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"Is it There or Not?" Why Augmented White Canes Do Not Need to Provide Detailed Feedback about Obstacles

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ABSTRACT

Visually impaired people (VIP) need information about upcoming obstacles to avoid harmful collisions. This initial study explored whether augmented white cane (AWC) users could distinguish between and deemed a higher granularity of information about the elevation height of obstacles useful for travelling. Four VIP evaluated a prototype AWC capable of communicating the vertical location of obstacles at three different granularities: 1) binary, 2) torso or above, 3) knee-, waist- or head-level. VIPs walked towards an obstacle elevated at three different heights a total of 12 times per condition in random order. The VIPs preferred binary feedback and did not want early alerts to upcoming obstacles since they wanted to physically interact with obstacles in order to navigate their environment. This contradicts the conventional AWC designs, which communicate in detail the horizontal distances to obstacles using continuous or high-granular vibration feedback.

CCS CONCEPTS

• **Human-centered computing → Accessibility design and evaluation methods**; *Accessibility technologies*; *User studies.*

KEYWORDS

White cane, visually impaired, electronic travel aid, electronic mobility aid, granularity of feedback, elevated obstacles

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1 INTRODUCTION

Loss of vision limits the individual's mobility, making simple travel challenging and unsafe [24, 28, 30]. To improve mobility, visually impaired people rely on mobility aids, most commonly white canes [11], to *preview* the path ahead for e.g. obstacles, drop-offs, and landmarks. However, the white cane bears a major shortcoming. Its limited preview cannot detect obstacles elevated above waist-level, and obstacles above knee-level are detected too late for users to terminate their gait [2]. This led to more than 50% of visually impaired people colliding with elevated obstacles (e.g. scaffolds or road signs) at least once a month [18, 30].

To address this shortcoming, researchers have designed augmented white canes (AWC), utilizing distance sensors extending the preview (1-4m) to both detect obstacles elevated and/or beyond the reach of the cane [22]. Mapping the obstacles horizontal distance to continuous or higher granular vibration patterns e.g. increasing intensity [17] or frequency [10]. In contrast, most AWCs only provide binary feedback about the vertical location of the obstacle in relation to the user. Hence, visually impaired users only know that an elevated obstacle was detected, not if it was located at their waist or head. To the best of our knowledge, no study present an argument for why AWCs only provide binary feedback, nor evaluate if the visually impaired user would benefit of a higher granularity of information about elevated obstacles.

We present a design of an AWC, utilizing ultrasonic sensors capable of alerting to elevated obstacles at three different granularities: knee-, waist-, or head-level. Four visually impaired people tried out the AWC followed by an in-depth focus-group interview. Our results and discussion contributes an initial novel perspective that challenges how AWCs traditionally have been designed and provides suggestions on how the design needs to change.

2 BACKGROUND RESEARCH

To improve the white canes limited preview and inability to detect elevated obstacles, researchers have developed electronic mobility/travel aids (EMA or ETA) [22]. These EMAs are able to detect obstacles or verify clear-paths, at a larger range than the white cane. A sub-group of EMAs are augmented white canes (AWC) characterised by embedding distance sensors (ultrasonic, infrared, or laser) on the shaft and/or handle of the traditional white cane [3]. By basing the design on the white cane users can still

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unitize traditional orientation and mobility (O&M) techniques necessary to navigate the environment - e.g. by wayfinding between landmarks [30].

When the AWCs distance sensor detects an obstacle the distance is then communicated through 1-4 vibrotactile actuators incorporated into the handle, mapping the haptic feedback either using spacial patterns [7, 13, 20], frequency [2, 10], or intensity [15, 17, 21]. To avoid the alerted obstacles, travellers need to know its location relative to their direction of travel (at least distance and horizontal location). AWCs provide this two dimensional information by having the user triangulate distance information coming from the augmented feedback modality, with orientation information coming from the kinetic modality from the users hand/arm when pointing the cane towards the obstacle. However, very few AWCs provide any information about the vertical position of the obstacle, the exceptions being the UltraCane [10] and the Advanced Augmented White Cane (AAWC) [21] which provided a vertical granularity of two and three respectably. Both systems provided vertical feedback by mapping different vertical zones into spatially separated vibrators, e.g. the UltraCane had one vibrator alerting obstacles 2m or 4m ahead around waist-level, and another alerted to elevated obstacles around the upper-body and head. Each of the vibrators then provide distance feedback to obstacles within their given elevation zone, through either vibration intensity (AAWC) or a non-linear increase in frequency the closer an obstacle (UltraCane). However, AAWC never tested the usability of the vertical information on end users [21] and the UltraCane did not report the benefits or shortcomings of a higher vertical granularity [10]. Hence, to the best of our knowledge, no study have evaluated whether or not the addition of vertical information about the elevation of obstacles would benefit the user.

3 APPARATUS

Like the majority of AWCs, to detect elevated obstacles we utilized ultrasonic distance sensors, placed on the shaft of the cane directly below the handle [10, 25, 29]. The sensors angle ensured detection of elevated obstacles at either knee-, waist-, or head-level. We limited the threshold for the preview range, in-which obstacles can be detected around 1.2m ahead of the user (see Figure 1).

Inspired by Pyun et al. [21], three vibration actuators spatially arranged on the cane handle to be under the index, middle, and ring finger, provided the user with feedback about the elevated height of the obstacles. We designed three conditions with increasing granularity of feedback from one (binary), up to three (see Table1).

Table 1: Informing users about the evaluation of obstacles vibrotactile actuator (black dot) activates depending on the elevated level (knee-, waist-, or head-) detected obstacles for each of the three conditions.

	obstacle location		
Feedback granularity	Knee-level	Waist-level	Head-level
binary	● ○ ○	● ○ ○	● ○ ○
above or below waist	● ○ ○	● ○ ○	○ ● ○
knee, waist, or head	● ○ ○	○ ● ○	○ ○ ●

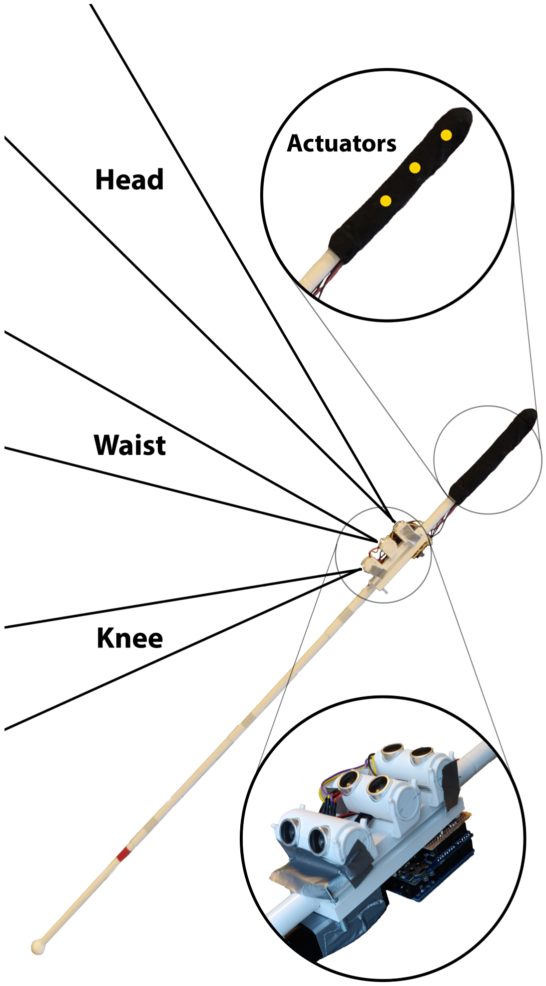

Figure 1: Augmented white cane, capable of detecting obstacles at knee, waist, or head-level mapped to three actuators on the bottom side of the handle.

In the binary condition, users were only alerted to an obstacle, but not their elevation. For the ternary condition alerts distinguished between obstacle located above or below their waist. In the most detailed (quaternary) condition, alerts communicated three obstacle heights (knee, waist, or head). To ensure we only evaluated the need for vertical information we excluded distance information to the obstacle.

We used an Arduino Uno to compute the input from the ultrasonic sensors and output to the actuators. Occasionally, the ultrasonic sensors (HC-SR04, opening angle 15°) created false positive/negative readings, caused by crosstalk between the sensors, due to their close proximity and identical ultrasound frequency (40 kHz). To remove outliers we used a sliding median from a five sample (100 Hz) to determine if an obstacle was within the detection threshold. During obstacle detection the actuators continuously vibrated. See the final prototype Fig. 1.

Figure 2: Picture of the setup: red - trail created from folded tape. yellow - the boxes used as obstacles

4 PARTICIPANTS

The test was conducted with four male visually impaired participants (VIP) between 57-72 years old (m=64). Three of the VIPs were completely blind while one (VIP2) had no central but 3% peripheral vision. On his request "*to get the full experience*", he walked blindfolded. While all four were expert white cane users, VIP4 preferred his guide dog.

5 PROCEDURE

Our evaluation consisted of three parts; 1) familiarization with the conditions, 2) a trial of the three AWCs conditions, and 3) qualitative group interview discussing the usefulness of AWCs and higher granularity of information.

The VIPs were first presented with the AWC, to get a feel of the product while we informed them how the system worked. VIPs experienced each of the three conditions by activating one vibrator at a time while being explained the meaning of the feedback in that condition. Once they felt familiar with the mapping, we verified their ability to distinguish and interpret the feedback in each of the conditions by activating the relevant vibrator(s) in random order a total of 12 times. During the whole familiarization the participants stood still to only focus on the vibration feedback.

After the familiarization process, we tested their ability while walking and sweeping the cane. A a shoreline in the middle of the room allowed VIPs to follow same path during each walk (see Fig. 2). To test the three different granularity conditions, we held a cardboard box (30x25x20cm) at one of three different heights (60cm, 120cm, and 170cm) and at varying distance (4-6m) to the VIPs starting position. Before walking the VIPs were familiarized with the cardboard box, and ensured that collision would be harmless. The test itself consisted of the VIPs following the shoreline towards the cardboard box. Once the VIP perceived vibration feedback they stopped and stated the level at which they perceived the box. Box collisions were scored as non-detections. They repeated each condition 12 times with all three heights appearing equally often. Conditions were counterbalanced across the four VIPs. After all four VIPs had completed the test we had a focus group, in-which VIPs reflected and commented about the experience using our system.

6 RESULTS

When standing still and getting familiar with the vibration pattern of the granularities, VIPs correctly identified the pattern for a granularity of two 100% of the time, while the accuracy lowered to 93.75% for the granularity of three. While walking, VIPs detected only half (M=50.2%) of the obstacles (same for all conditions (sd=3.3%)). Of the detected obstacles, the VIPs could correctly identify between below and above the waist 90%, and 61.5% between knee, waist, and head level. The binary case did not allow for identifying height.

From the interview we classified the two main themes: *use of vertical information* and *the increase of the detection distance*. All quotes constitute translations from Danish.

Use of vertical information: All of the VIPs said that while traveling they only needed binary feedback, since the purpose was to inform them to stop due to the presence of an obstacle, "*I just need to know if it is there or not*" (P1). Nonetheless, as P2 pointed out that once they were alerted to an obstacle, they need to locate it in order circumvent it. Here P2 saw a great potential in a higher granularity of information about the obstacle as that could shorten the localization process, and with practice, one might be able to read the vibrations in real-time, thereby avoiding terminating their gait making the travel more efficient. However, VIP1 argued that knowing the obstacles horizontal location should be enough to walk around the obstacle, and that vertical information was too situational to obstacles you have to walk underneath to be useful in everyday travel.

P4, who preferred to use a guide dog, wanted to apply the technology to the dog handle, since the dog had a tendency to not look up, and therefore, like the cane, not alerted to elevated obstacles.

Increasing the preview range: All the VIPs agreed that an increased detection range of the cane could be beneficial in open spaces or cases where they wanted to avoid the obstacles without making physical contact such as cyclists or other pedestrians. Especially "*old people with walkers*", since they are slow and silent, making them difficult to detect before hitting them with the cane. However, in cases where another pedestrian walks directly in front and at the same speed as the AWC user, it would be unnecessary to get constant feedback about them being there, since they do not affect the VIPs travel. Thus, P3 suggested that the system's warning threshold should be based on whether or not an obstacle get closer to towards the user. Thereby, only providing information about the obstacles that may have an influence on their travel.

The VIPs were not interested in avoiding all obstacles when travelling. Instead, they *want* to purposely make physical contact with static objects which could be used as landmarks. Landmarks are essential to orientate and navigate the environment, as P3 said "*without identifiable landmarks I have no chance of knowing where I am*". The VIPs were sceptic that simple identical vibrations can replace the rich information from hitting an obstacle with the cane. P2: "*Based only on the vibration I don't know anything about the obstacle I'm being alerted to. Is it hard, metallic, movable, etc? The* *cane gives me all these information*". Even the guide dog user had a small identification cane he used to explore obstacles alerted to by the dog.

Two of the VIPs believed a 25-50cm increase in the white canes preview range was sufficient for detecting all the obstacles that may appear, since they do not want to be alerted sooner than necessary. Furthermore, while the VIPs did like the idea of being alerted to the distance of an obstacle, they feared it would be too cumbersome to understand compared to binary feedback. Situations where participants preferred not to get feedback included e.g. when standing in a queue at the supermarket, since there are too many objects to detect.

P3 had previously used Sunu Band a wristband EMA with an ultra sonic sensor designed to detect obstacles above knee-level. However, he found it too troublesome to use, since it detected objects to the side of his path every time he moved his hand/arm. It forced him to move his arm in an unnatural manner to ensure only obstacles in front of him was detected. However, while the VIPs agreed that alerting about static obstacles not in the path ahead was unnecessary while walking, it could be useful to alert about moving obstacles - if they were heading towards their current path. Furthermore, all the VIPs stated it would be beneficial to have an on-demand long range side view when crossing a road or bike lane to alert about incoming traffic.

7 DISCUSSION

Whether or not VIPs want or need information about the elevation of an obstacle depends on the state of the user when receiving it. While walking, binary feedback was sufficient for alerting users to terminate their gait. Once standing still, VIPs wanted to locate the obstacle precisely to decide about how to proceed. In this context, higher granular information may be useful. However, as expected as the granularity increased, so does the number of identification errors, meaning users may incorrectly perceive where the obstacle was located. With extensive training, the error rate may reduce. However, the practical use of high granularity vertical information may be too contextual to justify the practice users needed to distinguish the vibration pattern, compared to just scanning the space ahead by moving their arm up and down. To minimize the training needed and identification errors, vertical information should at most distinguish between two heights: 1) from knee to torso, and 2) the head.

While our VIPs found longer preview ranges useful in some contexts e.g. open spaces, they wanted AWCs default preview to be short just surpassing horizontal reach of the white cane and only provide binary feedback. Yet, most AWCs provide detailed, i.e. continuous information about the distance to the detected obstacle [2, 7, 10]. But very few studies have quantified the accuracy with which users can interpret the distance or how the information affects their travel. In a lab setting, only in 69% of cases could subjects accurately distinguish between five distances with a proportional mapping from distance to vibration intensity [17]. The challenge for users was making an absolute estimation of the intensity without a reference and then map it to a distance. Furthermore, users do not have enough time to estimation the vibration since most alerts last under a second, due to sampling caused by sweeping the white cane from side to side [14].

Our VIPs need for a short detection ranges go against the design conventions in AWCs research, which hope to give users enough lead time to circumvent obstacles without slowing down or making physical contact [30]. Evidence to that effect is still lacking [23]. Most researched AWC designs alerted to obstacles much further than the white cane reach; usually 1-4m [7, 10] but some up to 15m away [6]. Our results suggest this might be a misguided goal. Since our VIPs did not want to circumvent all obstacles. Instead, VIPs intentionally seek to physically interact with obstacles in the hope of using it as a landmark for navigation. Similarly, much to the disapproval of VIPs sighted people tend to provide information about obstacles too early and actively try to stop VIPs from hitting obstacles with the cane [27]. One problem with substituting the white canes rich obstacle feedback (size, material, moveability, etc.) with vibrations is that all objects in the environment become identical. While no AWC research has addressed this - it might complicate the travellers task in creating a cognitive map of the environment, e.g. for wayfinding.

Another reason for the increased detection ranges of AWCs has been based on the idea of sensory substitution by providing as much environmental information as possible to the VIP [9]. This led some AWC design to alert to obstacles outside the field of view of a sighted person [4]. This too might be a misguided goal. Instead, our visually impaired users wanted information only about obstacles that affected their travel. Alerting to obstacles moving away from the user or static obstacles to the side of the users path did not improve travel and only lead to users unnecessarily slowing down pace [23]. Even worse, alerts to irrelevant obstacles can lead to AWC abandonment as reported previously by Williams et al. [27] and by one of our participants. In recent years, studies have successful filtered out alerts to obstacles outside the path ahead [12] and moving obstacles not approaching the user [1]. However, these studies did not evaluate if this led to higher adoption of the AWCs, which remains for future work to address.

Increasing detection ranges can have some benefits. When using traditional O&M techniques, two-point touch or constant touch, user sweep their white canes from side to side, synchronized with the gait cycle to preview the area they are going to place their foot next [14]. However, due to users forward momentum and sweeping frequency this only previews 70% of the ground in the travelled path [5, 16, 26]. Thus, a longer detection range can preview the parts of the path missed by the white cane. Hence, the challenge is not to increasing the preview as much as possible, but just enough so the user can preview the entire path ahead and terminate their gait. Another situation where a longer detection range could be beneficial is in open spaces with very few obstacles and limited information detectable with the white cane [27]. Hence, an on-demand longer detection, like the UltraCane provides, is beneficial to fit the different needs of the situation.

In summary, the development of AWCs have traditionally been technology driven [8, 13, 19], leading to design conventions (e.g preview range) with little empirical evidence quantifying how they affect users' safety (e.g. collisions) and efficiency (e.g. walking speed). Future work needs to systematical evaluate design conventions influence on safety and efficiency (e.g. by alternating the preview range), and classify how user needs differ depending on their task (e.g. wayfinding) and environment (e.g. open spaces).

8 CONCLUSION

VIPs only wanted to know about the presence of elevated obstacles and not their height. Furthermore, VIPs wanted to make physical contact with obstacles to aid their navigation, and deemed the vibration alerts such a poor substitute that the long alert ranges became a nuisance. This goes against augmented white canes predominating design convention of providing detailed information about the horizontal distance to upcoming obstacles. Instead, our limited sample size suggested that AWCs should provide simple binary alerts to obstacles within a short distance.

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