

Extended summary

Study for a novel electromagnetic travel aid for visually impaired people

Curriculum: Elettromagnetismo e Bioingegneria

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Abstract. The autonomous mobility of visually impaired and blind people can be extremely difficult and very often requires the use of assistive devices, as the white cane. Many Electronic Travel Aids (ETAs) have been proposed during last decades with the aim of reducing the difficulties in mobility task. To date, no one of them meets neither the international guidelines for ETAs nor the requests of visually impaired people. Therefore, the research activity has been focused on the study of an innovative assistive device based on electromagnetic (EM) fields, never used before for this purpose. The work started with both experimental and theoretical preliminary studies that confirmed the enormous potentialities of EM fields to detect the presence of obstacles and even additional information on distances, materials and dimensions. Moreover, a portable EM system, able to alert the user about the presence of obstacles by means of acoustic alarms, has been realised and tested by a blind volunteer with encouraging results. Next, the attention has been mainly focused on system miniaturization designing new radiating elements characterised by: high working frequencies and accordingly reduced dimensions; ultra wide band and hence high spatial resolution; radiation pattern wide over vertical plane to protect the user from ground to head level and narrow over horizontal plane to allow manual or electronic scanning of the environment. Using printed technology for antenna realisation seems to be the best solution because it allows easy integration with other circuits and feeding lines and the structure flexibility makes the antenna easily attachable onto the cane and paves the way to design a device wearable over or under user clothes with evident comfort for the user.

Keywords. Electromagnetic sensors, electronic travel aid for blinds, obstacles detection, visually impaired users.

1 Problem statement and objectives

Vision impairment is a physical and sensory disability affecting a large number of subjects around the world. According to the World Health Organization there are 285 million people estimated to be visually impaired all over the world [1]. These subjects live strong limitations in their social life. In particular, autonomous mobility can be very difficult and it often requires the use of assistive devices, as for example the white cane. It is the largely used and accepted device among blind community, because it is cheap and easy to use. Nevertheless, it is just a pure mechanical device dedicated to the exploration of the area scanned by the tip, so it suffers the limit of providing only information on static obstacles from the ground and a portion of less than 1.5m in front of the user's feet. The presence of obstacles located at chest or head level is not detectable. Moreover, the cane does not allow information about speed, volume and distances, which are necessary for safe navigation [2] and therefore, it forces the partially sighted user to be able to stop suddenly at any moment [3]. In order to overcome such limitations, many assistive technologies have been proposed with the aim of reducing the difficulties of visually impaired subjects in mobility task [4]. For example, the Electronic Travel Aids (ETAs) are devices that transform the information about the environment relayed through vision into a form that can be conveyed through another sensory modality. They are mainly based on the transmission of an energy wave and the detection of the echoes from objects located along user's pathway. Some examples of ETAs proposed in literature are reviewed in [4]. There are: ultrasonic systems, such as the guide cane or the Cyram and optic systems, such as the Tactile Vision System or the Tylos, while some products are already available on the market: the Laser Cane, the Miniguide, the Ultracane and others. Despite recent improvements, these devices, whatever is the physical quantity they are based on, still present some drawbacks, such as limited functionalities, relatively high cost and limited acceptability by the users, and most importantly no one of them meets the international guidelines defined for ETAs [5]. Moreover, it is interesting to note that both in literature and on the market there is a lack of devices based on the use of electromagnetic (EM) radiation as the physical quantity able to deliver the information about the presence of obstacles to visually impaired users.

Therefore, bearing in mind the recognized limitations of existing technologies and the dearth of EM travel aids, the idea has been to design a novel ETA using EM technology.

2 Research planning and activities

The research activity can be divided into four subunits concerning different aspects of the study for a novel EM travel aid for visually impaired people. In the following each unit will be presented.

2.1 A preliminary experimental study

As first step an experimental comparison between performances of an EM system and an ultrasonic system, which is a golden standard among ETAs, has been carried out. The aim was twofold: to investigate the potentialities and to highlight the peculiarities of a system based on the measurement of the Time of Flight (TOF) of an EM pulse to detect signals reflected from different type of obstacles [6].

Since the two systems are quite different, a specific attention has been directed to make them equivalent in terms of aperture beam (about 40°) and spatial resolution (about 12cm).

The EM set up used is depicted in Figure 2-1: a double ridge horn antenna matched from 700MHz up to 18GHz, a Vectorial Network Analyzer (VNA) to measure the reflection coefficient at the antenna input and a laptop for off-line signals processing.

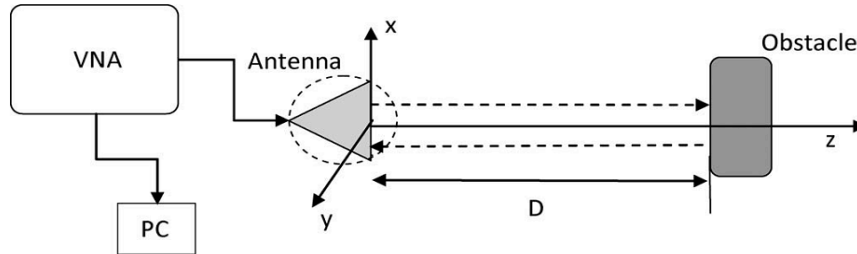


Figure 2-1. System diagram of the EM obstacle detection sensor.

The experimental investigation has been carried out on selected scenarios, using typical objects of everyday life potentially dangerous for the safe walking of visually impaired people. The systems capability to detect an obstacle and to provide the correct distance D between the obstacle and the sensor has been tested in indoor controlled environments considering several obstacles: a plastic basket, a suspended chain, an open door and a plastic pole; moreover, three obstacles made of plastic, wood and metal but with the same shape, dimensions and position have been investigated in order to test the influence of materials only.

2.2 The obstacle detection problem

In the contest of the design of an EM obstacle detector to be used as support to visually impaired user mobility, it could be interesting to study all the desired scenarios, with one or more obstacles and, most importantly, with different type of antennas in order to test and compare their performances. This is possible studying the problem by means of numerical methods as for example those based on finite differences in time domain. Figure 2-2 shows an example of the volume to be simulated.

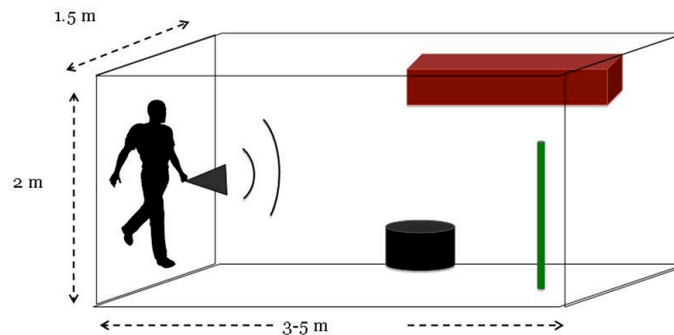


Figure 2-2. Example of a possible scenario

It is important to underline that:

- the antenna and the objects can have complex geometries and then an high resolution is required to represent small details;
- the distances involved are large, up to 3-5m;
- the working frequency is high ($>1\text{GHz}$).

These mean that the discretization of the whole volume requires an extremely high computational cost. Many solutions exist to sort out the problem, but the idea has been to reduce the computational cost implementing a simple approach: the whole problem is divided into a small number of less complex sub-problems and some of them are solved by analytical methods and the others by numerical codes [7]. The main aim of such an approach is to take the advantages of numerical codes, as for example in designing complex geometries and simulating material properties, and those of analytical models whenever possible. To this end an analytical model has been implemented to approximate the E field radiated by an antenna with a small number of waves, suitable to be imported as sources in commercial EM software. The model is based on the hypothesis of knowing the field radiated by an antenna only in N points (matching points) properly chosen close to the obstacle. The model allows, through a matching point technique, to find N waves that approximate, with the desired fidelity (defined as the maximum of the correlation between approximated and actual signal), the field radiated in a generic P point close to the object. For example, it has been shown that once defined an analytic function that describes the field radiated by an aperture, it is possible, by the knowledge of the field values just in 5 points, to approximate the field radiated in a generic P point through 5 spherical waves (that in the far field region can be considered as locally plane) with a fidelity of more than 99%, choosing a distance of sampling less than $\lambda/2$. The main advantage is that one can choose the parameters involved (i.e. the number of points and waves, the size of the region of space where the field approximation is necessary, etc...) in a completely arbitrary way, as a trade off between fidelity of approximation and time for solution.

2.3 A simple prototype

After the successful preliminary studies, the next step of the research activity has been the realization of a portable EM system able to both detect obstacle and communicate with a final user in order to guide him along a pathway [8], [9].

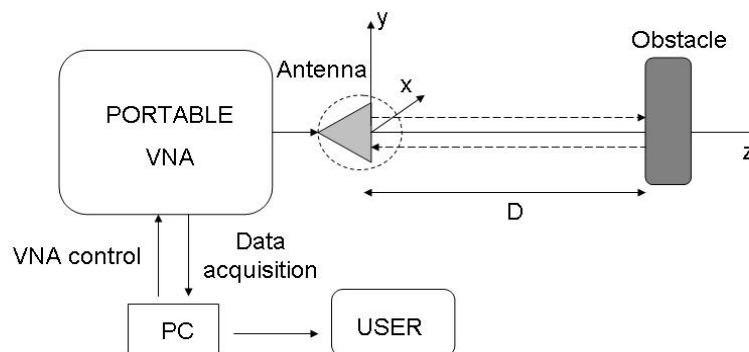


Figure 2-3. Scheme of the portable EM system

Figure 2-3 depicts the block scheme of the new set up realized, consisting of a transmitting and receiving antenna, a portable VNA and a laptop. It still represents a laboratory prototype, but two important improvements have been introduced with respect to the set up used for the preliminary study. The first one concerns the system portability: in fact the VNA used is the Agilent N9928A FieldFox handled and the antenna is a simple and light-weight helix directly connected to the VNA port. The second one is the development of an easy-to-use interface to both remotely control the VNA and most importantly communicate with the user. In detail, the antenna receives the sum of all the echoes coming from the surrounding and the VNA calculates the S_{11} coefficient at the connection with the antenna for each frequency in the range of interest. At this point, due to the MATLAB code, it is possible to get the data from the VNA, calculate the Inverse Fast Fourier Transform (IFFT), obtain the signal in time domain and then calculate the difference with a reference signal representing the free-space antenna response, just to improve the SNR. Each second the signal difference is compared with a prefixed threshold and an acoustic alarm is produced when the threshold is exceeded in order to alert the user about the presence of an obstacle.

2.4 System improvements

As final step some suggestions to improve system performance have been investigated. The attention has been focused on one of the main advantages of using EM: the possibility of working at high frequencies and then the system miniaturization. Two different antennas have been proposed, paying attention to the need for a radiation pattern shaped as a vertical fan beam, that is: narrow enough over horizontal plane to ensure the desired resolution (for example to detect semi-open doors) and wide over vertical plane to protect the user from ground to head level.

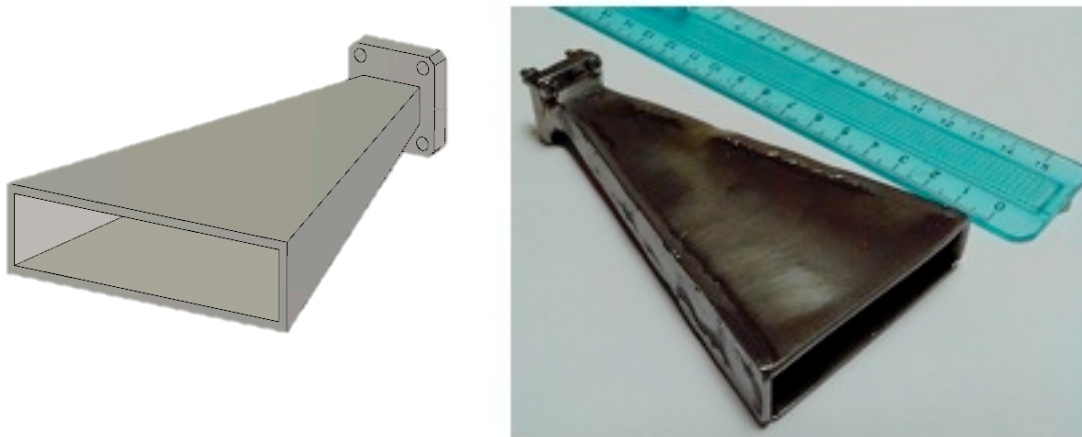


Figure 2-4. Horn antenna at K-band. CST model (left), picture of the actual antenna (right)

The simplest way to satisfy the requirements regarding the radiation pattern is to use a horn antenna: it radiates a directive beam whose aperture angles, over azimuth and elevation planes, mainly depend on aperture dimensions. Therefore the first antenna proposed, shown in Figure 2-4 is a small horn antenna working at K-band (18 - 26.5 GHz). This type of structure has been chosen because it is easy to design, optimize and realize and so it has

given us the chance of testing new system performances (high working frequencies, ultra wide band and vertical fan beam) in a short time and using the same portable set up presented in the previous section (Figure 2-3).

Nevertheless, the main aim of this project is the realisation, step by step, of a final device as small as possible that could be widely accepted among blind community. Therefore the use of printed technology could represent a suitable way to design a small and flexible antenna, easily integrable with existing microwave circuits and feeding lines, paving the way for the realization of a final EM assistive device attachable onto the white cane or wearable by the user. To this end, a second antenna configuration is under investigation. As Figure 2-5 shows, it is a planar slots array with reduced dimensions, characterised by an ultra wide band and a vertical fan beam. The antenna still needs to be optimised in term of side lobe level.

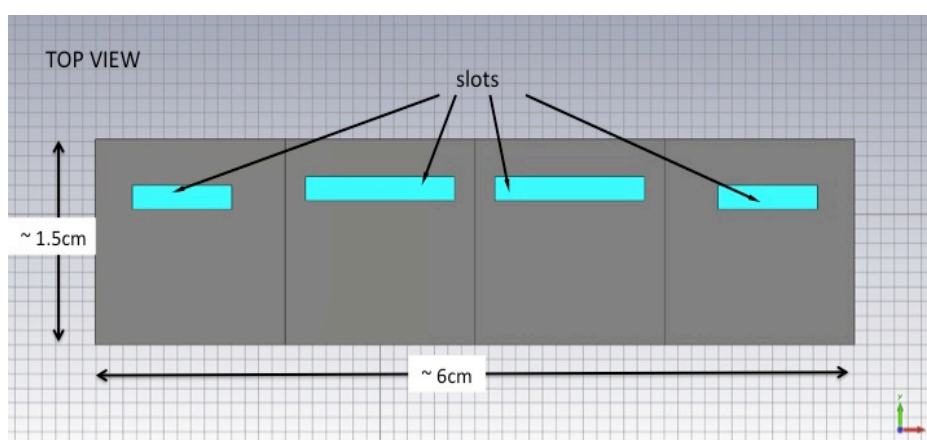


Figure 2-5. Planar slots antenna

3 Analysis and discussion of main results

In this section the main results obtained during the research activity concerning the study for a novel EM travel aid for blinds will be described, following the topics subdivision presented in the previous section.

3.1 A preliminary experimental study: results

As explained above the study has been conducted comparing the performances of an EM laboratory set up with those of an ultrasonic system that is a benchmark for ETAs [6]. First tests have been carried out in indoor controlled environments, considering a large number of obstacles different from each other for shape, dimension, material, positions and so on. The results have shown that the EM system is able to detect all the obstacles, and in some cases, such as in presence of a plastic pole or a semi-open door, the precision in the determination of the obstacle is even superior respect to the ultrasonic system.

Moreover, the EM system has been tested in real cluttered environments where the presence of many scattering targets, which are not along the walking path, could mask the detection of obstacles:

- 1) indoor environment: a corridor of the faculty without obstacles and with three obstacles placed along the walking path, Figure 3-1 (left);

- 2) outdoor environment 1: the entrance of the faculty car parking where the obstacle is a horizontal moving bar;
- 3) outdoor environment 2: a metal chain separating the pedestrian area in the faculty car parking, Figure 3-1 (right).

As Figure 3-1 shows there is no significant degradation of system performance, in fact all the obstacles and their positions are clearly identified by the signal peaks received by the antenna, although cabinet, lateral walls, irregular ground, trees and other elements create cluttering effects.

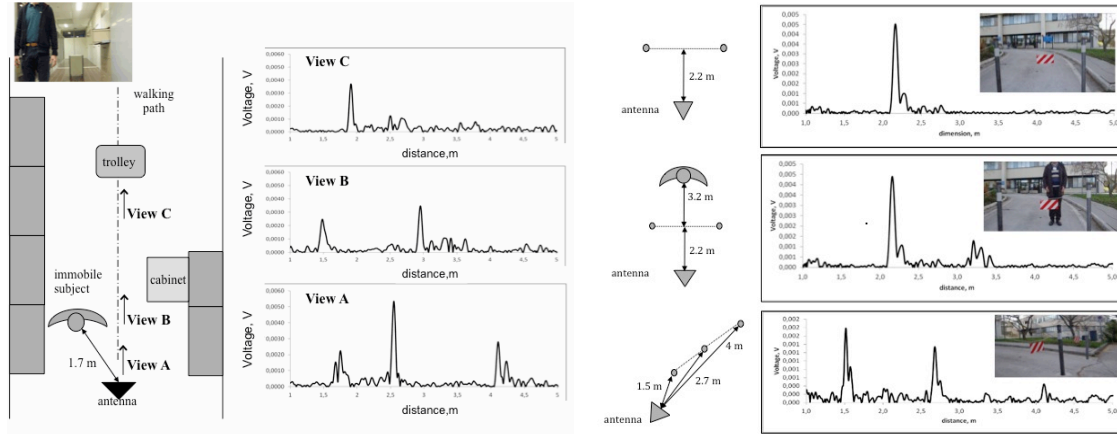


Figure 3-1. Examples of measurements in cluttered environments

3.2 The obstacle detection problem: results

In order to test the analytical model proposed in Section 2.2, it has been used within a mixed approach with the final aim of calculating the voltage signal at antenna port (a double ridge horn antenna), received from a squared metal obstacle located at a distance of 3.5m. The problem is depicted in Figure 3-2

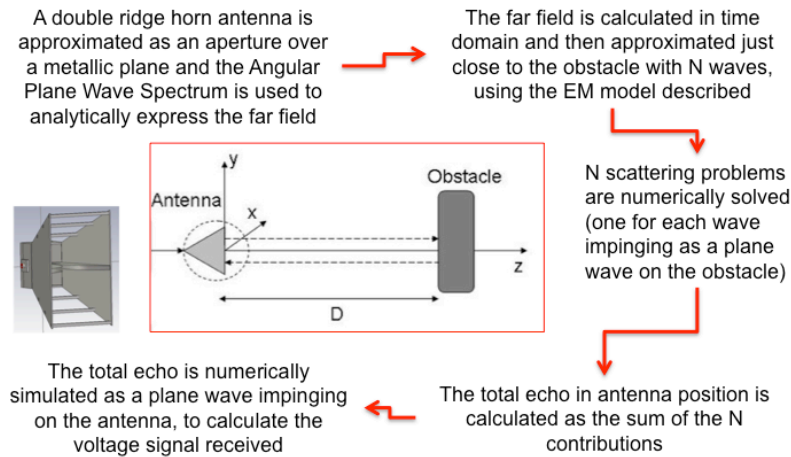


Figure 3-2. Scheme of the mixed approach proposed to solve the scattering from an obstacle distant 3.5m from a double ridge horn antenna.

The results obtained with the proposed approach (voltage signal and E field values) have been compared with both experimental value of the voltage signal obtained for the same

scenario set in the laboratory (Figure 3-3), and with the E field values calculated in front of the obstacle with a full wave CST simulation (numerical solution of the whole volume).

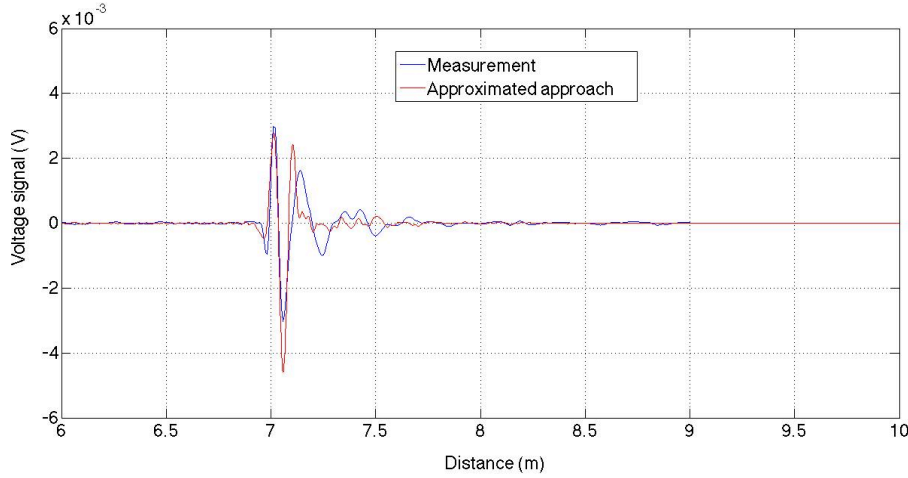


Figure 3-3 A comparison with experimental measurements.

The fidelity parameter is about 88% in the first case and 81.6% in the second one. These deviations are typical of comparisons between simulations and measurements, when a complicated measurement chain is involved. Therefore the values for the fidelity are largely satisfactory especially if one considers that they are obtained with only 5 plane waves and that the time for solution decreases from several days required for a full-wave simulation, to about 10 hours (on a standard workstation: Intel Xeon Processor E5640 12M Cache, 2.66 GHz, 5.86 GT/s). It is important to note that the accuracy can be chosen by the user: the fidelity can be improved just increasing the number of waves used for the approximation, but to the detriment of time for solution.

3.3 A simple prototype: test with a blind user

Once studied the EM obstacle detection problem from both an experimental and a theoretical point of view, a portable EM radar system has been realized, as explained in Section 2.3. After a detailed characterization of the portable EM system in presence of one or more obstacles, different from each other in materials, shapes, dimensions and other features, the most significant tests have been conducted thanks to the collaboration of a blind volunteer. The user held in his hand the portable VNA with the antenna connected to it and wore a backpack containing the laptop for signal processing. Since the idea is to attach the first version of the device onto a white cane, the system parameters have been set to obtain an observation range between 70cm (nearer distances can be manually scanned by the tip of the cane) and 3m in front of the user (farther distance are useless). In general the user has been asked to achieve many tasks, avoiding ten soft obstacles located in a different configuration for each test, using his own cane or the portable EM system with the final aims of: comparing systems performance and receiving useful feedbacks from the user. A detailed explanation of the system and the proofs carried out can be found on [10].

To conclude, it is possible to say that the system needs to be optimized in terms of: signal processing to increase walking speed; dimensions to reduce weight and improve portability; user interface, because a vibro-tactile signal is preferred respect to an acoustic alarm.

Nevertheless, the simple prototype realized has already demonstrated the potentialities of the EM technology: it is possible to alert the user in advance about the presence of obstacles and to detect even those obstacles suspended at chest or head levels. The system can be improved by optimizing antenna dimensions and its radiation pattern, for example designing antenna able to radiate a vertical fan beam in order to better protect the user, as described in Section 2.4.

4 Conclusions

The research activity presented has been focused on the study of a novel EM travel aid for visually impaired people. The system has to detect the presence of obstacles along user's pathway and transduce the information in a suitable signal for blinds (acoustic or vibration signals).

First of all the actual possibility of using a system based on the launch of an EM pulse and the detection of echoes coming from the surrounding has been investigated by comparing the EM system performance with those of an ultrasonic device (a golden standard among ETAs). The tests carried out have highlighted the numerous advantages of EM system: the possibility to alert the user in advance, the precision in the determination of obstacles such as semi open doors is superior with respect to the ultrasonic system; the possibility of working at higher frequencies with the consequence of reducing system dimensions and increasing user comfort; no performance degradation in cluttered environment; the possibility of designing an antenna with a radiation pattern shaped as a vertical fan in order to protect the user from ground to head level.

Secondly, the issues concerning the obstacle detection problem have been studied. The possibility of solving the scattering problem by means of commercial software gives the important chance of comparing performance of different antennas in many possible scenarios. On the contrary they can have limitations due to high computational costs required to simulate large volumes with high resolution at high frequency. To overcome these issues, a novel mixed analytical-numerical tool has been proposed. It is based on the idea of dividing the whole problem into a small number of less complex problems and solving some of them by analytical methods and the others by numerical codes. In particular, an analytical model has been developed to approximate the field just close to the obstacle with a small number of waves and it has been used within a mixed tool to find the voltage signal received at the port of a double ridge horn antenna and scattered from a squared metallic object. The results have been compared with both a full wave numerical simulation of the problem and experimental measurements.

After the preliminary studies, a simple prototype has been realised in order to test the EM technology directly with a final user. To this end a blind volunteer has been asked to go toward a sound source using first his own white cane and then the EM radar avoiding ten soft obstacles located along his pathway. Each time that the presence of an obstacle was detected, an acoustic alarm was produce to alert the user. The main aim of the tests carried out with the blind subject has been to collect information to improve system performance. According to user's feedbacks the system is useful because can detect suspended obstacles and it is easy to use, but it needs to be optimized in terms of: signal processing to increase walking speed; dimensions to reduce weight and improve portability; user interface, because a vibro-tactile signal is preferred respect to an acoustic alarm.

Next, the attention has been focused on system miniaturization: a small horn antenna working in the K-band (18-26.5GHz) has been designed, optimized and realized. This structure has been chosen because is the easiest way to perform a good impedance matching over an ultra wide band and radiate the desired vertical fan beam just setting the suitable aperture dimensions. The new antenna has been characterised both in frequency and time domain. The last step will be the set up of a suitable portable system with the aim of testing it with a large number of visually impaired and blind volunteers following the standard protocol for the ETAs tests.

Moreover a new antenna model has been proposed. It is a planar slots array based on printed technology. The structure still need to be optimised, but from first results obtained by numerical simulations, it is already clear that the small antenna is able to perform a very good impedance matching over an ultra wide band and it radiates a well defined vertical fan. The main advantages of such new structure are: reduced dimensions, printed technology that makes the antenna easily integrable with other microwave circuits and feeding lines and structure flexibility that makes the antenna easily attachable onto the cane or even wearable over or under user clothes.

Finally, since UWB technology has unmatched advantages in terms of spatial resolution and low power consumption, a study aimed to better understand how such technology could improve the performance of our system has been conducted in collaboration with the Bioengineering Research Team at London south Bank University (LSBU). In particular during a stage of 6 months at LSBU, new ranging and tracking algorithms for indoor UWB radar applications have been developed and experimentally tested. The idea is to apply such algorithms to the EM travel aid for visually impaired people as additional feature able to detect and track moving obstacles such as people, cars or other vehicles that could be dangerously present along user pathway. Of course further extensions and improvements are required for such application.

To conclude, it is important to underline that the research activity described in this work doesn't claim to design a novel EM system to be substituted to existing technologies, but rather to be integrated with other sensors. In fact is author's belief that the design of a navigation system based on more than one technology (for example ultrasonic, optic and electromagnetic sensors all together) could allow to merge their advantages and, in the meanwhile, to reduce their drawbacks and overcome their limitations.

References

- [1] World Health Organization (2012) Visual impairment and blindness – Fact Sheet 282. <http://www.who.int/mediacentre/factsheets/fs282/en/>
- [2] B. B. Blasch, W. R. Wiener, and R. L. Welsh, “Foundations of Orientation and Mobility”, AFB Press, 1997
- [3] M. Hollins, “Understanding Blindness: An Integrative Approach”, Lawrence Erlbaum Assoc., 1989
- [4] D. Dakopoulos and N. G. Bourbakis, Wearable Obstacle Avoidance Electronic Travel Aids for Blind: A Survey, IEEE Trans on systems, man, and cybernetics—Part c: Applications and reviews, 40, 1, (2010).
- [5] National Research Council, “Electronic Travel Aids: New Directions for Research”, Nat. Acad. Press, 1986.
- [6] L. Scalise, V. M. Primiani, P. Russo, D. Shauh, V. Di Mattia, A. De Leo, G. Cerri, “Experimental Investigation of electromagnetic obstacle detection for visually impaired users: a com-

- parison with ultrasonic sensing”, IEEE Trans. On Instrumentation and Measurement”, vol. 61, no. 11, November 2012
- [7] Di Mattia, V., Russo, P., De Leo, A., Scalise, L., Mariani Primiani, V., Cerri, G., “An Efficient Numerical-Analytical Tool for Time Domain Obstacle Detection”, IET Science, Measurement and Technology, October 2013.
- [8] Di Mattia, V., Russo, P., Scalise, L., De Leo, A., Mariani Primiani, V., Petrini, V., Cerri, G., “Electromagnetic Travel Aid for Visually Impaired Users”, Electromagnetics in Advanced Applications (ICEAA), 2013 International Conference on, vol., no., pp.1408,1411, 9-13 Sept. 2013., Torino.
- [9] L. Scalise, V. Di Mattia, P. Russo, A. De Leo, V. Mariani Primiani, V. Petrini and G. Cerri, “Electromagnetic sensign of obstacles for visually impaired users”, ForitAAl, 23-25 Ottobre, Ancona (to be published in Ambient Assisted Living, Longhi, S.; Siciliano, P.; Germani, M.; Monteriù, A.; Springer, 18 Aprile 2014)
- [10] Test demonstration of the EM system. Available online at: <http://www.youtube.com/watch?v=AyUngKPWtyE>