure 4) ensures that the device is always properly oriented (front facing to the front of the subject) and that the tactile actuators remain always in contact with the neck. Furthermore, the device may be combined with a pair of speaker/headphones and a microphone, thus providing a complete sensory audio-visual and tactile environment to the user.

An electronic controller located in the back of the device and powered by a small rechargeable battery pack operates the device based on signals received form an external source through a wireless receiver.

Based on signals received from a mobile communication device, computer, or game console, the device impresses sequences of tactile stimuli at specified locations around the subject's neck, thereby providing the subject with intelligible information.

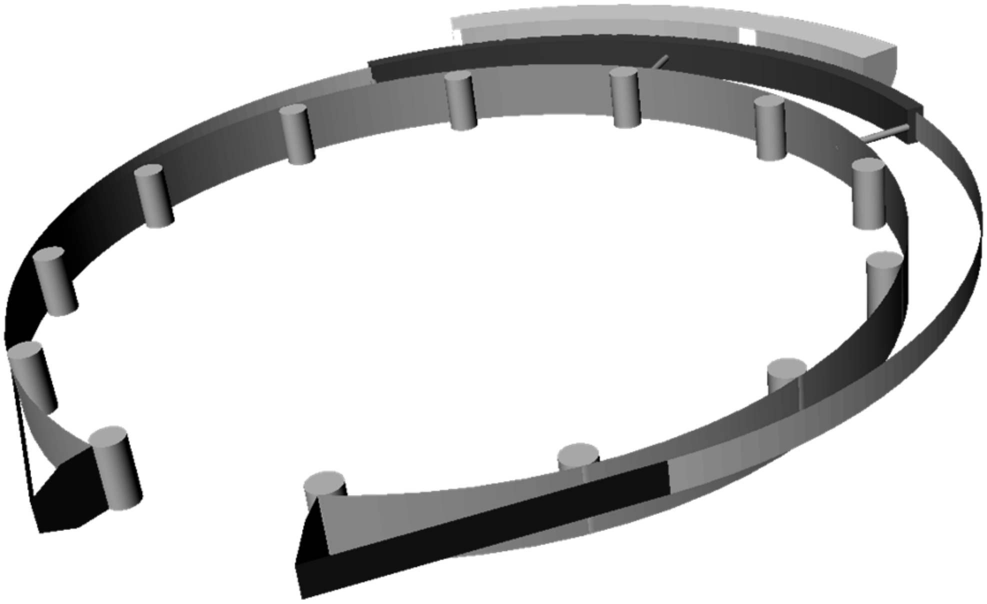

***Figure 3.* The device shown with 12 actuators equally spaced and held by a holster**

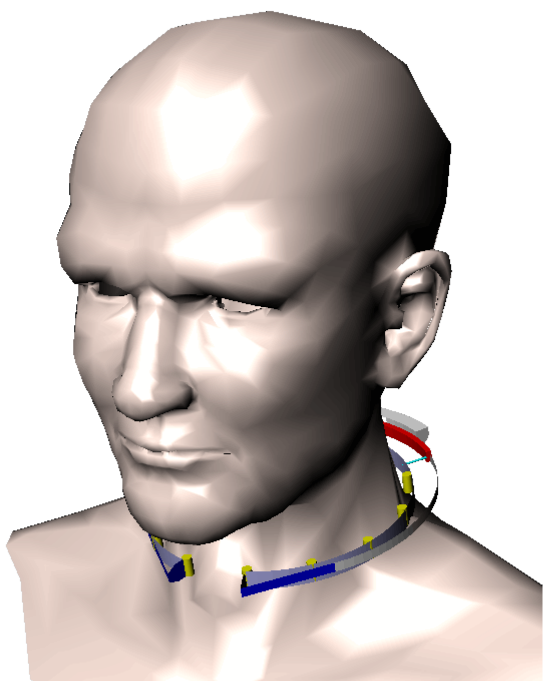

Figure 4. Subject wearing the device

The Neck Skin As A High-Resolution Sensory Organ

One measure of the effectiveness of a form of communication is how fast complex information can be transmitted to an individual using that form of communication. The speed of communication or bandwidth may be measured by how many characters are involved and the rate at which these characters are conveyed and comprehended by the individual.

In general, the skin is an imprecise sensory organ. While a person can discriminate between tactile stimuli applied to individual fingers, toes, other body parts or wide expanses of skin, the ability to discriminate tactile stimuli applied to neighboring skin locations is limited. However, the neck skin has a unique property that enables a person to accurately discriminate tactile stimuli applied from various directions onto its surface. Tactile stimuli applied at various angles around the neck can be discerned despite the closeness of the application points. An untrained individual is often capable of discriminating as many as 12 different peripheral locations around his or her neck. With some training, an individual may be trained to distinguish the location of tactile stimuli applied to many more angular locations around the neck.

With such a resolution, an individual is also able to distinguish between combinations of directions. By simultaneously stimulating several locations around the neck it is possible to communicate complex information to an individual. This approach may also be used to communicate with the blind, the autistic, and those unable to communicate verbally or visually.

Tactile semaphores

Tactile semaphores are created by turning individual actuators on or off at various frequencies and with various intensities thus generating various tactile patterns on the subjects neck. Figure 5 shows two examples of tactile semaphores where the back and white circles indicate "on" and "off" actuators.

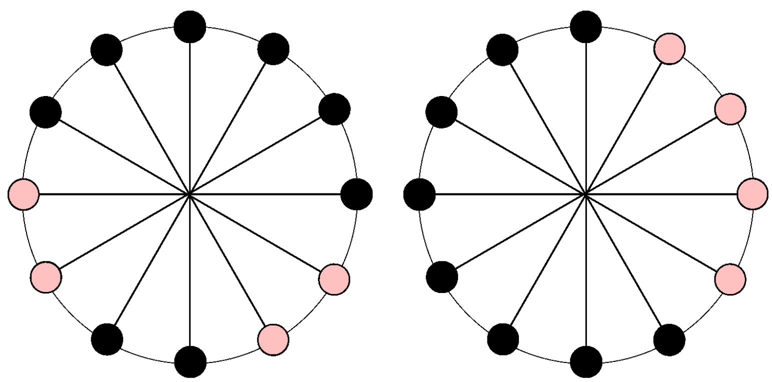

Figure 5. **Two examples of semaphores generated by 12 "on" (shown in black) and "off" (shown in gray) actuators**

Semaphores for representing distance to a target

Because of the one-to-one relationship between directions and locations around the neck, bearings can be intuitively conveyed using this device, but in order to represent distances, certain analogies or paradigms need to be used. Each analogy has its applications and limitations.

The approaching cruiser analogy

As the target approaches (Figure 6), the patch of active actuators expands, with the average direction of the patch of active actuators pointing towards the approaching target.

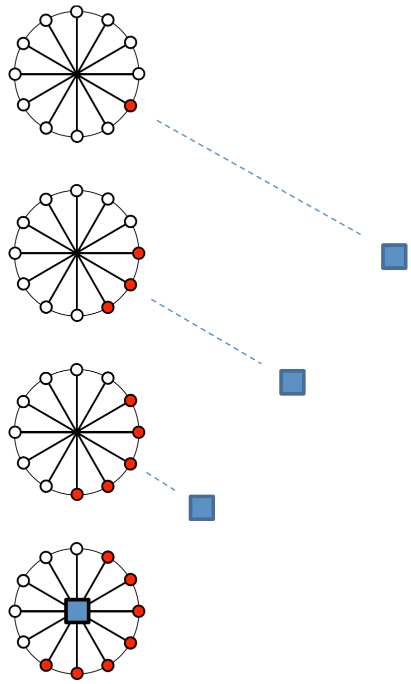

Figure 6. **The approaching cruiser analogy: as the square object approaches, the patch of active actuators expands**

The radar analogy

Instead of representing the location of an object with several contiguous and continuously active actuators, a single actuator pointing in the direction of the object may be turned on and off at a frequency depending on the distance of the object to the subject. As the object approaches, the on/off frequency increases. When the object is very close to the subject, the frequency is maximal. As the object recedes, the frequency diminishes.

By linking the distance of an object (to the subject) to the on/off frequency of actuators, multiple objects located at various distances from the subject may be tracked, each represented by a single actuator pointing in that direction and turning on and off at a frequency representing the distance of that object to the subject.

The approaching noise source analogy

As an object approaches, the intensity of the stimulation on the skin may be increased. As the object recedes, the intensity is reduced. The intensity of the stimulation may be controlled with the intensity of the electrical current fed to each actuator. In this fashion, multiple objects located at various distances from the subject may be tracked, each represented by a single actuator pointing to that object and operating at an intensity based representing the distance of that object to the subject.

Semaphores used to indicate departure from the vertical axis

One application of this device is as an aid to pilots in preventing loss of horizon: a dangerous condition caused by bad weather and low visibility and resulting in disorientation and accidents. Loss of horizon occurs when all visual cues about the "up" and "down" directions are lost. Most aircraft are equipped with electronic navigational systems, including gyroscopes. A gyroscope keeps track of the horizon and the current attitude of the aircraft and, with the help of the onboard navigational systems, displays the horizon through an instrument called artificial horizon. However, in certain emergencies, a visual display of the horizon may be confusing to a pilot who must scan multiple instruments under extreme workloads.

The electronic navigational system of the aircraft calculates the angle between the acceleration vector experienced by the pilot—which points along the pilot's neck axis—and the vertical axis OZ associated with the horizon.

Figure 7 shows the neck axis, represented by the vector $\vec{n}$, and the vertical axis OZ. As the "up" direction (perceived by the pilot, vector $\vec{n}$) drifts away from the real "up" direction (axis OZ calculated by the instruments), the actuator located at P is activated to indicate the direction in which the neck should be tilted to realign it with the vertical axis. Point P may be calculated as the intersection between two planes: plane ∑ and the plane containing the axes OZ and the vector $\vec{n}$.

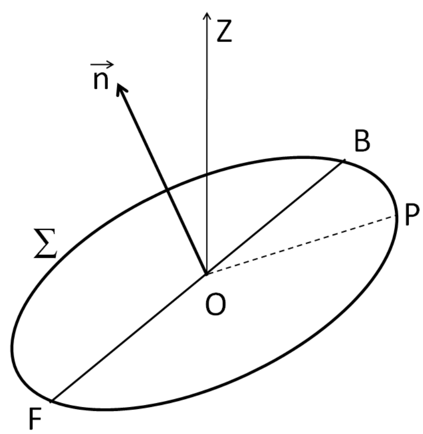

Figure 7. **Vertical axis OZ associated with the artificial horizon provided by an aircraft's navigation instrument, and the vertical perceived by the pilot (vector $\vec{n}$) associated with the plane of the device, ∑**

Semaphores for representing acceleration

In racing games this device may be used to convey the direction and intensity of the acceleration vector experienced in a virtual environment such as a videogame or a simulation. Figure 8 shows that as the acceleration experienced by the user increases in intensity and changes directions, the patch of active actuators increases in size as a function of the intensity of acceleration, and the average direction of the patch of active actuators points in the opposite direction of the acceleration vector. Thus, the player experiences accelerations as if a yoke placed around his/her neck drags him in various directions, with the size and direction of the patch of active actuators causing a variable pressure on the neck skin.

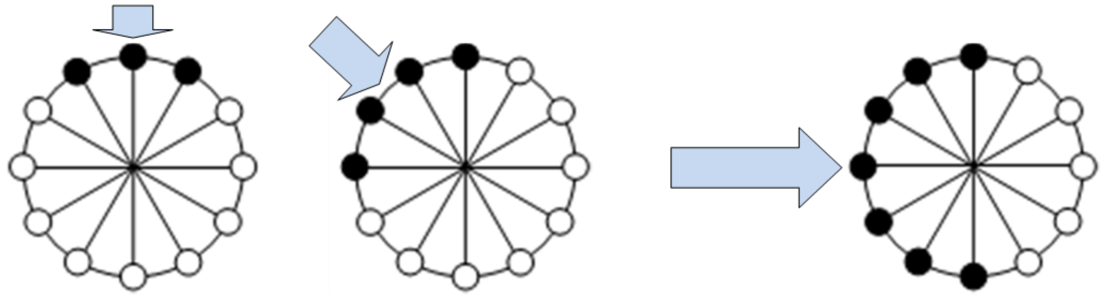

Figure 8. **As the direction and intensity of acceleration experienced by the user changes, the average direction and extent of the patch of active actuators is modified.**

In an alternate and more realistic method of conveying acceleration, at lower accelerations, the extent of the patch of active actuators increases with increasing acceleration up to a certain value of acceleration; then, the intensity of tactile stimulation increases with increasing acceleration while the extent of the patch remains constant. This method mimics the car headrest paradigm in which initially, the contact surface between the neck and the headrest foam material increases as a function of the acceleration module—the constant pressure phase. Once the maximum contact surface is reached, the pressure applied on the neck increases with the acceleration module—the constant contact area phase.

Marquee patterns as dynamic tactile semaphores

Marquee patterns are dynamic tactile patterns. Table 1 shows an example of a marquee pattern making the subject feel as if a point of contact is turning around his/her neck. The numbers indicate the sequence in which the actuators are activated.

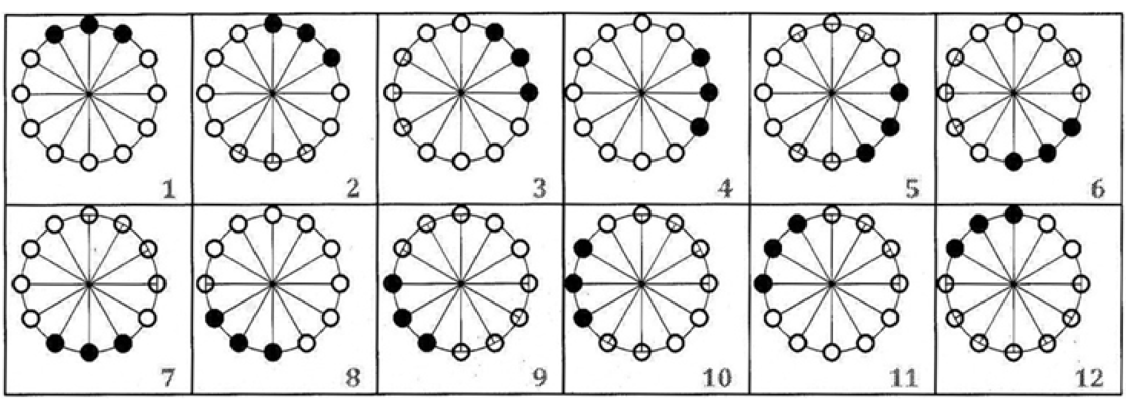

Table 1**: Example of marquee patterns causing a rotating point of contact around the neck**

Table 2 shows another example of marquee pattern causing a sensation of back and forth movement of a pressure point on the left and right sides of the neck. Dark circles represent active actuators and clear circles are inactive. The numbers indicate the sequence in which the actuators are activated.

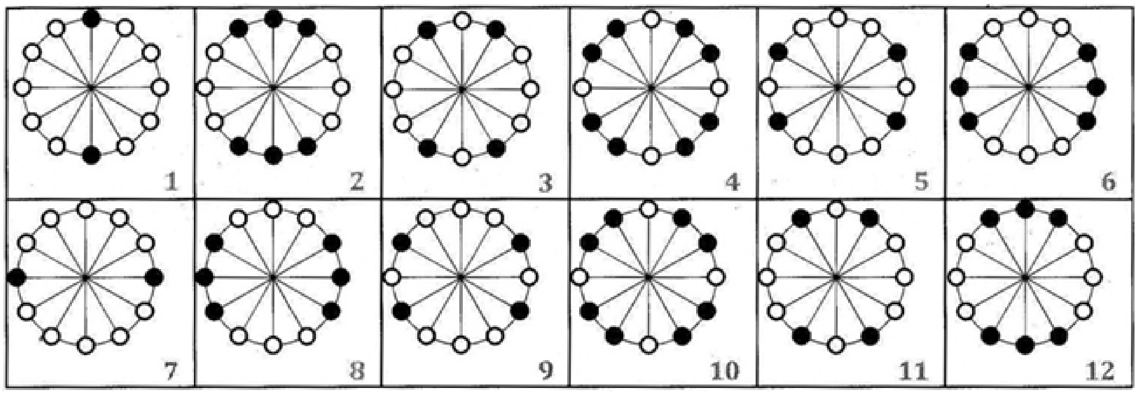

***Table 2:* Example of marquee patterns causing a back and forth movement of a point of contact on the neck**

Table 3 shows yet another example of marquee pattern causing a repetitive constriction around the neck of the subject. Such patterns and the sensations they provoke may be used to convey certain game conditions such as ‘diminishing health’, ‘about to be shot’, ‘ball at reach’, ‘falling’, or ‘dying’.

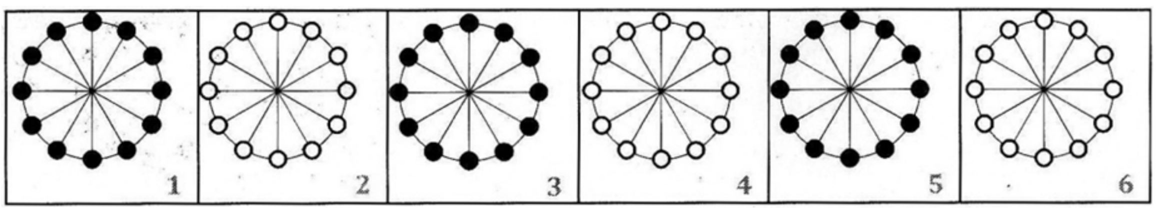

***Table 3:* Example of marquee pattern causing a repetitive constriction around the neck of the subject**

Table 4 shows an example of a tactile alphabet based on the static tactile patterns generated by 12 actuators around the neck.

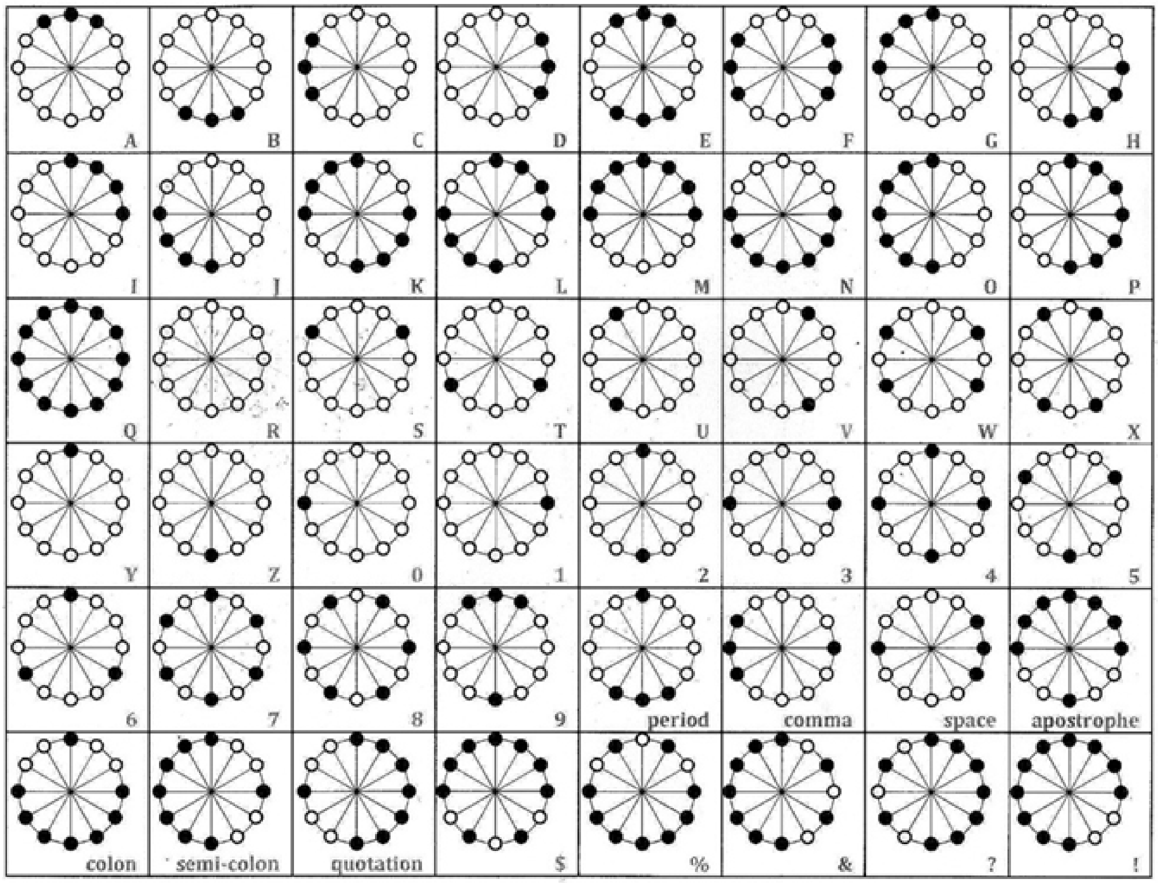

Table 4: **Example of a tactile alphabet based on the tactile patterns generated by 12 actuators**

Applications for the blind

Blind individuals are increasingly taking part in sports and leisure activities. To safely practice these activities, the blind individual often has to follow a guide who carries a small bell or speaks continuously so the blind subject can locate them. With both the guide and the blind individual carrying a mobile communication device, the blind individual's mobile can home in on the guide's mobile device and use a special program to tactilely communicate the bearing and range of the guides mobile to the blind subject wearing the device.

In an alternate application for the blind, the blind individual wearing the device and carrying a mobile equipped with a GPS and an electronic compass can navigate a city. A weak pulse in the North direction will provide the individual with a constant reference to the North, and a slightly stronger pulse using the "radar analogy" described earlier, will indicate the bearing and range of a landmark they wish to reach.

Application to the tactile perception of music and sounds

Using the device, music may be translated into tactile patterns impressed on the neck of a deaf person. Each note of a musical scale may be mapped to a specific actuator or group of actuators, which may be turned on and left on for a duration equal to the timing value of that specific note. In this fashion, the synchronous production of tactile patterns on the neck enables the deaf individual to experience music in a tactile fashion.

To translate music into an intuitive tactile experience, contiguous notes may be mapped to contiguous actuators, with higher-pitched notes mapped to the back and the lower-pitched notes mapped to the front of the neck. The tactile sensing of music may be made more pleasant by mapping each note simultaneously to pairs of symmetrical actuators located on the left and right side of the neck, thus providing the subject with a more symmetrical tactile experience.

Application of the Device as an Accompaniment to Music

A computer, video gaming system, personal music delivery device such as an iPod, or a public music delivery system may use the device to simultaneously deliver music and rhythmic organized tactile patterns to listeners.

An example of such an application is the use of the device as a tactile metronome delivering a complex beat pattern in the form of sequences of marquee patterns. In this fashion, a musician may use the device as a tactile metronome to "feel" complex beats while playing his/her instruments. In a dance club or a choir ensemble dancers or singers wearing the device may receive rhythmic organized tactile patterns along with the music assisting them in dancing or singing in unison.

Conclusion

A device is presented in which tactile stimuli is applied to the periphery of the subject's neck using multiple evenly spaced tactile actuators arranged in a circle, in the form of a C-shaped structure worn snug around the neck by the subject. An electronic controller operated by a computer program drives the device based on signals received wirelessly from an external source. The device impresses sequences of tactile stimuli around the subject's neck providing the subject with intelligible information, cues and warnings or certain game-related sensations.

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