

# TActile Glasses (TAG) for Obstacle Avoidance

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**Abstract.** In this paper, we present a wearable tactile device called TAG (TActile Glasses) to help visually impaired individuals navigate through complex environments. The TAG device provides vibrotactile feedback whenever an obstacle is detected in front of the user. The prototype is composed of – in addition to the eyeglasses – an infrared proximity sensor, an ATMEGA128 microprocessor, a rechargeable battery, and a vibrotactile actuator attached to the right temple tip of the glasses. The TAG system is designed to be highly portable, fashionable yet cost effective, and intuitive to use. Experimental study showed that the TAG system can help visually impaired individuals to navigate unfamiliar lab environment using vibrotactile feedback, and without any previous training. Participants reported that the system is intuitive to use, quick to learn, and helpful.

**Keywords:** Haptic user interface, Interaction Design, Tangible user interfaces, user support systems.

## 1 Introduction

The World Health Organization (WHO) estimated in October 2013 that about 285 million people are visually impaired worldwide, with 90% living in developing countries (around 15% blind and 85% with low vision) [1]. Although 80% can be cured through clinical treatment, the remaining 20% rely on modern technology and innovation to enhance awareness of their surroundings.

Traditional mobility assistance techniques such as walking stick or trained dogs suffer from several limitations [2]. For instance, walking sticks are not efficient and result in undesirable heavy cognitive load whereas trained dogs are too expensive and require extensive training. Advanced technologies for mobility assistance seem a promising approach to complement (or maybe replace) traditional approaches using other modalities such as touch and audio.

There are two categories of multimedia aides for the visually impaired: audio feedback and haptic feedback [3]. Auditory feedback has few limitations such as cognitive obtrusiveness since it hinders the user's ability to hear background auditory cues (speech, traffic, etc.). Moreover, auditory cues require significant training to interpret

the sound-scape in order to de-multiplex the temporal data into spatial cues. On the other hand, although individuals who loose vision have difficulty maintaining their independence and mobility, they become more acquainted with tactile interaction than people with normal vision [4]. Consequently, several haptic interfaces have been developed to convert visual cues to tactile stimuli on different parts of the body such as on the head, chest, arms, and fingertip [5].

One fundamental need for the visually impaired individual is safe navigation through collision avoidance. Geometry-to-tactile translation systems have been utilized in the literature where ultrasonic transceiver behaves like a 'cane' and translates geometry information (such as the size and the depth of an obstacle) into a tactile cue that is displayed using tactile interface [3][6]. However, current tactile display approaches for spatial information are challenged by relatively low space resolution, poor recognition rate, and cognitive obtusiveness [7].

The motivation behind this work is to seize the hardships faced by visually impaired individuals in dealing with their daily navigation activities. The proposed system, embedded in fashionable eyeglasses with circuitry in the grip, detects obstacles in front of the user and alerts her/him via vibration. The vibration intensity increases nonlinearly as the user approaches a physical barrier. Despite its simplicity, the integrated hardware solution improves safe mobility.

The remainder of the paper is organized as follows. Section 2 introduces state-of-the-art related work and highlights existing limitations and potential challenges. Section 3 introduces the hardware and software design of the TAG device. In section 4 the experimental setup and procedure, along with the obtained results, are presented. Finally, section 5 summarizes the merits of the paper and provides perspectives for future work.

## 2 Related Work

Existing research on tactile-visual sensory substitution for the blind or the visually impaired adopts two major approaches. One consists of imitating the concept of the cane for the blind and converting the sensed distance-to-obstacle to vibrotactile cue on the hand [8-9]. The distance is measured using ultrasound, infrared, or laser range-finders. The other approach uses imaging devices, such as a camera, to drive a two-dimensional haptic display placed on the user's skin [10-11]. Both approaches have experienced limitations related to intuitive cognition [12].

An early study has confirmed the feasibility of using a haptic display for navigation guidance [13]. A wearable navigation system based on tactile display embedded in the back of a vest, with infrared sensors and a predefined map to locate the user, provided route planning [13]. Another example is the Intelligent Glasses System (IGS) – a travel aid system that grants visually impaired users a simplified representation of the 3D environment [14]. A 2D map is displayed using an Air Mass Flow (AMF) actuator that stimulates tactile sensations.

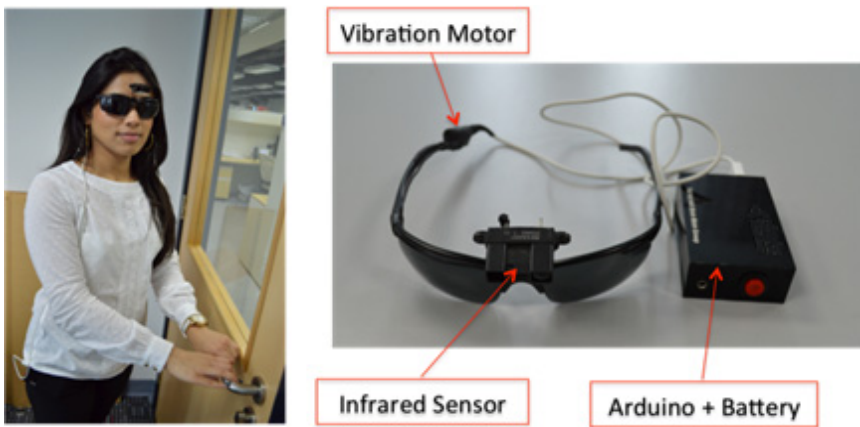
A remote robot provided visual-to-tactile substitution for visually impaired in the field of obstacle detection and avoidance [15]. The authors presented a visual-to-tactile mapping strategy and experimental results with visually impaired subjects. Subjects have shown increased navigational abilities when provided with spatial information through the tactile modality. A similar system used a smart phone with Catadioptric stereo imaging to acquire spatial data and display vibrotactile sensations using an interface comprised of an 8x8 matrix of coin vibration motors [16].

A multimodal interaction device, named Tyflos [18], provided reading and navigating assistance for visually impaired users [19]. The device integrated two cameras to capture the surroundings and a 2D vibration vest to display 2D depth image. A similar prototype provided a sense of position and motion by inducing rotational skin stretch on the skin at the elbow [17]. Experimental results showed that rotational skin stretch is effective for proprioceptive feedback myoelectric prostheses.

Experimental results in previous works show that the users need to learn a large number of tactile patterns and map them to spatial properties, which results in an undesirable heavy cognitive load and excessive training. This paper presents the work towards an easy to use and learn tactile interface that provides visually impaired users with obstacle avoidance assistance. The TAG prototype implements a mapping algorithm to translate range of obstacles into intensity of vibration.

### 3 TAG System Design and Implementation

We are designing the TAG system to allow users perceive range distance to an obstacle using vibrotactile stimuli, much like a ‘haptic radar’. An infrared sensor is capable of sensing obstacles, measuring the distance to the obstacle, and displaying this information as a vibrotactile cue using the vibrotactile motor attached to the tip of the right temple of the glasses. A snapshot of the TAG prototype is shown in Figure 1.



**Fig. 1.** TAG prototype as a wearable device

### 3.1 Hardware Design

The TAG system is composed of the Sharp GP2Y0A02 infrared range sensor, the Atmel microprocessor (ATMEGA128), a chargeable battery, and the Pico-Vibe Precision Microdrives vibrotactile motor (Figure 1). The microprocessor and the chargeable battery are packed in a small box that can be placed in the user's pocket. The microprocessor receives signal from the Sharp GP2Y0A02 sensor, determines the distance to the obstacle, and generate Pulse Width Modulation (PWM) signal to control the vibrotactile motor. The infrared sensor and vibration motor are selected based on distinguished features, namely low cost, high availability, and efficient power consumption.

The infrared range sensor (Sharp GP2Y0A02) is characterized by a spatial awareness range of 20cm to 150cm. The Pico-Vibe Precision Microdrives vibration motor is an off-weight coin motor that rotates at 13500 RPM. Since the vibration motor's speed and frequency of vibration are proportional to the voltage applied to the motor, we apply PWM signal to control precisely the intensity and frequency of vibrotactile stimulation.

### 3.2 Software Architecture for the TAG System

The software architecture for the TAG system is shown in Figure 2. The Obstacle Detection component processes the infrared signal and determines whether an obstacle is in front of the user. Once an obstacle is detected, the infrared sensor data is transmitted to the Geometry Estimation component to compute the distance to the obstacle. The distance to the obstacle is transmitted to the Geometry-to-Tactile Translation component to generate the corresponding tactile stimulus (intensity and duration of vibration). The Actuator Driver component generates a PWM signal and supports sufficient current to drive the vibrotactile motor to vibrate at the desired frequency and intensity.

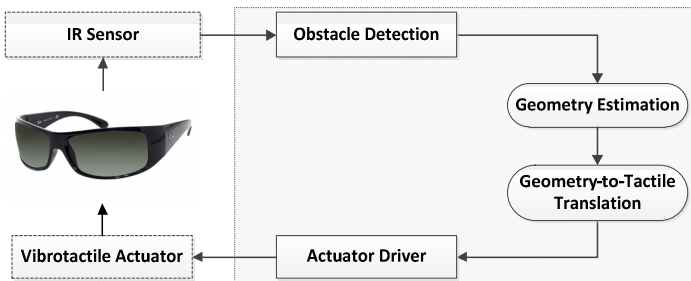


Fig. 2. Software architecture for the TAG system

### 3.3 Geometry-to-Tactile Translation

Vibrotactile cues were designed to convey range and size of the obstacle. The intensity of vibration is inversely proportional to the distance to the obstacle. Note that the

sensor is not capable of distinguishing multiple obstacles and thus we assume one obstacle scenario. Equation 1 shows the intensity to distance mapping where  $a_0$  is the maximum displayable intensity and  $\alpha_0$  is the vibration adaptation coefficient. Obstacles that are closer to the subject produce higher intensity of vibration. The frequency of vibration is proportional to the size of the obstacle. Equation 2 describes the mapping between size and frequency of vibration where  $a_1$  is the maximum displayable frequency and  $\alpha_1$  is the frequency adaptation coefficient).

$$I = a_0 e^{-\alpha_0 d} \quad (1)$$

$$F = a_1 e^{-\alpha_1/s} \quad (2)$$

Note that the constants  $\alpha_0$  and  $\alpha_1$  can be used to fine-tune the vibrotactile stimulation cues to meet specific application requirements or personal user's preferences. A usability study can be conducted to find the optimal values for these parameters. In the current prototype, the range-to-intensity of vibration mapping (equation 1) is been utilized whereas the size-to-frequency mapping (equation 2) will be implemented in future work.

## 4 Experimental Study

A pilot experimental study was conducted to investigate the effectiveness of the TAG device to help visually impaired individuals perceive the range of obstacles and actively avoid them. The objective of the experiment was to evaluate the experience of subjects performing a real world navigation task, designed particularly for this experiment.

### 4.1 Experiment Test-Bed

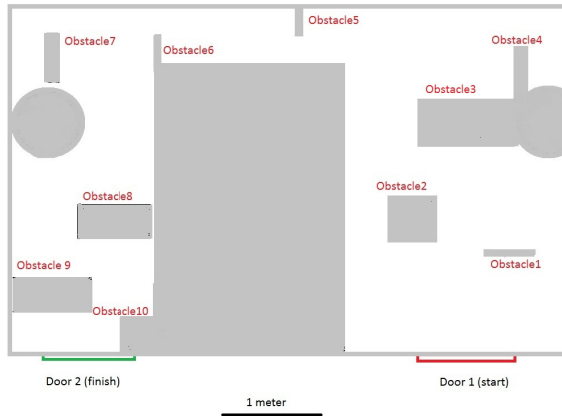
A total of fourteen participants took part in this experiment, aged between 22 and 44 (three of them were female). All the participants were well-experienced computer users and half of them were using eyeglasses. All of the participants reported normal visual and haptic abilities. The experiment took about 15 minutes on average per subject. The performance metric was defined in terms of the following parameters: the Task Completion Time (TCT) and the Obstacle Avoidance Rate (OAR).

### 4.2 Method

After a brief practice session of less than 5 minutes, twelve blindfolded participants were asked to use the TAG device to navigate a route designed particularly for the experiment in the engineering lab of New York University Abu Dhabi (Figure 3). Ten obstacles were used in the simulated route. All subjects performed the same activity. As the subject traversed the course, a test moderator was counting the number of obstacles actively avoided and the number of obstacles hit by the subject; he also

recorded the time it took to complete the task. At the end of the course, the subject was debriefed for feedback and comments.

In order to evaluate the learnability of the TAG device, two additional subjects were asked to perform the navigation task 12 times and observed the improvement in performance over iterations. Note that the obstacles locations were changed randomly for each trial to avoid any biases from subjects learning the navigation path and the obstacles locations.



**Fig. 3.** Navigation task with 10 obstacles

### 4.3 Experiment Results

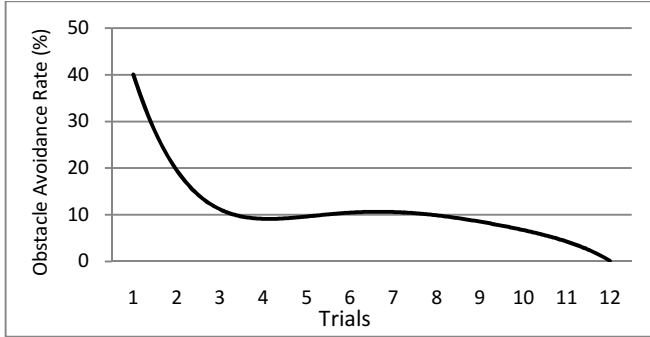
Table 1 shows the average and standard deviation for the two quality parameters TCT and OAR. During the experiment, participants were able to avoid obstacles and navigate comfortably without any previous training (about 70% of obstacles were actively avoided using the TAG device, with a standard deviation is 8.28%). This is promising as it demonstrates that the TAG device can be used intuitively. However, a relatively higher variance was observed in the task completion time (standard deviation of 2.15 minutes). Finally, participants also reported the TAG device as intuitive to use, quick to learn, and helpful.

**Table 1.** TCT and OAR for 12 participants

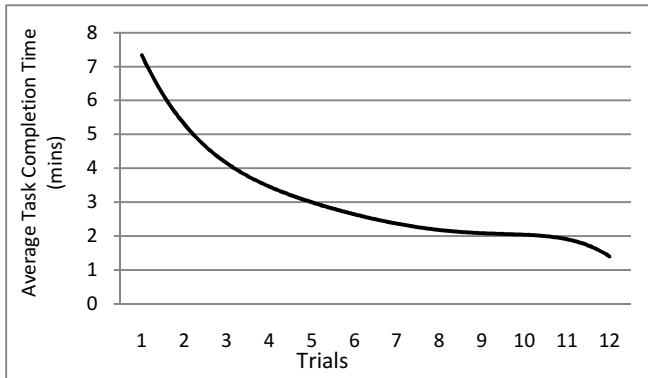
<i>Parameter</i>	<i>Average</i>	<i>Standard Deviation</i>
Task Completion Time (TCT)	4.28 (minutes)	2.15 (minutes)
Obstacle Avoidance rate (OAR)	70.0 (%)	8.28 (%)

Figure 4 shows that subjects have learned very quickly (only after 3 iterations) how to use the system and actively avoid obstacles. Figure 5 demonstrates a similar trend in terms of task completion time (the time to complete the task has significantly dropped from around 7.2 minutes at the first iteration to around 2 minutes at the ninth iteration).

Figure 4 and Figure 5 clearly show that the overall performance of both subjects has significantly improved (both, in terms of obstacle avoidance rate and task completion time) with less than 10 trials. Note that Figure 4 and Figure 5 are based on the average data for the two subjects.



**Fig. 4.** Obstacle Avoidance Rate (OAR) over iterations



**Fig. 5.** Task Completion Time (TCT) over iterations

## 5 Conclusion

In this paper, we presented the TAG device to assist individuals with visual impairments to actively avoid obstacles in unknown environments using vibrotactile feedback. The experimental study demonstrated how intuitive it was to use the system for the first time (70% of the obstacles were actively avoided using the TAG device). However, few subjects expressed interest in receiving hints regarding the direction to take to reach a particular target while avoiding the obstacle.

In future work, we plan to investigate a way to capture more information about the geometry of the obstacle so the TAG device would provide guidance on how to get around obstacles and reach safely a particular target. Another important functionality

that we plan to explore is the ability to detect small obstacles such as small steps and stairs to help the user navigate safely along a path. We will consider means to increase the coverage range and precision to detect smaller obstacles.

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