Design and Development of a Prototype Rehabilitative Shoes and Spectacles for the Blind

Ziad O. Abu-Faraj, Ph.D., *Senior Member*, IEEE
Department of Biomedical Engineering
American University of Science and Technology
Beirut, Lebanon

Paul Ibrahim, *Student Member*, IEEE
Department of Biomedical Engineering
American University of Science and Technology
Beirut, Lebanon

Elie Jabbour, *Student Member*, IEEE
Department of Biomedical Engineering
American University of Science and Technology
Beirut, Lebanon

Anthony Ghaoui, *Student Member*, IEEE
Department of Biomedical Engineering
American University of Science and Technology
Beirut, Lebanon

***Abstract*—Assistive technology has not yet reached an acceptable level of success in addressing the needs of blind individuals to navigate safely, comfortably, gracefully, and independently. Accordingly, this paper addresses a prototype, smart rehabilitative shoes and spectacles, designed and developed to facilitate safe navigation and mobility of blind individuals. Each shoe is mounted with three pairs of ultrasonic transducers placed on the medial, central, and lateral aspects of the toe cap so as to detect ground-level obstacles of different heights as well as ground pits and holes. The corresponding tactile outputs are provided by three miniature-sized vibrating motors embedded within the collar of the shoe. The spectacles are instrumented with a pair of ultrasonic transducers mounted centrally above the bridge, and with a buzzer at one of the temples. They are used to detect obstacles at head level. The developed shoes and spectacles are controlled via a battery-operated, microcontroller-based belt pack unit. The developed system has been subjected to several validation tests. A sighted young adult male subject, instrumented with the developed system, underwent an extensive training session, during which he had the chance to get familiarized with the sensory-substitution process that the device offers. Results obtained from the validation tests are to allow final fine-tuning of the system before putting it into real-world rehabilitative application. The developed system is regarded as a step-forward towards the advancements in Electronic Travel Aids, and should contribute to the betterment of the life of individuals with vision loss.**

Keywords - Blindness; Electronic Mobility Aid; Electronic Travel Aid; Low Vision; Rehabilitative Shoes; Rehabilitative Spectacles; Vision Loss; Visual Impairement .

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Z. O. Abu-Faraj is the Founding Chair of the Department of Biomedical Engineering at the American University of Science and Technology, Beirut, Lebanon (telephone: +961-1-218716 ext. 249; facsimile: +961-1-339302; e-mail: bme@aust.edu.lb), while the co-authors are senior-year biomedical engineering students at the same institution.

I. INTRODUCTION

Blindness, low vision, visual impairment, and vision loss have dramatic impacts on individuals experiencing such disabilities. These carry with them physiological, psychological, social, and economic outcomes; hence, impacting the quality of life and depriving such individuals from performing many of the Activities of Daily Living (ADL), the most crucial of which is navigation and mobility. Mobility is "*the ability to travel safely, comfortably, gracefully and independently through the environment*", as defined by Foulke [1], while navigation refers to "*the global problem of navigation*", such as when negotiating a safe path. Accordingly, this paper addresses a prototype, smart rehabilitative shoes and spectacles, designed and developed to facilitate safe navigation and mobility of these individuals.

Before delving into the subject matter of this study, it is imperative to introduce the proper definitions and uses of terminology associated with *blindness* as set by visual standards. In 2002, the International Council of Ophthalmology introduced to the World Vision Community the terms blindness, low vision, visual impairment, functional vision, and vision loss so as to alleviate any confusion about the appropriate use of the term "*blindness*", its definition, prevalence, and incidence; as well as to differentiate between "*blindness*" as such and the prevention and remediation of lesser levels of vision loss that do not fit under this generic term [2].

Blindness is a qualitative term that describes the clinical condition whereby individuals have no light perception as a result of total vision loss. Blindness also refers to those who have so little vision that they have to rely predominantly on other senses as vision substitution skills. On the other hand, *visual impairment* is a qualitative term used when the condition of vision loss is characterized by a loss of visual functions at the organ level, such as the loss of visual acuity or the loss of visual field. Whereas, *vision loss* is used as a general term that includes both blindness (total loss) and low vision (partial loss) diagnosed either on the basis of visual impairment or by a loss

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of functional vision. Last, *low vision* is utilized when describing lesser degrees of vision loss, whereby vision enhancement aids and devices can provide significant help [2].

Epidemiologic studies in 2012, reported by the World Health Organization (WHO, Geneva, Switzerland), estimated that there are 285 million visually impaired people in the world: 246 million have low vision and 39 million are blind [3]. What is more alarming is that the number of visually impaired individuals was 161 million in 2002, as was reported by the WHO [4], showing an increase of 124 million in the past decade. Thus, the need for adequate rehabilitative mobility aids for the blind is becoming an ever increasing necessity so as to improve the quality of life of these individuals.

II. LITERATURE REVIEW

The decades that followed the Second World War witnessed a surge in the development of biomedical instrumentation, among which were mobility and navigation aids for the blind that benefited most from radar and sonar technologies. Such a surge coincided with the widespread use of the transistor that made Electronic Travel Aids (ETAs) possible. Table I represents selected US patents on ETAs between the years 1965 and 2011.

In 1982, Brabyn presented a comprehensive review of early developments in mobility and orientation aids for the blind [5]. Beginning with the *long cane* as the most popular mobility aid, Brabyn then listed a number of Electronic Mobility Aids that were invented since the early 1960's, some of which are: the *Kay Sonic Torch* [6], the *Russel Path Sounder* [7], the *Binaural Sonic Aid* [8], the *Mowat Sensor* [9], the *Nottingham Obstacle Detector* [10], the *Laser Cane* [11], the *AFB Microprocessor-assisted Ultrasonic Range Device* [12], and the *Talking Signs* [13].

In 1990, Borenstein reported on a computerized ETA for the blind and visually impaired, under the name *NavBelt*, that was under development at the University of Michigan, Michigan, USA [14]. This device allows a blind individual to maneuver in a quick and safe manner around obstacles and through unfamiliar terrains. The device was further enhanced using mobile robotics technology to become a prototype of a modern ETA. It uses stereophonic imaging techniques to process the signals acquired from ultrasonic sensors, and feeds back the extracted information to the user via stereophonic headphones [15].

In 2007, Costa *et al.* reported on the design and development of a portable prototype device that captures surrounding information through stereoscopic vision using dual video cameras. The captured images are transferred to and processed via FPGA and DSP, which in turn generate action signals to a tactile feedback system in real time [16].

In 2008, Deville *et al.* reported on the development of a prototype mobility aid for the visually impaired that allows the user to create a mental representation of his/her environment, using the auditory pathway encoded spatially with musical instrument sounds. This system detects salient regions within video frames in real time through the reconstruction of a 3-D

TABLE I. Selected US Patents on Electronic Travel Aids from 1965 to 2011. Source: United States Patent and Trademark Office, Alexandria, VA, USA.

US Patent No.	Date mm/dd/yy	Authors	Title
3,198,952	08/03/1965	Benham TA, Benjamin Jr JM	Photosensitive obstacle and curb detection device for the blind
3,366,922	01/30/1968	Kay L	Blind aid
3,594,823	07/27/1971	Collins CC, Bach-Y-Rita P, Homlund GW	Visual substitution system with receptor scanning means
3,654,477	04/04/1972	Benjamin Jr JM	Obstacle detection system for use by blind comprising plural ranging channels mounted on spectacle frames
3,907,434	09/23/1975	Coles DK	Binaural sight system
3,996,950	12/14/1976	Mier R	Obstacle detection device for use by the blind
4,280,204	07/21/1981	Elchinger GM	Mobility cane for the blind incorporating ultrasonic obstacle sensing apparatus
4,660,022	04/21/1987	Osaka T	System for guiding the blind
4,712,003	12/08/1987	Ban I, Mitsuta Y	Blind person guide device
4,761,770	08/02/1988	Kim W	Ultrasonic binaural sensory aid for a blind person
4,858,125	08/15/1989	Washizuka I, Tsugei S, Inoue T	Electronic cane with environmental and human body condition sensors and alarm for indicating existence of undesirable conditions
4,907,136	03/06/1990	Jorgensen AA	Echo location system for vision-impaired persons
4,991,126	02/05/1991	Reiter L	Electronic-automatic orientation device for walkers and the blind
5,032,836	07/16/1991	Ono *et al.*	Guiding device for visually handicapped person
5,097,856	03/24/1992	Chi-Sheng H	Electronic talking stick for the blind
5,144294	09/01/1992	Alonzi LW, Smith DC, Burlak GJ, Mirowski M	Radio frequency message apparatus for aiding ambulatory travel of visually impaired persons
5,409,380	04/25/1995	Balbuena AU, Cantabrana AL	System to assist the guiding of the non-sighted
5,487,669	01/30/1996	Kelk GF	Mobility aid for blind persons
5,806,017	09/08/1998	Hancock MB	Electronic auto routing navigation system for visually impaired persons
6,469,956	10/22/2002	Zeng X	Ultrasonic distance detection for visually impaired pedestrians
6,671,226	12/30/2003	Finkel JL, Jiping H	Ultrasonic path guidance for visually impaired
7,957,901	06/07/2011	Shin BS, Ahn HN	System for guiding an obstacle avoidance direction including senses for supersonic waves

TABLE II. Features of the ideal mobility aid. Adapted from Szeto (2012).

Feature	Capabilities & Features	Description
1	Obstacle detection	Detect nearby obstacles that are ahead, at head level, and at ground level and indicate their approximate locations and distances without causing sensory overload.
2	Warn of impeding obstacles	Reliably locate and warn of impeding potholes, low obstacles, step-downs and step-ups.
3	Guidance around obstacles	Guide the traveler around impeding obstacles.
4	Ergonomically designed	Offer voice and/or tactile feedback of traveler's present location. Capable of voice input operation and/or have tactually distinct push buttons.
5	Wayfinding	Able to monitor the traveler's present location and indicate the direction toward the destination.
6	Route recall	Be able to remember a previous rout and warn of changes in the environment due to construction or other blockages.
7	Operational flexibility	Reliably function in a variety of settings; i.e., outdoors, indoors, stairways, elevators, and cluttered open spaces.
8	User friendliness	Be portable, rigged, fail-safe, and affordable for a blind user.
9	Cosmesis	Be perceived by potential users as cosmetically acceptable and comfortable to use in terms of size, styling, obtrusiveness, and attractiveness.
10	Good battery life	Have rechargeable batteries that can last for at least 6 hours per charge.

depth-based feature map to guide the focus of attention of the user to specific regions of interest [17].

In 2010, Velázquez presented a review of the most significant work on wearable assistive devices for the blind so as to understand universal design concepts in this category. The review included those devices which are mounted on the head, vests, and belts, and those that are worn on fingers and hands, on the wrist and forearm, on the tongue, and on the feet [18].

In 2012, Szeto in a comprehensive study on the field of Assistive Technology and Rehabilitation Engineering proclaims that in spite of intensive research and development, there exists no effective and widely accepted ETA that deals with the challenges posed by the vast constraints and existing environments of the severely blind [19]. Szeto emphasizes that these challenges are compounded by the fact that the concerned individuals have to adequately divide their attention in real-time to process a barrage of incoming information so as to make sound decisions pertaining to their safe, comfortable, graceful, and independent navigation. The author then delineated the 10 features that are to be found in an ideal mobility aid as shown in Table II. These features form the cornerstone around which the current design has been developed.

III. Materials and Methods

This study was conducted in the Biomechanics and Human Performance Laboratory of the Department of Biomedical Engineering at the American University of Science and Technology. The developed prototype system consists of an instrumented pair of high-top hiking shoes (US Size 8 for Men) and an instrumented pair of spectacles as illustrated in Figure 1.

Figure 1. The instrumented shoe and spectacles.

Each shoe is mounted with three pairs of ultrasonic transducers (transmitter and receiver) placed on the medial, central, and lateral aspects of the toe cap. The orientation of these transducers has been empirically adjusted so as to maximize the scope of the ultrasonic beam coverage, allowing it to detect ground-level obstacles of different heights as well as pits and holes, while concurrently minimizing crosstalk among the transducers. A 12 V, 2500 mAh NiMH battery-operated, microcontroller-based belt pack unit is used to control the transmitted signal of each of the three transducers, and to relay the transducer's reflected signal via an activation signal to the corresponding tactile output. This output is provided by a miniature-sized vibrating 5 V motor embedded within the collar of the shoe: one below the medial malleolus for the medial transducer, one centrally above the calcaneus for the central transducer, and one below the lateral malleolus for the lateral transducer.

The Ray-Ban (Luxottica Group S.p.A., Milan, Italy) spectacles are used to detect obstacles at head level. They are instrumented with a pair of ultrasonic transducers mounted centrally above the bridge, and with a buzzer mounted at one of the temples (See Figure 1). These spectacles are controlled via the same belt pack unit. Once an obstacle is detected, the control unit sends a signal to the buzzer so as to produce a warning sound to the wearer.

The modus operandi for the developed system is detailed herein. Beginning with the toe cap ultrasonic transducers, the medial set is designed to detect low-level obstacles–below the knee–and is adjusted vertically to cover a distance of 90 cm in front of the wearer. The central set is designed to detect medium-level obstacles–below the abdomen–at a maximum distance of 90 cm in front of the wearer and within a cone having an azimuth angle of +45° from ground level–that is considered as 0°. The lateral set is designed to detect pits in the ground as well as downwards steps; hence, it works in a manner contrary to the aforementioned two sets. This set detects depths within a distance of 15 cm, taking into consideration the fact that blind individuals tend to walk with a shuffled-gait. Additionally, design considerations mitigated the effects of ipsilateral and contralateral foot swing, ground detection, stair climbing and descent, as well as other impediments that might be perceived as obstacles. As for the spectacles' transducers, they are designed to detect head-level obstacles at a distance of 90 cm in front of the wearer within a +45° cone–centered at eye-level.

IV. Results

The developed system has been subjected to several validation tests. The first of these was a routine bench test of all system components in terms of their operability, accuracy, and reliability. Subsequently, a sighted young adult male subject (Age: 22 years; Mass: 75 kg; Height: 175 cm), instrumented with the shoes and spectacles, underwent an extensive training session, whereby each sensor was independently triggered and the corresponding tactile output was activated. Thus, the user had the chance to get familiarized with the sensory-substitution process that the device offers. The last validation stage, currently an ongoing process, consists of having several sighted, gender non-specific, test subjects wear the system and ambulate while being blind-folded through various terrains scattered with different obstacle combinations. Results obtained from this stage will allow final fine-tuning of the system before testing it on totally blind individuals (males and females); henceforth, putting the system into real-world rehabilitative application.

V. Discussion and Conclusions

A prototype, smart rehabilitative shoes and spectacles has been designed and developed to facilitate safe navigation and mobility of blind individuals. The system has been designed for individuals with visual loss requiring enhancement and substitution aids in accordance with Table III.

The design criteria behind the system's development were set to correlate with the 10 features of the ideal mobility aid proposed by Szeto [19]; these features are delineated in Table II. Obstacle avoidance is addressed in Features 1-3, navigational guidance or wayfinding is addressed in Features 4-7, user friendliness and cosmesis are addressed in Features 8-9, and good battery life is addressed in Feaure 10. The level of

TABLE III. General ability ranges. Adapted from Colenbrander (2002).

Range	Performance			Ability Score
		Exceptional Ability		> 100
Normal	Normal or near-normal performance	Has reserves	No aids	100 ± 10
Mild Loss		Lost reserves	↓	80 ± 10
Moderate Loss		Normal with aids	Enhancement Aids	60 ± 10
Severe Loss	Restricted performance	Restricted with aids		40 ± 10
Profound Loss		Marginal with aids	↓	20 ± 10
Near Inability		Near-impossible		0 – 10
Total Inability		Impossible	Substitution Aids	0

completion of each of the 10 features is categorized according to the following listing:

1- Completely implemented: obstacle detection (Feature 1), ergonomic design (Feature 4), user friendliness (Feature 8), cosmesis (Feature 9), and good battery life (Feature 10).

2- In progress: warning of impeding obstacles (Feature 2) and operational flexibility (Feature 7).

3- Not included at this level of development: guidance around obstacles (Feature 3), wayfinding (Feature 5), and route recall (Feature 6).

Subsequent to the completion of Features 2 and 7, future directives of the system developed in this study will include a comparative statistical analysis involving two test groups: the first comprises of 10 normal-sighted, blind-folded, individuals, and the second incorporates 10 totally blind individuals. As for Features 3, 5, and 6, they will be integrated in futures versions of the system.

The rehabilitative system developed in this study is regarded as a step-forward towards the advancements in Electronic Travel Aids, and should contribute to the betterment of, and add value to, the life of individuals with vision loss.

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