Technology-enabled autonomous navigation systems for Blind People: a user centered approach

Federica Barontini[1,2,3] Manuel G. Catalano[3] Matteo Bianchi[1,2]

Abstract—**It is broadly know that vision impairment is one of the most common disabilities worldwide. The number of people currently suffering of vision impairment is still increasing, with important societal implications. Indeed, severe impairments of the sense of sight significantly limit to the capabilities of a person in activities of daily living, such as autonomous navigation in indoor and outdoor environments. In this extended abstract, we critically revise the major technological solutions or electronic travel aids for assisting blind people during autonomous walking tasks, with a discussion of the points of strength and the limitations. Finally capitalizing on our research results on haptics-enabled navigation systems, we attempt to define the characteristics that the ideal *Electronic Travel Aid* should exhibit, following a user-centered design approach.**

Index Terms—**autonomous navigation, blind user, sensory substitution, travel aids**

I. Introduction

Vision loss is the third most common impairments worldwide. According to the Wold Health Organization, approximately 253 millions of people all over the world are blind, of which 36 millions are completely blind and 217 millions are visually impaired [1]. A recent report from IAP [2] states that these numbers will likely increase of 25% in the next 30 years. Blindness dramatically limits the quality of life of these people and their families, especially in terms of privacy and autonomous walking. Despite a lot of technological effort has been devoted to increase blind people autonomy, the development of effective navigation systems is still an open problem. Indeed, several issues need to be considered, which are related to: i) the design of mechatronic systems able to profitably provide information to the user relying on sensory substitution ii) the definition of an efficient framework to deliver spatial information on the surrounding environment, which ultimately should be codified in a compact message to be conveyed to the user through the devices at point i). Traditional travel aids used by blind people for navigation and obstacles avoidance rely on the usage of the white cane and specially-trained guide dogs. However, these allow to gather only a partial spatial information, mainly reduced to the localization of low obstacles. Furthermore, they require extensive training and the occupancy of one user's hand. In literature there have been many attempts to develop assistive technologies for blind people with the goal of substituting or augmented the white cane or the guide dog. However, they have been generally met with scarce acceptance, with an extremely high percentage of rejection for the usage in everyday life. These systems are generally referred to as Electronic Travel Aids (ETAs) [3]. ETAs can surrogate spatial and position information on the obstacle location and deliver it to the users via sensory substitution, relying on auditory or haptic cues. The spatial information can be gathered using various sensing modalities, which include sonar, laser and RGB-D and stereo cameras.

*This project has received funding from the European Research Council (ERC) under Grant No. 810346 (Natural BionicS), and from the Italian Ministry of Education and Research (MIUR) in the framework of the CrossLab project (Departments of Excellence) and in the framework of PRIN (Programmi di Ricerca Scientifica di Rilevante Interesse Nazionale) 2017, with the project TIGHT: Tactile InteGration for Humans and arTificial systems, grant number 2017SB48FP.

[1]Centro di Ricerca "Enrico Piaggio", Università dui Pisa, Largo Lucio Lazzarino 1, 56122 Pisa, Italy federica.barontini@phd.unipi.it

[2]Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Via Caruso 16, 56122 Pisa, Italy

[3]Soft Robotics for Human Cooperation and Rehabilitation, Fondazione Istituto Italiano di Tecnologia, via Morego 30, 16163 Genova, Italy

Fig. 1. Traditional travel aids: a) white cane, and b) guide dog.

Without any claim of exhaustiveness and capitalizing on our previous research presented in [10], in this work we analyze the pros and cons of the technologies presented. The final goal is to sketch the requirements that an ideal ETA should have, following a user centered approach.

II. General overview on current ETAs

According to the previous definition of ETAs, we can cluster together the devices based on their principal characteristics. First, we can group the devices in wearable and portable devices: a portable device requires a constant interaction with the user's hand, it cannot be worn but it is usually lightweight and can be easily carried around. A wearable device, instead, allows hands-free interaction.

A. Portable devices

Among the portable devices it is worth mentioning the devices that try to augment the existing traditional solutions such as the white cane, which are commonly employed by blind users in their everyday life. For example in [4], the authors present the GuideCane, a wheeled system, that can detect the obstacle and steers around it; the user feel this steering action on the hand. In [5] and [6] the NAvCane and the Halo system are presented, respectively. The first one is a sensorized cane device able to deliver priority information about obstacles in the path, while the latter is a portable and affordable device that can be attached to the standard cane and is able to detect low-hanging obstacles. All the devices here described the spatial information is transmitted to the user using tactile or auditory cues. The major drawback of these devices is related to the fact that the user's hands are not free to touch and explore the environment. Furthermore, the acoustical information distracts the user, and possibly cause disorientation, loss of equilibrium, finally impacting social interactions.

B. Wearable devices

Looking at the sensory substitution approaches, the practical usability of the acustical feedback, as said before, is often limited for mobility applications. For these reasons, tactile feedback seems to represent a more natural manner to convey navigational cues. Under this regard, wearable haptic systems recently have gained an important role in terms of intuitiveness and naturalness of usage. Indeed, they can be easily worn and likely minimizes the impact on the social acceptance. The most common sensory substitution feedback relies on vibrational or skin-stretch stimulation. Vibration can be easily integrated within belts or gloves. In [7] the authors present vibrating bracelets worn on the user's forearm, to give directional information to a blind skier. Vibration at the calf level is used in [8] to guide the user in outdoor environments, relying on a global position system (GPS). In [9] the authors present a vibrating belt, placed around the abdomen, used to convey information regarding the presence of obstacles. All these solutions, while promising, have failed in reaching an everyday usage, since the technological developments have often discarded to move from a correct identification of users' needs and requirements. We believe that putting the user at the center of the design process could be the key factor to develop systems for real people with real needs. In [10], we tried to follow this approach by involving blind people since the early design phase of a new navigation system. The system is based on an RGB-D camera, a computer and a fabric based device. The camera detects the obstacles, the computer processes the image to find a free path and a fabric belt placed on the arm, is used to provide directional cues to avoid the obstacle, relying on skin stretch stimuli. The promising results we obtained pushed us to try to define the characteristics of an ideal wearable haptic ETAs, following a user-centered approach.

III. A User-Centered approach

According to the information extracted from the analysis of the navigation system presented in literature [11] and the results presented in [10] we can devise the guidelines for the design of an effective wearable device that can be considered a reliable solution for autonomous navigation in unknown environments. The "ideal device" should guarantee the following characteristics:

- provide clear instructions regarding the presence of high obstacle such as window.
- provide a quick and effective alarm stimulus when stairs, holes, or other obstacles are along the path.
- implementing a segmented path to avoid the obstacles
- rely on tactile cues instead of acoustical cues
- keep the users hands free to explore the surrounding environment, i.e. a hotel room or an office, in such a way to enable the user to create a mental map of the surrounding world.

The latter point is in favor of the usage of wearable haptics systems. In addition these systems should be small, lightweight, easy to dress up. Moreover, if we consider white cane users as targeted end users, it could be useful to distinguish between expert users and non expert users of white cane. Indeed, white cane users usually prefer not to substitute their traditional travel aid with a technological solution but, instead, to integrate the usage of the wearable haptic system with the usage of the white cane. Indeed, as we found in [11], expert users prefer to to have a certain degree of autonomy while avoiding the obstacles. On the other side, a non expert user of white cane prefers to be guided in all the decisions, and prefers to receive the information, related to both the obstacle position and the path to follow. Of course, the path for developing effective systems to be used in everyday life is still long, and we do not claim to give here the final requirements of an ideal ETA. However, we do believe that only a deep involvement of the end users in the design process since the early phases, could be the key for successfully reaching this ambitious goal.

References

[1] Bourne, R.R., Flaxman, S.R., Braithwaite, T., Cicinelli, M.V., Das, A., Jonas, J.B., Keeffe, J., Kempen, J.H., Leasher, J., Limburg, H. and Naidoo, K., 2017. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. The Lancet Global Health, 5(9), pp.e888-e897.

[2] www.iapb.org

[3] D. Dakopoulos and N. G. Bourbakis, "Wearable obstacle avoidance electronic travel aids for blind: a survey," IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 40, no. 1, pp. 25–35, 2010.

[4] J. Borenstein and I. Ulrich, "The guidecane-a computerized travel aid for the active guidance of blind pedestrians," in Proceedings of International Conference on Robotics and Automation, vol. 2. IEEE, 1997, pp. 1283–1288.

[5] V. V. Meshram, K. Patil, V. A. Meshram, and F. C. Shu, "An astute assistive device for mobility and object recognition for visually impaired people," IEEE Transactions on Human-Machine Systems, vol. 49, no. 5, pp. 449–460, Oct 2019.

[6] Y. Wang and K. J. Kuchenbecker, "Halo: Haptic alerts for low-hanging obstacles in white cane navigation," in 2012 IEEE Haptics Symposium (HAPTICS). IEEE, 2012, pp. 527–532.

[7] Aggravi, M., Salvietti, G., Prattichizzo, D. (2016, February). Haptic assistive bracelets for blind skier guidance. In Proceedings of the 7th Augmented Human International Conference 2016 (pp. 1-4).

[8] Velazquez, R., Pissaloux, E., Rodrigo, P., Carrasco, M., Giannoccaro, N. I., Lay-Ekuakille, A. (2018). An outdoor navigation system for blind pedestrians using GPS and tactile-foot feedback. Applied Sciences, 8(4), 578.

[9] H. C.Wang, R. K. Katzschmann, S. Teng, B. Araki, L. Giarrè, and D. Rus,"Enabling independent navigation for visually impaired people through a wearable vision-based feedback system," in 2017 IEEE International Conference on Robotics and Automation (ICRA), May 2017, pp. 6533– 6540.

[10] Barontini, F., Catalano, M. G., Pallottino, L., Leporini, B., Bianchi, M. (2020). Integrating Wearable Haptics and Obstacle Avoidance for the Visually Impaired in Indoor Navigation: A User-Centered Approach. IEEE Transactions on Haptics.

[11] Dakopoulos, D., Bourbakis, N. G. (2009). Wearable obstacle avoidance electronic travel aids for blind: a survey. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 40(1), 25-35.