Fingertip Vibratory Transducer for Detecting Optical Edges Using Regenerative Feedback

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Abstract

We present a new method for sensing the visual environment using multiple transducers, each mounted on an individual fingertip to sense a single point in the visual surroundings. Unlike many light-to-tactile transducer systems that use a camera to capture an entire image, our system delegates to each finger the task of interrogating its own independent small region of the physical environment by means of a small laser system, which converts properly oriented edges into tactile vibration. The system may allow visually impaired individuals to interact with the environment by "feeling" objects at a distance, such as sidewalk curbs, doorways, or furniture, by combining multiple fingertip interrogations of object boundaries. We describe in this paper an initial prototype and report very preliminary results on its use by a single subject.

CR Categories: K.8.2 Personal Computing Hardware, I.4.1 Image Processing and Computer Vision Digitization and Image Capture.

Keywords: Sensors, Vision, Interaction techniques, Operator interfaces, Assistive technologies for persons with disabilities

1 Introduction

Visually impaired individuals have been presented with a wide variety of devices that transfer to another sense at least some of the vision-related capabilities of normally-sighted individuals. The primary assistive technologies presently used by the blind to navigate through the environment are essentially unchanged from those used twenty years ago, namely, white canes and guide dogs [1]. Although these two methods can provide the ability to travel safely in a wide variety of environments, neither provide the kind of assistance needed to straighten a picture frame on the wall or find a can of soup on a counter-top. Electronic navigation aids are finding some acceptance, especially laser and ultrasound canes, as well as portable computers with global positioning systems (GPS) and electronic Braile or speech interfaces [2]. Replacing the more general capabilities of vision to provide detailed information about objects in the environment has proven much harder.

The main candidates for a substitute sensory system are touch and hearing. Although hearing offers a potentially wider bandwidth, it is crucial not to impede its existing use, which can be acutely well developed by those who lack normal vision, providing essential acoustic cues about the environment [3]. As for touch, the hands offer the greatest versatility and sensitivity, but it is also important not to usurp their use, since they are essential for so many tasks in daily living. Thus we choose to develop tactile transducers for the top surface of the fingertips (dorsal aspect of the distal phalanges), attaching our device over the fingernail so as to minimize interference with the normal use of the hand. We treat each finger separately, permitting potentially up to ten transducers to be used simultaneously. We call our device the Single Pixel Laser Optical Transducer (SPLOT) and describe here the design and preliminary testing of the first prototype.

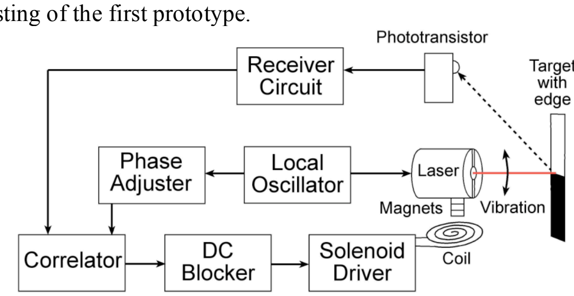

Figure 1. Diagram of the Single Pixel Laser Optical Transducer (SPLOT) for a single finger photo-haptic Transducer.

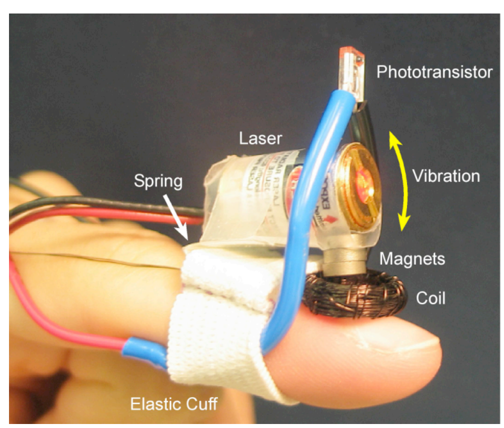

Figure 2. Photograph of a working prototype, showing the laser, magnets, coil, and phototransistor mounted on the fingertip. The laser vibrates across a properly oriented optical edge.

2 METHODS

The SPLOT system works by transmitting a modulated laser beam and detecting its reflection from objects in the environment. The strength of the reflection is determined by the distance, reflectance, orientation, color, etc., of the object. By amplifying the received signal and using it to power a solenoid to change the orientation of the laser, it is possible to create regenerative feedback in the same way that a microphone will “feed back” when placed too close to the speaker of an audio amplifier. Moving the laser across an optical edge (e.g., at the boundary of an object or an abrupt change in its color) causes a change in the amount of reflected laser light. This change, when amplified and fed back to the solenoid, can result in the oscillatory motion of the laser, if the laser is suspended by a spring.

Fig. 1 shows a block diagram containing the elements of the SPLOT system. The optical edge is depicted as an abrupt transition between black and white regions on the target. To avoid interference from ambient light, including sunlight and 60/120 Hz. artificial lighting, we modulate a 5 mW (class IIIA) red laser with a 10 KHz square-wave oscillator (“local oscillator”). Reflected light is detected using a phototransistor, and the signal is filtered and amplified by a receiver circuit. Since both the frequency and phase of the modulated laser signal are known, autocorrelation can be effectively used to detect its presence in noise. The phase of the local oscillator is adjusted empirically to optimally compensate for phase shifts in the overall system, and the DC component of the autocorrelation is blocked leaving only the changes caused by movement across an optical edge. These changes are used to power a solenoid (consisting of a coil mounted on the finger and a stack of miniature rare-earth magnets attached to the laser), to produce vibration in the laser when a properly oriented edge is found.

As shown in Fig. 2, the key elements of the SPLOT system (besides the electronics, which could be reduced to a watch-sized package) are attached to the finger by an elastic cuff, which circles the finger at the distal inter-phalangial joint. A small plastic hinge forms the spring, which holds the laser at its midpoint when no current is in the magnet, permitting the laser to be displaced in either direction, towards or away from the finger by a corresponding current in the coil. The fingertip itself and its medial pad are left free for normal use. (A future version could be cemented to the fingernail to encumber the finger even less).

When the SPLOT is activated, a beam of red light is generated, which may be steered in an intuitive manner by pointing the finger. The phototransistor detects the presence of any reflection of the beam. When an optical edge is encountered oriented across the direction in which the laser can vibrate on its spring, such vibration is caused to happen by regenerative feedback. Because regenerative feedback finds an appropriate frequency for any phase, optical edges of either polarity (dark-light or light-dark) cause vibration. The vibration is felt in the finger under the coil. In this manner, SPLOT constitutes a complete photo-haptic system permitting the user to feel optical edges at a distance.

3 RESULTS

A preliminary test was conducted to determine if the SPLOT could detect edges at a distance, and whether such detection was indeed orientation-specific. A white paper target with horizontal dark blue stripes 1 cm thick was placed at distances ranging from 2 to 10 inches from the fingertip, in 2-inch intervals. When the finger was oriented horizontally, so that the laser would vibrate across the edge of the stripe, sustained vibrations were felt up to 8 inches away. Sustained vibrations were not felt when the finger was oriented such that the laser could only vibrate along the stripe. Vibrations for this prototype were at approximately 10 Hz.

4 CONCLUSIONS AND FUTURE WORK

We have successfully demonstrated the basic concept of a fingertip vibratory transducer detecting optical edges at a distance by means of regenerative feedback. The resonant frequency of the regenerative feedback in this system was constrained by the relatively large mass of the laser’s metal housing. We are currently pursuing the design of a smaller system with a much lighter laser, which could resonate at a higher frequency.

The receptivity of mechanoreceptors at different frequencies has been extensively studied [4-6]. At the frequency of the present prototype (10 Hz) the FA-I receptors would be expected to dominate. Above about 40 Hz, the deep FA-II receptors (Pacinian Corpuscles) could mediate the response; these are dense in the fingertip and could be stimulated by the device. If we can make the SPLOT device resonate at even higher frequencies (above 100 Hz) we would expect to stimulate the SAII mechanoreceptors, which populate the region around the fingernail relatively densely.

Our next-generation, SPLOT device will also be more easily duplicated for multi-finger use and psychophysical testing. We expect the device to provide interesting results in the perception and identification of object shape and location, leading potentially to a useful tool for the visually impaired.

Although our laser is no brighter than a typical laser pointer (class IIIA), it presents a potential annoyance, if not an actual danger, to other people. It does, however, offer the capability of working in total darkness. We are exploring alternative, passive systems, which focus ambient light on a sensitive photodiode, using a lens and a pinhole. We have shown that such a passive system is capable of causing vibration across an optical edge in the same way as the SPLOT. We call the passive system simply the Single Pixel Optical Transducer (SPOT). It avoids the problem of shining a laser in another person’s eyes, but requires ambient light. The SPOT device is, at this point, less sensitive and less sharply focused than the active SPLOT system. We are currently working on overcoming these signal-to-noise and resolution issues in the SPOT system.

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