Natural sense of vision
through acoustics
and haptics

Sound of Vision

Sound of Vision

Final Report

European Commission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 643636. The content of this publication reflects the views of the Authors and not necessarily those of the European Union or European Commission. No warranty of any kind is made in regards to this material.

Contents

INTRODUCTION

This report provides a non-technical overview of the Sound of Vision project (grant no. 643636) in which the consortium partners designed and develop a solution for visually impaired persons (VIPs) to help them better understand their surrounding environment and improve their mobility. As a part of the SoV solution the consortium also developed training instruments and procedures.

The report highlights the main achievements of the project and is split into two main sections.

Following this Introduction, is the technical part which provides an overview of the objectives, the results and the main conclusions from the project. It also provides description of the technical work, how the work progressed beyond the state of the art and an overview of the how the partners will continue exploiting the results from the project.

Following the technical section, comes an overall assessment section, which is split into qualitative and quantitative parts.

Finally, the reports ends with providing the project's conclusions and further information (project website and demonstrative videos).

TECHNICAL REPORT

A. OVERVIEW: OBJECTIVES, RESULTS, CONCLUSIONS

Context, Motivation: 285 million people suffer from visual impairments, 39 millions of them being blind and 246 have low vision (moderate visual impairment combined with severe visual impairment are grouped under the term “low vision”). The difficult situation of these people has threefold important aspects:

1. minimal mobility may lead to isolated and sedentary lifestyle, and development of both physical and mental health problems;
2. their lack of work and social involvement is a major loss for the society;
3. their inability to take care of themselves entirely accounts for large healthcare costs.

Objective: Sound of Vision had the objective to create a concrete wearable assistive system with enough capabilities to substantially alleviate the situation of visually impaired people - allowing them to perceive the environment and move independently, in indoor or outdoor areas, without the need for predefined tags/sensors located in the surroundings.

Action: Sound of Vision performed analysis, design, implementation, iterative refinement and testing/validation activities, for the original hardware and software device. The solution:

- is a state-of-the art device, using latest technologies (3D cameras, advanced GPU computing, haptics, naturalistic sensory substitution, wearable electronics) to provide rich and customizable functionality that surpasses any other existing solution;
- works by permanently scanning the environment, extracting essential information and conveying it in real-time to the user through audio (sounds) and haptic (vibrations);
- is accompanied by rich material that supports users to quickly achieve proficiency.

The development:

- **Key aspects:** participation of visually impaired in design and validation, interdisciplinary design, implementation and validation, pervasiveness, wearability, rich natural audio-haptic representations, essentiality of training.
- **Iterative development and testing:** During the project, following the initiation (brief analysis and design), three versions (functional prototypes) were developed and extensively tested. Each new version included improvements based on the experience with the last prototype (test results and feedback provided by visually impaired persons, training specialists and specialists in psychophysics). Overall, more than 45 visually impaired persons participated in the evaluation. One important proof and conclusion was that, even with a small amount of training, visually impaired participants are able to perform difficult mobility tasks with the Sound of Vision system just as well as with the white cane, and learn a better and more complex perception of the environment, which leads to safer mobility and increased confidence.

The end result – Sound of Vision final prototype – is a hardware & software solution, plus related training material.

The hardware components of the system are:

- a headgear (comfortable frame holding 3D cameras, IMU and headphones),
- a haptic belt (with a matrix of 60 vibrating motors, worn on the abdomen),
- processing unit (in a backpack),

- wireless remote control (held in a pocket),
- wiring (connecting the processing unit to the headgear and belt).

Figure 1. Sound of Vision system. (Left) The final prototype. (Right) Various parts of the system

How it works ? The process includes these repetitive steps:

- captured 3D depth and color information from cameras;
- analyze the raw 3D data and break it into individual objects;
- Selects most relevant objects;
- Generate audio-haptic stimuli for each relevant object.

This sequence of steps is repeated many times per second, thus the output is permanently updated, as the user moves within the environment, or the environment itself changes.

The audio-haptic outputs (*Fig. 2* below) includes:

- **2 full scene encoders**:
  - **Iterative** renders objects one by one, in increasing order of distance from user;
  - **Continuous** renders all the objects simultaneously.

  In both cases, the rendering of each individual object has both audio and haptic outputs, which are carefully synchronized.

  Both of the full scene encoders provide several options regarding the way that individual objects are rendered, as it is presented below in *Fig. 2.* For example, in Iterative, for audio the user can choose between types of stimuli named impact sounds and bubbles, while for haptics the user can choose between types of stimuli named shapes or closest points (all described later on).

  The scanning range defaults to 5.25m and is adjustable by user (2 - 5.25 m).

The maximum number of rendered objects is also adjustable by the user (between 1 and 5, with most used values being 3 and 4).

Furthermore, at any moment, the user can reduce temporarily the rendering of the full scene encoding only to objects located directly in front of the user (on the direction of the camera) - by activating the modifier ***Frontal Selector***. This modifier does not change the current encoding, only reduces rendering to objects located directly in the direction where the user is looking (typically 1-2 objects). It is helpful when a more careful examination of the scene is needed.

- **Tools** - each helps the user in certain situations:
  - ***Flashlight***: a simple encoding of the distance from camera to the first object touched by an imaginary line going straight out from the camera; helpful to carefully explore a scene and allows accurate perception of distances to objects' surfaces, and especially of their margins;
  - ***Best free space***: indicates the open space where the user can navigate;
  - ***Texts*** detection and reading
  - ***Signs*** detection and encoding
  - ***TTS Scene Description*** *(voice)*

  Tools can be activated by the user at anytime he desires, temporarily replacing the current full scene encoding.
- **Dangers** - identify and render to the user, through acute, hard-to-miss stimuli, the potentially dangerous elements from the scene - i.e. obstacles or holes on the ground that are located on collision course, in a specified range.

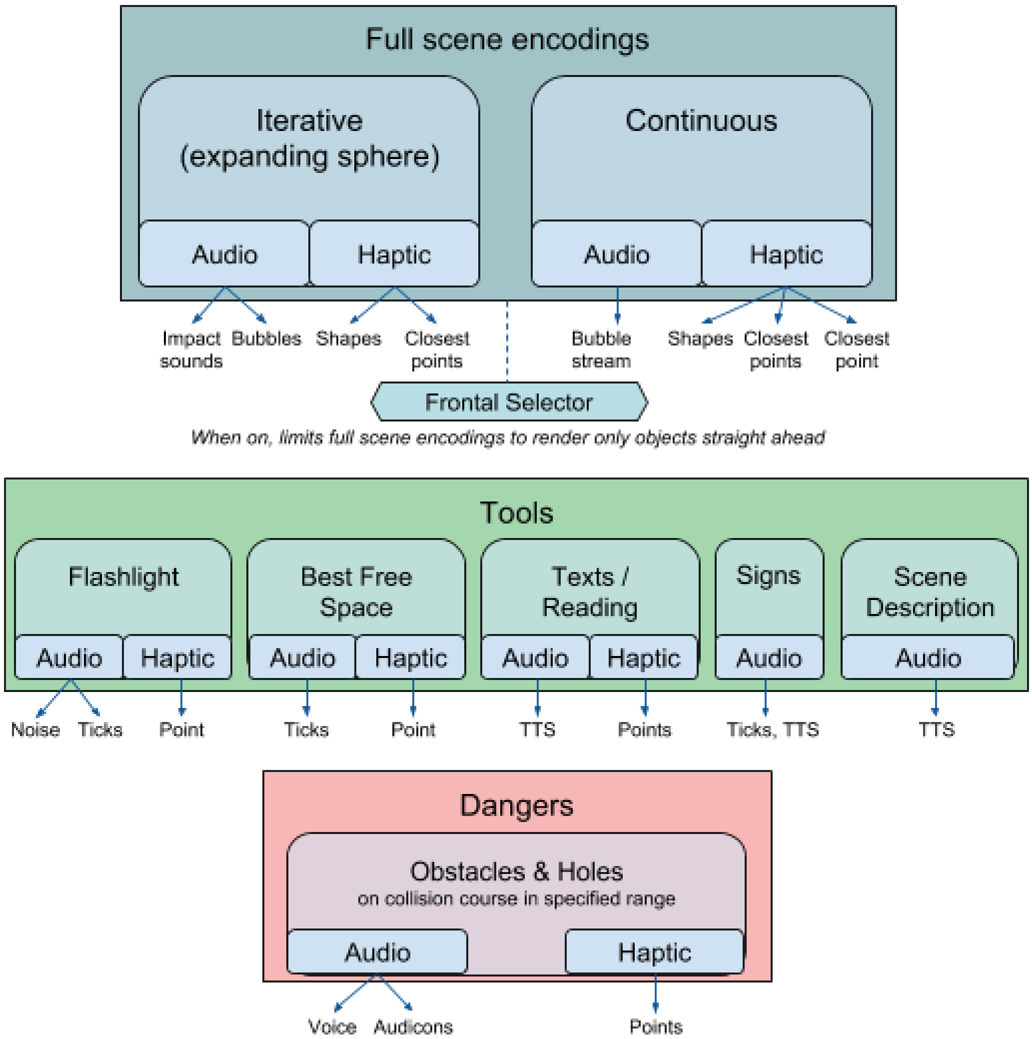

Figure 2. Sound of Vision audio-haptic information

The course material that accompanies the device includes:

- Virtual Training and Testing Environments – safe, controlled, cheap training:
    - 17 synthetic scenes ranging from basic to complex
    - a large realistic scene including indoor and outdoor environments
    - a fantasy explore & adventure game like environment
- Real-World Training Material Training Plan including:
    - series of scenes and tasks
    - guidance on how to approach the user and conduct the training

The extensive testing and evaluation showed the efficiency of our training resources, which led the advanced user to perfect scores in complex perception and mobility tasks.

Sound of Vision goes beyond the state of the art of visual of sensory substitution systems.

The final prototype is a TRL 7-8 solution, modular in terms of hardware and software, and with unprecedented functionality - richer, stronger than any existing/competing solution.

The system is 1-2 years of further development from the finite, affordable commercial product.

Sound of Vision large scale availability will have an immediate and strong social impact, helping visually impaired in daily life, improving their lifestyle, health, social integration.

Besides the prototype itself (and the related training resources), the development produced many punctual advancements beyond the state of the art in fields such as 3D real-time processing, audio-haptic encodings, basic audio and haptic research - **20 new individual algorithms and methods, with advantages over previous solutions**. These were disseminated to relevant publications and some are undergoing patenting.

Furthermore, to support the growth of the field of assistive solutions, the consortium decided to open-source two of the main components of the project:

- **Reusable sonification and haptification library:**
    - Contains all the audio-haptic encodings and tools created within the project
    - Can be linked to any other 3D acquisitions & processing solution
    - Can be linked to any other audio & haptic output solution

  This reusable library will help the fast creation of new sensory substitution devices for visually impaired.
- **Reusable training serious games:**
    - Large suite of virtual training and testing environments
    - Automatic distributed data collection
    - Statistics & analysis tools

  This reusable library will allow to easily train and evaluate the users of any sensory substitution device.

Sound of Vision produced 20 new algorithms and methods - individual advances beyond the state of the art, which are disseminated, and some are subject to patenting.

The consortium open-sources two large and essential part of the solution, to further support the growth of the field by 3rd parties.

B. WORK PERFORMED

The main result of the Sound of Vision Horizon 2020 Research and Innovation Action is the Final Prototype of the Sound of Vision system. It resulted after 3 years of intensive work carried out by 9 European research partners (5 universities, 1 company, 1 research institute, and 2 organizations for visually impaired).

The Sound of Vision system is to offer a novel way of presenting environment to the visually impaired people (VIP). From the very start of the design process the target users have been participating in all development stages of the SoV system.

The initial work has been carried out in two main parallel tasks (WP1). The first task was devoted to reviewing of the existing electronic travel aids for the visually impaired. The important conclusion from this study was that there is no any single electronic travel aid system or device that would be widely accepted and used by the visually impaired users. One of the causes of this state of the matters is the cost of the devices. Another reason for low acceptance of such devices is their poor ergonomics and non-adequate space presentation capabilities.

The second task has concentrated on identifying user requirements. Specification of the requirements was preceded by a large scale multi consortia survey with the visually impaired people. The identified barriers in space perception and mobility of the VIP have allowed to work out key system components and functionalities but also user training protocols for the designed new electronic travel aid.

Key conclusions from the surveys are the following: 1) the user should be able to choose from multiple operating modes of varying information complexity, 2) the system should complement the white cane, not replace it, 3) the testing and training should start in virtual reality spaces, then progress to controlled and real world environments. System required functionalities determined the system architectural design, i.e. main hardware components of the system comprising: depth cameras for sensing the geometrical structure of the environment in various light conditions, both audio (implementing 3D sound technology) and haptic devices, so called tactile displays on torso for nonvisual presentation of the environment to the VIP. However, the key design part of the system is the so called data processing pipeline, i.e. a dedicated software modules for real-time conversion of visual data into audio and haptic renderings.

Further work (WP2) concentrated on project technical work by evaluating and technical solutions (both hardware and software) that allowed to prepare Detailed Design Document (DDD) describing the SoV system. Also procedures were developed for testing the SoV system prototypes. Testing environments were prepared for mobility tests of the SoV system. In parallel studies have been carried out on verifying brain's abilities in using auditory and tactile representation of the environment.

In WP3 the work progressed to building the initial prototype of the SoV system. The prototype had undergone usability tests and VIP users' feedback was acquired. System user manual was prepared that describes the required safety precautions for direct users and their caregivers before, during and after using the device. An additional outcome of this work package was development of the virtual testing environments.

The critical phase of the project (WP4) was advancing the system to the advanced prototype that was to comprise all system hardware and software modules and functionalities that should pass technical tests and usability tests in real environments. Before embarking the users on the mobility trails special software tools were developed for the users to train their skills in using the SoV system, first in the virtual and realistic testing environments (VTE) and then training through serious games. Procedures for training in virtual environments (VE) and real world (RW) were developed with experts in psychophysics and O&M instructors. The advanced prototype went through rigorous technical tests consisting of benchmarking the algorithms for reconstructing 3D geometry of the environment enabling e.g. obstacle detection in indoor and outdoor environments. The concluding phase of verifying the advanced SoV system prototype was to carry out usability tests. There were 19 VIP participants taking part in the mobility trials in the controlled environments and real environments. The partners carrying out these trials received approvals of the Bioethics Commissions. We noted that the mobility performance of the users using the SoV system improved with learning although we noted high variance in the learning times. Another result was that when the SoV system was used together with the cane a smaller number of collisions were noted, however, at the cost of longer times required to walk through the testing paths. Important design modification guidelines were also collected from the users (e.g. the system was not comfortable to enough) that have enabled to improve the final SOV system prototype.

The Final SoV Prototype from the user perspective is a powerful assistive tool, with many advantages over the traditional assistive devices and other similar actions. It features advanced environment sensing capabilities and pervasiveness, rich and customizable non-visual presentation modes of the environment and finally rich support tools (line VTE) were created for efficient training.

The Final SoV Prototype is a complex and powerful solution – consisting of integrated hardware and software. It works in real time at high-frame rates, with continuous 3D scanning and analysis of the surroundings, powerful and naturalistic audio-haptics encodings of the environment, good ergonomics, stable. It is accompanied by a comprehensive set of training resources - to help users learn and achieve proficiency. It was extensively tested during the last part of the project, in both laboratory and real-world environments, with excellent results achieved by most of the visually impaired users. It was produced in a small number of units within the project, and the manufacturing process is relatively simple and easy to translate into larger scale productions.

The Sound of Vision solution is in the process of being transferred to industry and exploitation. Through this, also, the solution itself will be permanently improved, in regards of miniaturization, ergonomics, reliability, functionality and costs.

C. Progress beyond the state of the art

The prototype

As presented in previous section “Overview of objectives, results, conclusions”, the most important result of the project is the final prototype itself (a TRL 7-8 sensory substitution device with richer and stronger functionality than any existing system) accompanied by efficient training materials, and very close to reaching the finite, commercial product - with huge impact on the life of the visually impaired.

The brief description of the prototype’s hardware components, operation and various audio-haptic information offered to the users was provided in this previous section.

The prototype has proved its performance during extensive training and testing (evaluation of usability and performance) with end-users. Some of the most important results of evaluations are discussed in subsequent sections.

Individual advances

Throughout developing the prototype, a large set of punctual advances beyond the state of the art were achieved, which are summarized in the following table:

Technical Achievement	Patentable
Adjustable Multi-speakers	Maybe
Haptic Belt/Vest	No
Method for combined haptic and auditory space representation	Maybe
Method for simultaneous and dynamic haptic rendering objects’ shape, distance and type	Maybe
Algorithm for real-time understanding of stressful moments using biosignals.	No
GPU Rays-based Segmentation	**Yes**
GPU estimation and filtering of normal vectors	Maybe
Planar segmentation	No
Algorithm for labeling of ground, walls, ceiling, generic objects in indoor environments	No
Stair detection in indoor environments	No
Method for converting depth images into fluid sounds for real-time blind navigation	No
Method for estimating ground plane equation for an arbitrary roll rotation	No
Door detection in an indoor environment	No
Algorithm for real-time stereo-based 3D reconstruction in dynamic scenes	Maybe
Algorithm for real-time segmentation of outdoor environments	Maybe
Ground plane detection and tracking in stereo sequences	No
Wearable hardware and software system for acquisition of 3D information	No
Detection of negative obstacles in stereo sequences	No
Dual vectors based solution for the initial guess in the motion estimation problem	No

As indicated, several achievements are considered as possible patentable (further assessment of patentability and opportunity must be performed) and for one we already applied for patent.

Transferable principles and results

The creation and evaluation of the prototype confirmed the feasibility and efficiency, value of the key aspects of Sound of Vision. These results represent very important understandings and proofs, and their thorough dissemination will ensure their transfer to the entire field of assistive sensory substitution devices for visually impaired.

The following are the main transferable validated principles and results of Sound of Vision.

- Sensory substitutions: Rich, naturalistic full scene encodings and additional tools, that:
  - combine synchronized audio-haptic representation;
  - are flexible and customizable;
  - work in real-time at high-framerates;
  - emphasize the role of haptics.
- Design and validation processes:
  - Interdisciplinary approach (engineers, neuroscientists, mobility instructors).
  - Direct participation of the VIPs in the initial design;
  - Refinement through extensive testing and validation with VIPs;
  - Cognitive, affective and perceptual assessments;
  - Modular hardware and software design.
- Wearability and pervasiveness (indoor & outdoor, most lighting conditions; operation in any environments without any prior configuration or information).
- The essentiality of training:
  - training is necessary and able to lead users to proficiency;
  - virtual environments can be a highly-effective, safe and cheap component of a learning strategy.

The rest of this section includes brief discussions of these elements, providing further references where appropriate.

Sensory substitutions

As stated previously, all the audio-haptic encodings and tools created within the project are going to be **open-sourced**, to further support the growth of the field, as a “Reusable sonification and haptification library”. Here we summarize their core design principles, that were applied and validated.

Rich, natural-like perception, and additional tools - flexible and customizable

The goal of the SoV system is to provide information about the surrounding environment in order to create new perception that replaces vision, for visually impaired people. A rich representation allows for a better understanding of the environment. Naturality and similarity to the real visual sense allow for an easier adaptation of the brain to this new perception through neuroplasticity. The rich and natural-like perception is created by the SoV system by means of original audio, haptic or multimodal representations of the sensed environment . Audio encoding models inspired by natural phenomena like liquid behavior (Spagnol et al., “Auditory depth map representations with a sensory substitution scheme based on synthetic fluid sounds”) and image-like projections of objects onto the user’s abdomen by means of the haptic belt support our approach to natural perception. Additionally, the system provides several tools for perception, as well as safe and efficient mobility.

These encodings and tools were presented in a previous section ("Overview of objectives, results, conclusions").

All of them are under user's control and highly customizable. Our extensive evaluations has shown various users develop personal preferences and patterns when using the device, and make their own combination of activating encoding and tools in practical situation. Thus, Sound of Vision provides both power and flexibility - able to account for the inherent variation of the requirements of users with different conditions, in different situations and with different preferences.

Emphasis on the use of haptics

While the audio channel has been the focus of most research into sensory substitution, the SoV project laid a large emphasis on haptics as a means of conveying rich information to the visually impaired, as can be observed in the work by Jóhannesson et al., "The Sound of Vision Project: On the Feasibility of an Audio-Haptic Representation of the Environment, for the Visually Impaired". Technical experimentation, as well as deep neuroscientific analysis of the sensory substitution process and related practical aspects have revealed that haptics provide significant possibilities on their own, but particularly through combined usage with audio. The multimodal approach allows to compensate for many of the limitations of the auditory channel and facilitates better cross-modal training and perception.,It also lessens information overload of the hearing sense used by some visually impaired for echolocation purposes.The consortium therefore dedicated significant resources to the development of an original design for a haptic belt. The high resolution of the haptic belt (involving an array of 6x10 motors vibrating on the abdomen) allowed for the development of "full" haptic encodings offering a rich perception of the environment. Since tactile perception can compensate for highly prevalent age-related hearing loss, this powerful combination of haptic encoding and rendering solutions is of utmost importance to people of older age, which, according to the WHO, constitute 81% of the visually impaired population. Although also tactile perception accuracy decreases with age (Deshpande et al. 2008), investigations conducted in the SoV project as well as related studies on the sense of touch suggest that the 30 mm motor-distance as implemented in the SoV system enables sufficient tactile accuracy for older VIPs (Jóhannesson et al. 2017, Stevens and Patterson, 1995).

Powerful combinations of representations through audio and haptic

Original combinations of spatialized audio with haptic vibrations have been developed in the SoV project. The designed encodings offer the possibility of using the audio or haptics as standalone modalities, offering a rich perception of the environment by themselves. Still, the various multimodal representations are even stronger, by successfully compensating for each other's limitations. As an example, the haptic display conveys direction more accurately than audio, but it is difficult to exploit the amplitude of vibrations as an additional dimension for this representation. Audio can, on the other hand, convey a larger number of features (size, geometry) but even with spatial filtering it is not localized very accurately, especially in the sagittal plane. Thus, their combination is a powerful feature of the SoV system, allowing for a more accurate perception of the environment. Moreover, their strength also comes from their high level of customization, allowing the users to adjust the use of the system. Usability tests conducted during the SoV project revealed that users have individual preferences regarding the use of multisensory encoding, and, like to select different encodings depending on the task and situation. Therefore, we provide users with various options, e.g. they can choose to rely more on the audio or on the haptics but also receive simplified information through the other channel, or they can use both audio and haptic at the full capacity of each channel.

Design, refinement and validation

Interdisciplinary approach to design, implementation and validation

The concept behind the development of the SoV system was to bring together specialists from multiple fields, working together in a multi-disciplinary approach to the development of a complex sensory substitution device. Thus, the neuroscience and behavioral perspective provided valuable feedback and insight during the iterative design and implementation process (Kristjánsson et al., "Effective design of sensory-substitution devices: Principles, pitfalls and potential.") . Moreover, the interdisciplinary approach has also driven the development of efficient training programmes based on a mixture of traditional and novel methods. These methods rely on best practices provided by O&M instructors and on modern concepts like serious games, respectively, as can be seen in the work by Moldoveanu et al., "Virtual Mini-games - a Serious Learning Tool for Sensory Substitution Devices" or in the paper by Nagy and Wersényi, "Evaluation of Training to Improve Auditory Memory Capabilities on a Mobile Device Based on a Serious Game Application".

Overall, we conclude that the SoV project has overcome this limitation of other relevant similar actions of driving the development solely based on research teams consisting almost exclusively in ICT and electronics specialists with almost complete lack of involvement of specialists from other fields relevant for the subject.

Direct participation of the VIPs in the design, refinement and validation processes

An important objective that has been reached in the SoV project was to directly involve the target group, i.e., the visually impaired people, in the development process. This was of great importance as, in many cases, their goals and expectations differed from those of the specialists in electronics or signal processing. The iterative development process based on evaluation feedback had a significant impact upon the mediation of these discrepancies.

High importance given to pervasiveness

Most of the Sound of Vision competitors are solutions working in known and/or preconfigured environments. These systems are useful, but limited to their configured areas - requiring either a database to store the environment information, or certain hardware and software components or markers placed in predefined locations (bus stations, train stations) which interact with wearable assistive devices. The costs for configuring and maintaining such environments is relatively high, thus very few environments currently are available for such systems practical usage. The scope of Sound of Vision is larger than just assisted navigation in known environments. Just a few other solutions aim to support navigation in unknown environments (such as, among the most recent modern ones, Eyesynth, Ultracane, Smartcane, Aira, Wheatcroft) but none achieved the functionality offered by Sound of Vision.

An important aspect that drove the design and development of the SoV system was the availability and usability of the system in various environments, indoor and outdoor, and in various illumination conditions, from darkness to bright sunlight - without any pre-configuration or prior knowledge.

The core of this key aspect lies in a full hardware and software solution for both indoor and outdoor real time 3D acquisition and segmentation (Caraiman et al., "Computer Vision for the Visually Impaired: the Sound of Vision System").

To the best of our knowledge, compared to any other similar research in the field, the SoV system adopted the most complex approach to ensuring pervasiveness, wearability and sensory substitution, all at the same time.

Extensive evaluation with end users

To the best of our knowledge, the SoV action engaged one of the largest scale coordinated evaluation performed with an SSD during development: almost 1000 hours of usability testing involving over 45 visually impaired test takers. This was essential to support the development, collecting diverse feedback from users, and certifying the performances of the end result.

Training

High importance given to training

It is well known that dedicated, well designed and coordinated training leads to major performance improvements in acquisition and usage of any new skill. However, very few of the researches similar to SoV have dedicated considerable resources to the development of proper training programmes accompanying their technical solutions. The few, recent cases that actually focussed more on training then on the technical solution achieved some of the best results.

With the goal of producing an intuitive solution in mind, the SoV project did not neglect the importance of training. Moreover, significant resources were dedicated to developing effective and efficient training programs and instruments. These are based on the valuable input of O&M instructors that participated in the training and testing activities in the SoV project. This input has not only provided efficient techniques and procedures for training the VIP users in real world scenarios, but also for developing original training instruments and concepts based on virtual environments and serious games.
The results from usability tests, especially those run in WP5, prove the effectiveness and efficiency of the developed training programs, given the impressive results obtained by the VI participants in using the SoV system in very short time (Balan et al., "Improving the Audio Game--Playing Performances of People with Visual Impairments Through Multimodal Training").

Virtual training & testing environments

From start, we identified virtual environments' potential, as a cheap and safe way to support both the training of users and their systematic evaluation (Moldoveanu et al., "Mastering an Advanced Sensory Substitution Device for Visually Impaired through Innovative Virtual Training"). A large set of virtual environments was created, including:

- 17 synthetic scenes ranging from basic to complex
- a large realistic scene including indoor and outdoor environments
- a fantasy explore & adventure game like environment

The environments were accompanied by:

- Automatic distributed data collection;
- Statistics & analysis tools.

These were extensively used in both training our users and evaluating their progress. The results prove the efficiency of these environments, as an essential part of a training strategy. They can be used both to learn the basics of the system, before moving (with an instructor) to real world training, and later on - to fine tune usage and achieve impressive performance.
As stated previously, all these virtual training & testing resources are going to be **open-sourced**, to further support the growth of the field, as a "Reusable training serious game".

Cognitive, affective and perceptual assessments

We employed computational neuroscience and machine learning techniques to better understand the user experience of the visually impaired when navigating in unfamiliar outdoor environments assisted by mobility technologies and more specifically the SOV device.

Additionally, we performed a basic assessment of the vibrotactile spatial acuity of the torso, in order to fine tune the design of our belt.

Memorisation, recall, cognitive and affective load experienced when interacting with the audio and haptic modalities of the SOV system

We investigated the easiness in memorization and retrieval of acoustic and haptic information provided by the SOV device. Engaging both VIP and normally sighted, blindfolded participants, we found spectral differences which were due to a higher power in VIP individuals and were consistent in every SoV sound. This finding reinforced the notion that visual impairment may result in increased utilization of visuospatial faculties, both in storage and in rehearsal of stored auditory information. We also assessed the cognitive and affective load of the participants when using the SOV sound and haptic models, pointed out the intuitiveness of the sound and haptic encodings, comparing between the two modalities and highlighting their strengths and weaknesses in providing pleasant feedback (Saitis et al, "Cognitive Load Assessment from EEG and Peripheral Biosignals for the Design of Visually Impaired Mobility Aids.").

Impact of sonification and haptification variables in the information perception

In this study, we assessed the specific audio and haptic variables of the SOV device and the way they impact on the perception of information. The auditory and haptic stimulation models proposed in the SoV project evoke measurable Event-Related Potentials (ERPs), which were used to qualitatively and quantitatively evaluate (local peak amplitudes and other windowed measurements, etc.) and differentiate between various scene representations. Insights from these experiments showed which modality is the most adequate for the communication the required information in each situation.

Comparison of the cognitive and affective load evoked by the SOV device as compared to the white can and virtual environment navigation

We assessed the cognitive load of the VIPs when using the SoV device both in the virtual environment and in real-world outdoor and indoor environments but also when using the white cane. We provide a comparison between the cognitive load index and the accuracy of the performance recorded in terms of response times and collisions. Interestingly the cognitive load of the participants with the SOV device has shown to be greater but close to the one monitored during the navigation with the white cane despite the fact that the participants only practised the navigation with the SOV device for a brief period of time.

Real-life cognitive and affective assessment, prediction of stress, assessment of difficulties per category of sight loss

We aimed to better understand the cognitive-emotional experience of visually impaired people when navigating in unfamiliar urban environments, both outdoor and indoor. We proposed a multimodal framework based on random forest classifiers, which predicts the actual environment among predefined generic classes of urban settings, inferring on real-time, non-invasive, ambulatory monitoring of brain and peripheral biosignals. Model performance reached 93\% for the outdoor and 87\% for the indoor environments (expressed in weighted AUROC), demonstrating the potential of the approach. Estimating the density distributions of the most predictive biomarkers, we presented a series of geographic and temporal visualizations depicting the environmental contexts in which the most intense affective and cognitive reactions take place. A linear mixed model analysis revealed significant differences between categories of vision impairment, but not between normal and impaired vision. These findings pave the way to emotionally intelligent mobility-enhancing systems, capable of implicit adaptation not only to changing environments but also to shifts in the affective state of the user in relation to different environmental and situational factors.

Moreover, an in-depth analysis of the environments that most challenge people from certain categories of sight loss was presented together with an automatic classification of the perceived difficulty in each time instance, inferred from their biosignals. Given the limited size of our sample, our findings suggest that there are significant differences across the environments for the various categories of sight loss. Moreover, we exploited cross-modal relations predicting the cognitive load in real-time inferring on features extracted from the EDA. This paves the way for the design of less invasive, wearable assistive devices that take into consideration the well-being of the VIP.

Basic assessment of the vibrotactile spatial acuity of the torso

We tested discrimination of vibrotactile stimulation from eccentric rotating mass motors with in-plane vibrations. We placed motors on torso, experimenting with different center to center distances, which ranged between 13 mm and 30 mm. The experiments consisted in sending two tactile stimuli at very small time intervals and observing whether the testers discriminated the source of the stimuli (whether the second stimulus came from the same source or from a motor placed to the left/right of the motor that produced the first stimulus). The results of the experiments proved that the discrimination accuracy is well above chance even for very small distances such as 13 mm. Therefore, our work brings essential information for the design of vibrotactile devices.

D. NEXT STEPS BEYOND THE PROJECT

Integration of new 3D acquisition chips: In the first months following the end of the project UPB, TUI and UoI will continue with the development of the headgear and implementation of Structure Core camera. This component will be a significant upgrade to the structure light camera used in the prototypes as it is claimed to be faster, more reliable, provide better data quality, and much lighter. Furthermore, the Structure Core has an embedded IMU which will replace the headgear's IMU. This will simplify the assembly of the headgear and make it much lighter. Furthermore, it has potential to also replace the stereo cameras, further simplifying assembly and reducing the weight.

Haptic belt improvement will be continued by UoI and UPB, including: stretchability, breathability in order to wear close to body and improve the perception of vibrations, optimizing motors size, density, and energy use.

Partners who were responsible for development and implementation of the 3D image processing and audio-haptic encodings will evaluate whether their solutions can be patented. If it turns out that the solutions can be patented then the partners will submit patent applications. A patent application was already submitted by UPB, and will be monitored and continued.

The partners will continue writing up the project's results and submit them to academic journals and conferences. Notable, the latest and strongest results of the project (from last months) have not yet been published, so high impact papers are expected to be produced during 2018. In addition to presentations at academic conferences the consortium will continue to present the project's results to stakeholders and the general public. For an example the results will be presented in April 2018 - first to the general public at the annual Engineering day in Iceland and then at the nordic congress for low vision therapy (http://www.nordisksynkongress.com).

Two funded PhD projects will continue the research and development initiated in the Sound of Vision project for the next years.

PhD project on haptic perception. In combination with our development of the haptic belt, we have performed basic research regarding the nature of vibrotactile stimulation, which resulted in scientific publications, and various discoveries that we will pursue in future. A research program within the University of Iceland has been developed, which unites experts from Engineering and the Psychology. A PhD student from the SoV project will continue the tactile research with 2 year funding from the Technological Development Fund of the Icelandic Centre for Research (RANNIS) with the aim of pursuing basic research into human perception of touch, and thereby supporting further development of the SoV device.

PhD project on music appreciation for persons with cochlear implants. The tactile research will also be continued with a 4 year funding from Nordforsk. The Nordforsk funded project will fund one PhD student which will carry out research into how the haptic belt can be used and improved to provide improved music appreciation to persons with cochlear implants.

Bringing the Sound of Vision system to market. The consortium will also work on bringing the results from the project to the market - especially the SoV system. The marketing will be guided by the Business and exploitation plan created and developed in the project. It is foreseeable that initial market efforts will be put on a simplified version of the SoV system - i.e. a system which does not have all the capabilities of the SoV system developed in the project. This simplified system will be easier to make ready for the market and it will be less costly to make.

Overall assessment

Methodology

The approach used by the consortium to qualitatively and quantitatively assess the results of the project involved defining and constantly evaluating a set of Success Indicators (SI) and Key Performance Indicators (KPI) associated to the planned objectives and activities. These indicators addressed various aspects of the project development: management, system design & development, system evaluation, communication & dissemination.

The objectives set for the project management activities were evaluated with respect to the success of (i) the coordination of the communication, collaboration and coordination between partners, planning and coordination of the project activities, (ii) the permanent and proactive monitoring of the identified risks, (iii) the application of adequate correction actions in the case of work plan deflection, by establishing and evaluating the adequate quality standards application, (iv) keeping the project running within time and budgetary constraints, (v) the elaboration and delivery of all the required documentation and artefacts to relevant reporting authorities.

The system design & development was monitored through qualitative and quantitative measures, by defining and evaluating: (i) SI of the specific development activities undertaken throughout the project timeline, and (ii) KPI associated to the technical evaluation, respectively. Specific SI of the design & development activities were defined for each stage of the development. Overall, for the final system, the consortium aimed at ensuring: the inclusion of all the relevant and previously validated functionality in the final package; easy configurability in the typical setups; ease of use, reliability, safety; cost affordability in most EU countries; good documentation; improvement of users lifestyle through its subsequent use. The KPI for the technical evaluation were defined according to standard approaches of unit, integration and system testing.

The SI of the activities related to system evaluation were defined to ensure that: (i) any discrepancies of the system prototypes related to the URD are identified, (ii) relevant information for refining the technical and conceptual solutions is provided, (iii) tests are performed within safety frames, (iv) relevant data is collected.

With regards to project communication activities, the consortium prepared a communication plan during the first phase of the project. It was used to define target audience groups, to identify the most efficient means of reaching each target group, as well as to elaborate a number of Key Performance Indicators that were subsequently used for reporting project progress with regards to project communication and dissemination. Expected KPI values were defined for each 9-month interval, and were repeatedly assessed to ensure project communication activities remained to a high standard. The table below illustrates the most important KPI, together with planned and actual values for M36. We must mention that planned values were first identified during M03 of the project and were not adjusted.

KPI	Planned (M36)	Actual (M36)
Articles submitted to academic journals or conferences	60	80
Presentation at industrial events or exhibits	7	8
Scientific events organized by the project	4	5
Communication events and visits organized by the project	5	34
Printed dissemination materials available	10	12
Presentation within the audio-visual and printed media	12	13
Participants at events having contribution from Sound of Vision	3000	21000
Total website unique visitors Total website visits	15000	~10000 ~15000
Total material downloads from project website	4000	~6000
Total #SoVProject followers on twitter	200	~160

Qualitative assessment

Project management

Administrative coordination was provided by Dr. Runar Unnthorsson who received valuable help from the Project Office at University of Iceland(UoI). In fact, the Project Office was instrumental in ensuring that administrative coordination produced timely reporting and information exchanges. In addition, the effortless and constructive communication which UoI experienced with the project's PO's facilitated effective administrative coordination.

Technical coordination was effectively administered by the Project's **Steering Committee** (SC). Dr. Alin Moldoveanu and Dr. Runar Unnthorsson were part of the SC throughout the entire project. Dr. Pawel Strumillo was a member of the SC for the first year and Dr. Simona Caraiman was a member of the SC for the remaining 2 years. The SC met regularly - once a week throughout the most of the duration of the project. During the SC meetings the status of the tasks was reviewed and potential problems identified and mitigation measures discussed. Furthermore, during the agile development, the team leaders of the technical and testing teams were in regular contact with the SC and provided up to date information about the work and anticipated issues.

Overall, the management of the project was successful and the methods used for the coordination of partner activities and technical collaboration proved to be effective. Various problems were solved and potential conflicts avoided. This was accomplished by a combination of measures that ensured an open and productive environment for the project. The most important measures were:

- Effective communication between partners (face-to-face or online).
- Regular partner meetings (one to two times a year).
- Regular Steering Committee meetings (at least once a month).
- Effective management procedures defined for all important areas of the project.

- The use of powerful collaboration software solutions (EMDESK).
- A centrally-shared document repository (OwnCloud).

The KPIs used are:

- **How many deliverables were submitted on time**
  All deliverables except one was submitted on time. The late submission was due to Christmas holidays. The deadline of two deliverables in WP2 was extended after consultation with the PO. The extension did not affect the project work as the deliverables were submitted at the end of the WP. One deliverable was updated and resubmitted as previously planned with the Project's Officer.
- **Partner's Accessibility to project's files and information**
  All the project's files were made accessible to all partners through OwnCloud, Google docs and GitHub repository. Regular Skype meetings of development and testing teams provided up to date information to all relevant members. Furthermore the minutes of the meetings were distributed to the team members and the Steering Committee after the meetings. Finally, EMDESK provided information and overview of partner's use of resources.
- **Mean response time to partner's requests**
  Almost all of the requests which the coordinator received from partners were addressed within 2 days from receiving them. However, solving the requests often required more time as some of them required answers from third parties; e.g. specialists and the project's PO.

Requirements, design and development activities

The work towards the final version of the Sound of Vision system was initiated with the **analysis and specification of the general requirements for the system**. The main challenge at this stage was to benefit, in a small time frame, from a strong involvement of the visually impaired in order to define valid conceptual and technical requirements for the system. Besides analyzing the results of available users studies, the consortium conducted a *custom survey to assess user expectations* from the SoV system. It consisted in 89 interviews with visually impaired persons, conducted in 4 different countries (Hungary, Romania, Poland and Iceland). The work resulted in the specification of a set of requirements understood and agreed upon by all partners. These general requirements were further refined throughout the project timeline based on the acquired experience and findings regarding the challenges of visually impaired people. Specifically, the consortium performed a further study aiming to better understand the *cognitive-emotional experience of visually impaired people when navigating in unfamiliar urban environments*, both outdoor and indoor. Moreover, an in-depth analysis of the environments that most challenge people from certain categories of sight loss was performed, together with an automatic classification of the perceived difficulty in each time instance, inferred from their biosignals.

The aim of the **design process** that followed was to define appropriate solutions to the conceptual and technological challenges in order to meet the established requirements. The main challenges of this process were:

- to design hardware & software solutions that meet contradictory requirements of wearability, pervasiveness and real-time feedback;
- to provide a rich set of system features to respond to the diverse expectations of the VIPs from SoV (according to the results of the survey);
- to allow for the development of a highly customizable yet easy to use system.

Interspersed with the design process, the consortium performed an ample **exploratory prototyping** activity. It consisted in performing extensive experiments with technical alternatives (hardware & software) and selection of optimal solutions. A thorough study of existing algorithms and hardware components, necessary for the individual parts of the system, was performed: preliminary implementations of algorithms, exploratory integration and tests of hardware components, and comparative evaluation to select the best solution, or a reduced set of alternatives with best potential.

The general architectural design and detailed design adopted for the system supported the creation of the Sound of Vision system in the form of a powerful development framework. This framework allowed for fast prototyping, evaluation and integration of modular software and hardware solutions to specific aspects: 3D acquisition, 3D processing, audio & haptic encoding and rendering.

During WP3, WP4 and WP5, for the **actual implementation and refinement of the system**, the consortium organized in Agile teams, covering the main parts of development:

- 3D acquisition and processing;
- audio-haptic encoding and rendering;
- hardware;
- virtual environments;
- Testing;
- core & services.

The teams followed an **adapted Agile-Scrum process**, with iterations of 3 weeks during WP3 (where lot of experimentation was still needed), shortened to 2 weeks during WP4 and 5. The role of product owner (defining the needs and vision) for each team, as well as inter-teams coordination and mediation was provided by the Steering Committee.

Towards the end of each of these 3 work packages, a version of the prototype was released: **the initial, advanced, and final prototypes**. These 3 versions were then subject to **technical testing** and **extensive usability and performance testing with end-users** (a total of over 45 visually impaired were involved in testing). Clear *testing procedures* were defined and an important *software infrastructure for testing* was built and used, including virtual environments (introduced at end of WP3), error collection and reporting, automatic distributed data collection, statistical visualizations and analysis tools. Testing with end-users was a keystone for improvement, detecting issues, exploring a wide range of situations and types of user, collecting most valuable feedback - leading, gradually to prototypes stronger and more reliable. Additionally, the final suite of training and testing, performed at end of WP5, represents a clear certification of the capabilities of the prototype.

PILOTING ACTIVITIES AND EVALUATION

The validation of the developed solution was performed from both usability and technical points of view. The development of the system was interspersed with these two forms of evaluation in an iterative approach. Thus, each of the three system prototypes was subjected to specific technical tests and then to usability evaluation with visually impaired participants. The work associated with the technical evaluation had the role of tracking the implementation of the initially specified requirements throughout the development process, and to ensure the incorporation of the feedback obtained in the iterative evaluation process. Usability testing followed an approach of gradually increasing complexity throughout the system development timeline.

Overall, the success of the testing activities was measured with respect to: identification of the discrepancies of the advanced prototype related to the initially formulated requirements; provision of relevant information for refining the technical and conceptual solutions; insurance of participants' safety; collection of relevant data.

Technical evaluation

The developed and performed test cases have allowed to improve important system errors at different system levels. For each test case group there is list of minimum 6 test cases examining key properties and functions of the tested system module. Overall there are 102 test cases foreseen for evaluating performance of the Final System Prototype with respect to the system requirements and architecture specified in the User Requirements Document (URD), Architectural Design Document (ADD) and Detailed Design Document (DDD) .

With respect to the technical evaluation, we conclude that the final SoV system is complete, in the sense that it satisfies all its original functional requirements and, to a good extent also the non-functional ones. Certainly, some aspects related to completeness and qualification (from the perspective of a commercial product) lay beyond the scope of this research and innovation project: the industrial design, miniaturization and mass production, as well as thorough reliability testing at all levels. Indeed, our GA does not indicate these as goals of the project, but rather envisaged them as part of the further technological transfer & exploitation strategy (activity 5.5 from WP5).

Usability evaluation

We conducted experiments at the end of each WP to assess the functionality of each system prototype. The experiments were designed of increasing complexity, focusing at first on usability of the audio and haptic encodings, continuing by evaluating the use of the system in controlled laboratory setups and finally addressing the usability in operational environments.

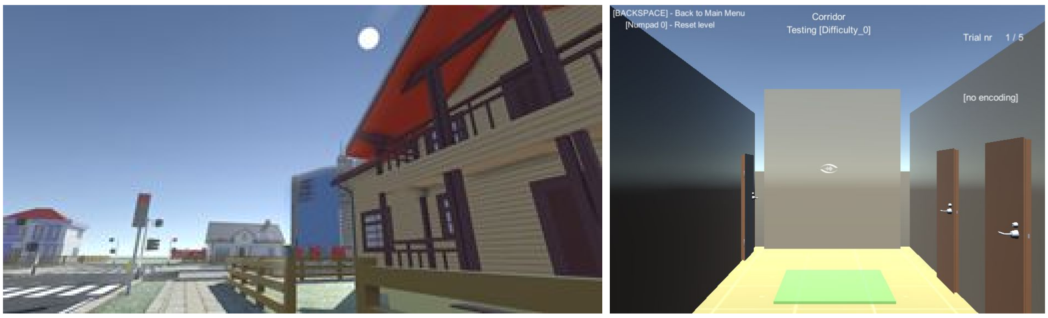

Figure 3. Training and testing using virtual environments

The results of usability tests in WP3 were taken as basis for the development of the Advanced Prototype, and the outcome of usability tests in WP4 guided the improvements in the Final Prototype. Finally, for evaluating the Final Prototype, extensive usability tests were designed, conducted and analysed, where we assessed the performance of end users with the prototype in indoor environments, outdoor environments, and a simulated virtual training environment. For these final prototype tests, we took the decision to focus on single-case studies with visually impaired participants, as those would be more informative at this point in the testing process, than extensive testing of healthy observers. It was important to assess the performance of end users and collect their feedback. To maximize efficiency, each partner centred upon a different important aspect of the usability testing. UPB and IW focused on collecting data for statistical analysis derived from the VTE, UoI and NIB focussed on quantifying the effect of training and the comparison between the SoV system and the white cane, TUI/TUL focused on assessing user performance in outdoor environments.

Tests in indoor environments were performed at UoI and NIB and UPB. The main objectives of the usability tests were to investigate whether the system is useful to the user in terms of spatial awareness and mobility and whether it is user-friendly, and to quantify training effects. In the final usability testing, VI participants received eight hours of training with the SoV system and repeatedly completed performances assessments, where they were asked to navigate through standardized navigation scenes with cardboard boxes as obstacles. In each of the assessments, participants relied on either the SoV system, the white cane, or both assistive devices, to avoid collisions. The results show rapid and substantial learning with the SoV system, with significantly less collisions and higher obstacle awareness. After as little as four hours of training, VI participants were able to successfully avoid collisions in a difficult navigation task as good as when using the cane, although they still needed more time.

Regarding the Real-World Indoor tests carried out at UPB, one of the most experienced test participants, after 20 training sessions averaging about 3 hours each, achieved the **shortest completion time** and the highest accuracy in almost all mobility exercises compared to the other test participants at UPB. His accuracy in identifying the object properties (width, distance) in scenes which we defined as complex was 100%, and in all navigation scenes his success rate was 100%. The other test participants were subject to a 7 days training and testing program; their performance gradually improved day by day, and they also achieved good results in most Real-World tests, with a 100% success rate in almost all perception and navigation exercises, at the end of day 7.

Figure 4. Tests in controlled and real world indoor environments

Tests in outdoor environments were performed at TUL and TUI. The main objective of testing in outdoor operational environments was to evaluate the performance for *perception* and *mobility* and to compare between three conditions: white cane only, SoV & cane, SoV only. Two types of users took part in real-world outdoor tests: VIPs who previously were fully involved in all VTE or RW tests and a new user who received a minimal training performed in VTE and RW outdoor. Accuracy, reaction time, time to completion and number of collisions were assessed to measure performance.

Figure 5. Tests in outdoor environments

Firstly, the main goals of the *perception* experiments were to evaluate whether the VI participants are able to perceive the environment using the SoV device from a stationary position, are able to identify obstacles and recognize specific objects in static environments, and if they are able to identify both static and dynamic obstacles and recognize specific objects in operational environments. Unlike the tests performed in previously WPs in VTE and indoor RW, the outdoor experiments included dynamic obstacles.

The perception evaluation conducted in ego-static scenarios helped us to conclude that the participants using the SoV device are able to perceive the environment even if they are not moving, all users obtaining an average accuracy greater or equal to 85% in both types of scenes. The overall average accuracy in the perception tests was 89.3%.

Thanks to the improvements in audio models (danger mode and to different encodings for special objects) users correctly identified obstacles (possible dangers) and special objects (hole, wall) in static environments. As a result, all of them correctly identified the special objects (100% accuracy) and 3 out of 4 users correctly pointed the direction and approximated the distance to the special objects.

Subsequently, the main goals of the *mobility* experiments were to evaluate if the VI participants are able to use the information conveyed by the SoV device to guide their interaction with the environment, if the VI participants are able to move around and avoid obstacles using the SoV device, and to assess the efficiency of navigation with SoV device compared to using only the cane.The mobility experiments were ego-dynamic and included two types of scenarios: semi-controlled environments (the testing team could control the structure of the scene) and uncontrolled environments (public areas, with varying, uncontrollable traffic). Specific static and/or dynamic obstacles (i.e., people) were purposely and systematically introduced in some testing scenarios.

The visually impaired participants reported that performing mobility tasks with the SoV device was easier than building a detailed perception of complex scenes. They were also more satisfied about the solution provided by the SoV system for these tasks and by the time it took to complete them, than for the perception tasks.

With minimal training in using the SoV system outdoor, the users could navigate in the environments with very high accuracy. For our sample of rather inexperienced white cane users, mobility with the SoV device was accomplished with performance comparable to using the cane, and sometimes better.

The added value of SoV compared to the white cane was confirmed by the participants to consist in: providing early feedback about static and dynamic objects, providing feedback about elevated objects, walls, negative obstacles and signs.

Tests with the virtual training environment were performed at UPB where improvements for all the scenes from the Single Attribute categories (except for Quantity) were recorded. For the Frontal Pickups and Passing by scenes, there was a performance improvement at the end of the tests for all tested parameters. For the Passing between scene, there was an improvement in completion time and similar in the final test for the number of collisions recorded. For the Boxes scene, there was an improvement in terms of the average values of the completion time for the Easy, Medium and Hard tasks. The same pattern was observed for the Corridor scene where the improvements in the average value of both completion time and collisions were recorded.

We conclude, overall, that the tests of the final SOV prototype were highly promising, boding well for continue development of the SOV system. Blind and visually impaired participants are able to use the system to navigate in difficult environments, in some cases reaching performance levels similar to their performance levels of the white cane after only a few hours of training, even though they have used the white cane for years or decades.

Sustaining and exploiting results

As explained in previous sections, the main next goal is bringing Sound of Vision to market. A preliminary agreement for transferring the IP rights to a newly founded company was approved by the consortium and a preliminary business plan was laid out. The plan shows sustainability and profitability even under very conservative assumptions about market penetration. Thus, following this approach, the Sound of Vision partners will establish the company leadership, handle IP transfer and investigate financing alternatives - beginning the final steps towards exploitation.

While transitioning to, and during the commercial exploitation, the system will undergo more improvements, including:

- Integration of new 3D acquisition chips (e.g. Structure Core);
- Headgear adaptation to new 3D unit, and design improvements;
- Significant haptic belt improvement (stretchable, close to body, motors size & density, energy use);
- Overall reliability;
- Optimization of power consumption & mobile computing;
- Certifications.

Besides commercial exploitation, sustainability and improvements of the final prototype, the Sound of Vision consortium agreed to support the development of the field, by open-sourcing two of the most important and complex parts of the final prototype: Reusable sonification and haptification library and Reusable training serious games. Open-sourcing will allow significantly faster creation of new sensory substitution devices, together with efficient, safe and cheap training of their users. The evolution of the open-source projects, and possible contributions from other parties, will, in turn, further improve Sound of Vision itself. In next months, partners will identify the optimal license for open-sourcing, protecting IP rights, allowing free access and use for research and non-profit, and fee-based access for possibly competing commercial entities.

The knowledge and concrete results of the project are also exploited academically, being embedded and improving bachelor and master courses, and being researched more in diploma, master and PhD thesis at all 5 academic partners.

According to the consortium agreement, partners have the right to continue the exploitation of results individually, within the IP rules set by the agreement. Several partners are already preparing applications for side-projects making use of Sound of Vision results.

Quantitative assessment

List of Deliverables

WP1

- D1.1 User requirements document (URD) (M03)
- D1.2 Report upon the existing devices and components and list of selected equipment (M04)
- D1.3 Document of the system architectural design (ADD) (M03)
- D1.4 Project web site (M03)

WP2

- D2.1 Solutions for 3D reconstruction of the surrounding Environment (M12)
- D2.2 Solutions for synthesis of spatial sounds (M12)
- D2.3 Prototyped special headphones (M12)
- D2.4 Report upon comparison between different sound rendering devices (M12)
- D2.5 Report upon exploratory prototyping and testing for the serious Game (M12
- D2.6 Specification of the simulation-testing environments and their creation at UoI,UPB, TUI, SZE and TUL (M12)
- D2.7 Rules for rendering the 3D model through sound signals (M13)
- D2.8 Report on BCI (or other appropriate methods) tests and Analysis (M13)
- D2.9 Detailed Design Document (DDD) (M13)
- D2.10 Scientific papers I (M13)
- D2.11 Studies on existing methods for brain training (M13)
- D2.12 Project website (updated) (M13)

WP3

- D3.1 Initial prototype of the system (M18)
- D3.2 Report upon compliance with medical standards and regulations (M18)
- D3.3 System user manual (M21)
- D3.4 Report upon the BCI (or other appropriate methods) tests (M21)
- D3.5 Report upon testing the initial prototype (M21)
- D3.6 Algorithms for additional modules ("Danger", "360degree", "Focus","Reading") (M21)
- D3.7 Scientific papers II (M21)
- D3.8 Project website (updated II) (M21)

WP4

- D4.1 Pilot system (M27)
- D4.2 User training procedures (M27)
- D4.3 Testing procedures (M27)
- D4.4 Report upon the BCI (or other appropriate methods) tests II (M29)
- D4.5 Usage questionnaires (M29)
- D4.6 Quality report (M29)
- D4.7 Scientific papers III (M29)
- D4.8 Patent proposal (M29)
- D4.9 Project website (updated III) (M29)

WP5

D5.1 Final Sound Of Vision system (M36)
D5.2 Course material (M33)
D5.3 Report upon the BCI (or other appropriate methods) tests III (M36)
D5.4 Reusable sonification software library (M36)
D5.5 Reusable training serious game (M36)
D5.6 Database with the performed tests and BCI (and other appropriate methods) (M36)
D5.7 Automatically updated database with anonymized usage data and users feedback (M36)
D5.8 Report on tests with the Sound Of Vision final system (M36)
D5.9 Doctoral reports (M36)
D5.10 Scientific papers IV (M36)
D5.11 Final version of the project website (M36)

WP6

D6.1 Report containing the management procedures (M03)
D6.2 Innovation and IPR Management Plan (M03)
D6.3 Activity report I (M18)
D6.4 Activity report II (M36)
D6.5 Report upon the detailed exploitation services and business plan (M36)

WP7

D7.1 H - Requirement No. 3 (M05)
D7.2 POPD - Requirement No. 5 (M05)
D7.3 POPD - Requirement No. 4 (M05)
D7.4 OEI - Requirement No. 6 (M05)

List of achieved milestones

WP1

MS01: Completion of Requirements Analysis and Specification (M3)
MS02: Completion of system architectural design (M5)
MS03: Initiation of the equipment acquisition process (M5)

WP2

MS04: Completion of detailed design (M13)
MS05: Solutions for the 3D reconstruction of the environment, sound synthesis and rendering, conversion of 3D models into sound signals (M13)
MS06: Completion of the creation of simulation-testing environments at UoI, UPB, SZE, TUI, TUL (M12)

WP3

MS07: Completion of the Initial Prototype;deliverable (M21)
MS08: Experiments completed for the initial prototype (M21)
MS16: Review of the first version of portable systems prototype (M27)

WP4

MS09: Completion of user training procedures and equipment testing procedures (M27)
MS10: Completion of Sound of Vision’s Advanced Prototype (M29)
MS11: Completion of patent proposal for Sound Of Vision system (M29)

WP5

MS12: Completion of the final Sound of Vision system (M36)
MS13: Reports upon the training and the final system testing results, validating the system(M36)
MS14: Release of the reusable sonification software library (M36)
MS15: Strategy for exploiting the project's results (M36)

LIST OF PROJECT MEETINGS

The following table presents the time frame for the project's general assembly meetings.

Date	Location	Meeting
2015, February 24-25	Barcelona, Spain	Project kick-off meeting; First general assembly
2015 September 22-24	Lodz, Poland	Second general assembly
2016 February 16-19	Budapest, Hungary	Third general assembly
2016 October 11-13	Bruxelles, Belgium	Fourth general assembly; First project review
2017 June 19-22	Reykjavik, Iceland	Fifth general assembly
2017 November 27-30	Bucharest, Romania	Sixth general assembly
2018 February 22-23	Luxembourg City, Luxembourg	Final project review

List of top publications

Below is the list of publications the project consortium feels as the most representative regarding the scientific advances achieved.

Type of scientific publication	Authors	Title of the scientific publication	DOI	Title of the journal or equivalent	Date
Chapter in a Book	P. Strumillo, M. Bujacz, P. Baranski, P. Skulimowski, P. Korbel, M. Owczarek, K. Tomalczyk, A. Moldoveanu and R. Unnthorsson	Different approaches to aiding blind persons in mobility and navigation in the “Naviton” and “Sound of Vision” projects	-	Mobility of Visually Impaired People, pp 435-468	08.06.2015
Article in Journal	S. Hostiuc, A. Moldoveanu and M.-I. Dascălu	Translational research—the need of a new bioethics approach.	/10.1186/s12967-016-0773-4	Journal of Translational Medicine	06.06.2016
Publication in Conference proceeding/ Workshop	C. Saitis amd K. Kalimeri	Identifying Urban Mobility Challenges for the Visually Impaired with Mobile Monitoring of Multimodal Biosignals.	-	International Conference on Universal Access in Human-Computer Interaction	06.06.2016
Article in Journal	Ó. Jóhannesson, I. O. Balan, R. Unnthorsson, A. Moldoveanu and Á. Kristjánsson	The Sound of Vision Project: On the Feasibility of an Audio-Haptic Representation of the Environment, for the Visually Impaired	10.3390/brainsci6030020	Brain Sciences	27.06.2016
Chapter in a Book	M. Bujacz, K. Kropidlowski, G. Ivanica, A. Moldoveanu, C. Saitis, A. Csapo, G. Wersenyi, S. Spagnol, O. I. Johannesson, R. Unnthorsson, M. Rotnicki, P. Witek	Sound of Vision - Spatial Audio Output and Sonification Approaches	10.1007/978-3-319-41267-2_28	Computers Helping People with Special Needs, pp. 202-209	06.07.2016
Article in Journal	C. Saitis, Z. Parvez and K. Kalimeri	Cognitive Load Assessment from EEG and Peripheral Biosignals for the Design of Visually Impaired Mobility Aids.	https://www.hindawi.com/journals/wcmc/2018/8971206/	Wireless Communications and Mobile Computing	28.02.2018
Publication in Conference proceeding/ Workshop	S. Spagnol, C. Saitis, M. Bujacz, O. Johannesson, K. Kalimeri, A. Moldoveanu, A. Kristjansson and R. Unnthorsson	Model-based obstacle sonification for the navigation of visually impaired persons		Proceedings of the 19th International Conference on Digital Audio Effects (DAFx-16)	05.09.2016
Publication in Conference proceeding/ Workshop	A. Dragos B. Moldoveanu, S. Ivascu, I. Stanica , M.-I. Dascalu, R. Lupu, G. Ivanica, O. Balan, S. Caraiman, F. Ungureanu, F.	Mastering an Advanced Sensory Substitution Device for Visually Impaired through Innovative Virtual Training	10.1109/ICCE-Berlin.2017.8210608	2017 IEEE 7th International Conference on Consumer Electronics	11.01.2017

	Moldoveanu and A. Morar				
Article in Journal	O. Bălan, A. Moldoveanu, F. Moldoveanu, H. Nagy, G. Wersényi and R. Unnthorsson	Improving the Audio Game--Playing Performances of People with Visual Impairments Through Multimodal Training		JOURNAL OF VISUAL IMPAIRMENT & BLINDNESS, pp. 148-164	01.04.2017
Publication in Conference proceeding/ Workshop	S. Caraiman, A. Morar, M. Owczarek, A. Burlacu, D. Rzeszotarski, N. Botezatu, P. Herghelegiu, F. Moldoveanu, P. Strumillo and A. Moldoveanu	Computer Vision for the Visually Impaired: the Sound of Vision System	10.1109/ICCVW.2017.175	2017 IEEE International Conference on Computer Vision Workshops (ICCVW)	28.10.2017
Article in Journal	S. Spagnol, R Hoffmann, M. H. Martínez, R. Unnthorsson	Blind wayfinding with physically-based liquid sounds	https://doi.org/10.1016/j.ijhcs.2018.02.002	Wireless Communications and Mobile Computing	28.02.201
Other	A. Csapo, S. Spagnol, M. Herrera Martinez, M. Bujacz, M. Janeczek, G. Ivanica, G. Wersenyi, A. Moldoveanu and R. Unnthorsson	Usability and Effectiveness of Auditory Sensory Substitution Models for the Visually Impaired		142nd AES Convention	11.05.2017

Below we present a table containing all scientific publications materialized during project implementation, which contributed to the dissemination and exploitation of the project's results.

ID	Authors	Title	Title of journal or equivalent	Open Access Type	URL	Date
Articles in Scientific Journals						
A01	G. Wersényi and J. Wilson	Evaluation of Head Movements in Short-term Measurements and Recordings with Human Subjects using Head-Tracking Sensors	Acta Technica Jaurinensis	Gold	https://doi.org/10.14513/actatechjaur.v8.n3.388	01.01.2015
A02	P. Barański P. and P. Strumiłło	Emphatic trials of a teleassistance system for the visually impaired	Journal of Medical Imaging and Health Informatics, 5(8), pp. 1640-1651	Hybrid Gold	https://doi.org/10.1166/jmihi.2015.1621	01.01.2015
A03	P. Skulimowski and P. Strumillo	Verification of visual odometry algorithms with an OpenGL-based software tool	J. of Electronic Imaging, 24(3)	Gold	https://doi.org/10.1117/1.JEI.24.3.033003	07.05.2015
A04	S. Spagnol, E. Tavazzi and F. Avanzini	Distance rendering and perception of nearby virtual sound sources with a near-field filter model	Applied Acoustics, 115, pp. 61-73	Green	https://doi.org/10.1016/j.apacoust.2016.08.015	08.06.2015
A05	Á. Csapó, G. Wersényi and M. Jeon	A Survey on Hardware and Software Solutions for Multimodal Wearable Assistive Devices Targeting the Visually Impaired	ACTA POLYTECHNICA HUNGARICA	Gold	http://dx.doi.org/10.12700/APH.13.5.2016.5.3	01.01.2016

A06	H. Nagy, G. Wersényi	Comparative Evaluation of Sighted and Visually Impaired Subjects using a Mobile Application for Reducing Veering during Blindfolded Walking	ACTA TECHNICA JAURINENSIS	Gold	http://dx.doi.org/10.14513/actatechjaur.v9.n2.404	30.04.2016
A07	Sorin Hostiuc,Alin Moldoveanu, Maria-Iuliana Dascălu, Runar Unnthorsson, Ómar I. Jóhannesson and Ioan Marcus	Translational research—the need of a new bioethics approach.	Journal of Translational Medicine	Gold	https://doi.org/10.1186/s12967-016-0773-4	06.06.2016
A08	Á. Kristjánsson, A. Moldoveanu, Ó. Jóhannesson, O. Balan, V. V. Valgeirsdóttir and R. Unnthorsson.	Effective design of sensory-substitution devices: Principles, pitfalls and potential.	Restor Neurol Neurosci., 34(5), pp. 769-87	Gold	https://doi.org/10.3233/RNN-160647	06.06.2016
A09	A. Ciobanu, A. Morar, F. Moldoveanu and A. Moldoveanu	Real-time segmentation of depth map frames on wearable devices	Accepted at Journal of Control Engineering and Applied Informatics	Gold	N/A (awaiting publication)	06.06.2016
A10	Ó. Jóhannesson, I. O. Balan, R. Unnthorsson, A. Moldoveanu and Á. Kristjánsson	The Sound of Vision Project: On the Feasibility of an Audio-Haptic Representation of the Environment, for the Visually Impaired	Brain Sciences	Gold	https://doi.org/10.3390/brainsci6030020	27.06.2016
A11	I.-C. Stănică, M.-I. Dascălu, A. Moldoveanu and F. Moldoveanu	An Innovative Solution Based on Virtual Reality to Treat Phobia	International Journal of Interactive Worlds	Gold	https://doi.org/10.5171/2017.155350	21.02.2017
A12	O. Bălan, A. Moldoveanu, F. Moldoveanu, H. Nagy, G. Wersényi and R. Unnthorsson	Improving the Audio Game--Playing Performances of People with Visual Impairments Through Multimodal Training	JOURNAL OF VISUAL IMPAIRMENT & BLINDNESS, pp. 148-164	Green	https://hdl.handle.net/20.500.11815/704	01.04.2017
A13	S. Spagnol, R. Hoffmann, Á. Kristjánsson and F. Avanzini	Effects of stimulus order on auditory distance discrimination of virtual nearby sound sources	The Journal of the Acoustical Society of America	Hybrid Gold	http://dx.doi.org/10.1121/1.4979842	30.04.2017
A14	Ómar I. Jóhannesson, Rebekka Hoffmann, Vigdís Vala Valgeirsdóttir, Rúnar Unnþórsson, Alin Moldoveanu, Árni Kristjánsson	Relative vibrotactile spatial acuity of the torso	Experimental Brain Research (2017) 235: 3505	Gold	https://doi.org/10.1007/s00221-017-5073-6	23.10.17
A15	C. Saitis, Z. Parvez and K. Kalimeri	Cognitive Load Assessment from EEG and Peripheral Biosignals for the Design of Visually Impaired Mobility Aids.	Wireless Communications and Mobile	Gold	https://doi.org/10.1155/2018/8971206	28.02.2018

			Computing			
A16	S. Spagnol, R Hoffmann, M. H. Martínez, R. Unnthorsson	Blind wayfinding with physically-based liquid sounds	International Journal of Human-Computer Studies	Green	https://doi.org/10.1016/j.ijhcs.2018.02.002	28.02.2018
A17	S. Spagnol, Á. Csapó, E. I. Konstantinidis, and K. Kalimeri	Mobile Assistive Technologies (Editorial)	Wireless Communications and Mobile Computing	Gold	https://www.hindawi.com/journals/wcmc/si/486761/	26.03.2018
A18	C. Saitis amd K. Kalimeri	Multimodal Classification of Stressful Environments in Visually Impaired Mobility Using EEG and Peripheral Biosignals	IEEE Transactions on Affective Computing	Green	N/A (awaiting publication)	TO APPEAR
A19	M. Bujacz and P. Strumiłło	Sonification: Review of Auditory Display Solutions in Electronic Travel Aids for the Blind	Archives of Acoustics (2016)	Gold	http://dx.doi.org/10.1515%2Faoa-2016-0040	
A20	S. Spagnol, G. Wersenyi, M. Bujacz, O. Balan, M. Herrera Martinez, A. Moldoveanu, R. Unnthorsson	Current Use and Future Perspectives of Spatial Audio Technologies in Electronic Travel Aids	Wireless Communications and Mobile Computing	Gold	https://doi.org/10.1155/2018/3918284	21.03.2018
Book Chapters						
B01	M. Owczarek , P. Skulimowski and P. Strumillo	Sound of Vision – 3D Scene Reconstruction from Stereo Vision in an Electronic Travel Aid for the Visually Impaired	Computers Helping People with Special Needs, pp. 35-42	Hybrid Gold	https://doi.org/10.1007/978-3-319-41267-2_6	06.07.2016
B02	M. Bujacz, K. Kropidlowski, G. Ivanica, A. Moldoveanu, C. Saitis, A. Csapo, G. Wersenyi, S. Spagnol, O. I. Johannesson, R. Unnthorsson, M. Rotnicki, P. Witek	Sound of Vision - Spatial Audio Output and Sonification Approaches	Computers Helping People with Special Needs, pp. 202-209	Hybrid Gold	https://doi.org/10.1007/978-3-319-41267-2_28	06.07.2016
Articles in Conference Proceedings / Workshops						
C01	O. Bălan, A. Moldoveanu and F. Moldoveanu	The Role of Perceptual Feedback Training on Sound Localization Accuracy in Audio Experiments	11th International Scientific Conference on eLearning and software for Education, Bucharest	Gold	https://doi.org/10.12753/2066-026X-15-074	23.04.2015
C02	O. Ferche, A. Moldoveanu, F. Moldoveanu, V. Asavei, A. Voinea,I. Negoi	Challenges and Issues for Successfully Applying Virtual Reality in Medical Rehabilitation	11th International Scientific Conference on eLearning and software for Education, Bucharest	Gold	https://doi.org/10.12753/2066-026X-15-073	23.04.2015

C03	P. Skulimowski, M. Owczarek M. and P. Strumillo	Ground plane estimation for an arbitrary camera roll rotation through V-disparity representation	2017 Federated Conference on Computer Science and Information Systems (FedCSIS)	Gold	https://doi.org/10.15439/2017F40	08.06.2015
C04	O. Bălan, A. Moldoveanu and F. Moldoveanu	Multimodal Perceptual Training Improves Spatial Auditory Performance in Blind and Sighted Listeners	Archives of Acoustics Journal, Vol. 40, No. 4, pages 491-502	Green	https://doi.org/10.1515/aoa-2015-0049	17.06.2015
C05	P. Baranski P. and P. Strumillo	Field trials of a teleassistance system for the visually impaired	2015 8th International Conference on Human System Interactions (HSI)	Not Open Access	https://doi.org/10.1109/HSI.2015.7170662	27.06.2015
C06	G. Wersényi, H. Nagy and Á. Csapó	Evaluation of Reaction Times to Sound Stimuli on Mobile Devices	International Conference on Auditory Display	Gold	https://smartech.gatech.edu/handle/1853/54148	06.07.2015
C07	O. Bălan, A. Moldoveanu H. Nagy, G. Wersényi, N. Botezatu, A. Stan and R.-G. Lupu	Haptic-Auditory Perceptual Feedback Based Training for Improving the Spatial Acoustic Resolution of the Visually Impaired People	21st International Conference on Auditory Display (ICAD2015), July 6-10, 2015, Graz, Styria, Austria	Gold	http://hdl.handle.net/1853/54096	08.07.2015
C08	O. Bălan, A. Moldoveanu and F. Moldoveanu	3D Audio and Haptic Interfaces for Training the Spatial Acoustic Resolution in Virtual Auditory Environments	The 21st International Conference on Auditory Display (ICAD-2015)	Green	https://www.researchgate.net/publication/283567621_3D_AUDIO_AND_HAPTIC_INTERFACES_FOR_TRAINING_THE_SPATIAL_ACOUSTIC_RESOLUTION_IN_VIRTUAL_AUDITORY_ENVIRONMENTS	08.07.2015
C09	M. Owczarek, P. Barański and P. Strumiłło	Pedestrian tracking in video sequences: a particle filtering approach, In: Computer Science and Information Systems (FedCSIS),	Pedestrian tracking in video sequences: a particle filtering approach, In: Computer Science and Info	Gold	https://doi.org/10.15439/2015F158	13.09.2015
C10	O. Bălan, A. Moldoveanu, F. Moldoveanu and A. Butean	Developing a navigational 3D audio game with hierarchical levels of difficulty for the visually impaired players	RoCHI 2015	Gold	http://rochi.utcluj.ro/articole/3/RoCHI-2015-Balan.pdf	24.09.2015
C11	B. Troancă, A. Butean, A. Moldoveanu and	Introducing Basic Geometric Shapes to Visually Impaired People Using a Mobile App	RoCHI 2015	Gold	http://rochi.utcluj.ro/articole/3/RoCHI-201	24.09.2015

	O. Bălan				5-Troanca.pdf	
C12	S. Spagnol, E. Tavazzi and F. Avanzini	Relative Auditory Distance Discrimination with Virtual Nearby Sound Sources	18th Int. Conference on Digital Audio Effects (DAFx-15)	Not Applicable	https://soundofvision.net/relative-auditory-distance-discrimination-with-virtual-nearby-sound-sources/	08.12.2015
C13	S. Spagnol and F. Avanzini	Frequency Estimation of the First Pinna Notch in Head-Related Transfer Functions with a Linear Anthropometric Model	18th Int. Conference on Digital Audio Effects (DAFx-15)	Not Applicable	https://www.ntnu.edu/documents/1001201110/1266017954/DAFx-15_submission_61.pdf	08.12.2015
C14	O. Balan, A. Moldoveanu, F. Moldoveanu and A. Morar	From game design to gamification and serious gaming - how game design principles apply to educational gaming	12th International Scientific Conference "eLearning and Software for Education"	Gold	https://doi.org/10.12753/2066-026X-16-047	21.04.2016
C15	V. E. Dinu, A. Moldoveanu, I. Negoi, T. I. Codarnai, M.-I. Dascalu and C. Taslitchi	A practical survey on health monitoring devices and their impact on quality of life	Proceedings of the 12th International Scientific Conference "eLearning and Software for Education"	Gold	https://doi.org/10.12753/2066-026X-16-048	21.04.2016
C16	C.-D. Nichifor, A. Moldoveanu, C.-N. Bodea, M.-I. Dascalu, A.-M. Neagu	Cognitive training games to improve learning skills	Proceedings of the 12th International Scientific Conference "eLearning and Software for Education"	Gold	https://doi.org/10.12753/2066-026X-16-051	21.04.2016
C17	I.-C. Stanica, A. Moldoveanu, C.-N. Bodea, M.-I. Dascalu, S. Hostiuc	A survey of virtual reality applications as psychotherapeutic tools to treat phobias	Proceedings of the 12th International Scientific Conference "eLearning and Software for Education"	Gold	https://doi.org/10.12753/2066-026X-16-056	21.04.2016
C18	C. Saitis and K. Kalimeri	Identifying Urban Mobility Challenges for the Visually Impaired with Mobile Monitoring of Multimodal Biosignals.	International Conference on Universal Access in Human-Computer Interaction	Not Open Access	https://doi.org/10.1007/978-3-319-40238-3_59	06.06.2016
C19	H. Nagy, G. Wersényi	Evaluation of Response Times on a Touch Screen Using Stereo Panned Speech Command Auditory Feedback	Proc. of. 18th International Conference, SPECOM 2016	Not Open Access	https://link.springer.com/chapter/10.1007/978-3-319-43958-7_33	13.08.2016

C20	S. Spagnol, C. Saitis, M. Bujacz, O. Johannesson, K. Kalimeri, A. Moldoveanu, A. Kristjansson and R. Unnthorsson	Model-based obstacle sonification for the navigation of visually impaired persons	Proceedings of the 19th International Conference on Digital Audio Effects (DAFx-16)	Gold	http://ant-s4.unibw-hamburg.de/dafx/paper-archive/2016/dafxpapers/43-DAFx-16_paper_25-PN.pdf	05.09.2016
C21	S. Spagnol, C. Saitis, K. Kalimeri, O. Johannesson and R. Unnthorsson	Obstacle sonification as a navigation aid for the visually impaired	XXI Colloquium on Music Informatics (XXI CIM)	Not Applicable	https://www.researchgate.net/profile/Simone_Spagnol/publication/311276070_Sonificazione_di_ostacoli_come_ausilio_alla_deambulazione_di_non_vedenti/links/587b90b808ae9275d4e0041f/Sonificazione-di-ostacoli-come-ausilio-alla-deambulazione-di-non-vedenti.pdf	28.09.2016
C22	S. Spagnol, S. Galesso and F. Avanzini	Estimation of spectral HRTF features for 3D audio rendering with non-linear anthropometric models	XXI Colloquium on Music Informatics (XXI CIM)	Not Applicable	https://www.researchgate.net/publication/311275975_Stima_di_feature_spettrali_di_HRTF_mediante_modelli_antropometrici_non_lineari_per_la_resa_di_audio_3D	28.09.2016
C23	A. Alexandrescu, A. Stan, N.-A. Botezatu, S. Caraiman	Real-time inter-process communication in heterogeneous programming environments	2016 20th International Conference on System Theory, Control and Computing (ICSTCC)	Green	https://doi.org/10.1109/ICSTCC.2016.7790679	13.10.2016
C24	A. Burlacu, A. Cohal, S. Caraiman, D. Condurache	Iterative closest point problem: A tensorial approach to finding the initial guess	2016 20th International Conference on System Theory, Control and Computing (ICSTCC)	Green	https://doi.org/10.1109/ICSTCC.2016.7790716	13.10.2016

C25	A. Burlacu, S. Bostaca, I. Hector, P. Herghelegiu, G. Ivanica, A. Moldoveanu, S. Caraiman	Obstacle detection in stereo sequences using multiple representations of the disparity map	2016 20th International Conference on System Theory, Control and Computing (ICSTCC)	Green	https://doi.org/10.1109/ICSTCC.2016.7790775	13.10.2016
C26	P. Herghelegiu, A. Burlacu, S. Caraiman	Robust ground plane detection and tracking in stereo sequences using camera orientation	2016 20th International Conference on System Theory, Control and Computing (ICSTCC)	Green	https://doi.org/10.1109/ICSTCC.2016.7790717	13.10.2016
C27	Á. Csapó, K. Árni, H. Nagy, G. Wersényi	Evaluation of Human-Myo Gesture Control Capabilities in Continuous Search and Select Operations	Proceedings of 7th IEEE Conference on Cognitive Infocommunications	Not Open Access	https://doi.org/10.1109/CogInfoCom.2016.7804585	18.10.2016
C28	K. Kalimeri and C. Saitis	Exploring multimodal biosignal features for stress detection during indoor mobility	Proceedings of the 18th ACM International Conference on Multimodal Interaction	Not Open Access	https://doi.org/10.1145/2993148.2993159	31.10.2016
C29	I.-C. Stanica, M.-I. Dascalu, A. Moldoveanu and F. Moldoveanu	Le Traitement Des Phobies Par La Réalité Virtuelle	Proceedings of the 28th International Business Information Management Association Conference	Not Open Access	http://doi.org/10.5171/2017.155350	10.11.2016
C30	L. Petrescu, A. Morar, F. Moldovean and A. Moldoveanu	Kinect depth inpainting in real time	2016 39th International Conference on Telecommunications and Signal Processing (TSP)	Green	https://doi.org/10.1109/TSP.2016.7760974	01.12.2016
C31	P. Skulimowski, M. Owczarek, M. Bujacz and P. Strumillo	Interactive sonification of the U-disparity maps of 3D scenes	Proceedings of ISon 2016, 5th Interactive Sonification Workshop, CITEC	Gold	http://interactive-sonification.org/ISon2016/proceedings/ISon2016_full_proceedings.pdf	16.12.2016
C32	D. Papuc, O. Bălan, M.-I. Dascălu, A. Moldoveanu, A. Morar	Brain Activation and Cognitive Load during EEG Measured Creativity Tasks Accompanied by Relaxation Music	Proceedings of the International Conference on Computer-Human Interaction Research and Applications	Green	https://doi.org/10.5220/0006511201560162	02.01.2017
C33	C. Nagy and G. Wersényi	Contrasting the Effectiveness of Controlled Experiments with Crowdsourced Data in the Evaluation of Auditory Reaction Times	Proceedings of IEEE CogInfoCom	Not Open Access	https://doi.org/10.1109/CogInfoCom.2016.	05.01.2017

					7804586	
C34	A. Dragos B. Moldoveanu, S. Ivascu, I. Stanica , M.-I. Dascalu, R. Lupu, G. Ivanica, O. Balan, S. Caraiman, F. Ungureanu, F. Moldoveanu and A. Morar	Mastering an Advanced Sensory Substitution Device for Visually Impaired through Innovative Virtual Training	2017 IEEE 7th International Conference on Consumer Electronics	Green	https://doi.org/10.1109/ICCE-Berlin.2017.8210608	11.01.2017
C35	A. Moldoveanu, B. Taloi, O. Balan, I. Stanica, D. Flamaropol, M.-I. Dascalu, F. Moldoveanu and I. Mocanu	Virtual Mini-Games - a Serious Learning Tool for Sensory Substitution Devices	EDULEARN17 Proceedings	Green	https://doi.org/10.21125/edulearn.2017.1376	01.03.2017
C36	H. Nagy, Á. Csapó and G. Wersényi	Audio-based mobile applications for Android using multisensory feedback in assistive technology	Proceedings of DAGA17	Not Open Access	https://www.dega-akustik.de/fileadmin/dega-akustik.de/publikationen/DAGA/DAGA_17_Programm.pdf	09.03.2017
C37	V. E. Dinu, D. Papuc, A. Gheorghiu, M.-I. Dascalu, A. Moldoveanu and F. Moldoveanu	Biometric Data in Learning Analytics: a Survey on Existing Applications	Proceedings of The 13th International Scientific Conference eLearning and Software for Education	Gold	https://doi.org/10.12753/2066-026X-17-151	28.04.2017
C38	C. Cosma, O. Bălan, A. Moldoveanu, A. Morar, F. Moldoveanu and C. Taslitchi	Treating acrophobia with the help of virtual reality	The 13th International Scientific Conference eLearning and Software for Education	Gold	http://proceedings.elseconference.eu/index.php?r=site/index&year=2017&index=papers&vol=25&paper=4f5df232be943b67a8ad87b777dce3e0	28.04.2017
C39	A. Csapo, S. Spagnol, M. Herrera Martinez, M. Bujacz, M. Janeczek, G. Ivanica, G. Wersenyi, A. Moldoveanu and R. Unnthorsson	Usability and Effectiveness of Auditory Sensory Substitution Models for the Visually Impaired	142nd AES Convention	Gold	https://hdl.handle.net/20.500.11815/715	11.05.2017

C40	Wersényi, György; Répás, József	Comparison of HRTFs from a Dummy-Head Equipped with Hair, Cap, and Glasses in a Virtual Audio Listening Task over Equalized Headphones	142nd AES Convention	Not Open Access	http://www.aes.org/e-lib/browse.cfm?elib=18642	23.05.2017
C41	H. Nagy and G. Wersényi	Evaluation of Training to Improve Auditory Memory Capabilities on a Mobile Device Based on a Serious Game Application	142nd AES Convention	Not Open Access	http://www.aes.org/e-lib/browse.cfm?elib=18581	23.05.2017
C42	K. Matusiak, P. Skulimowski, P. Strumillo	Improving matching performance of the keypoints in images of 3D scenes by using depth information	Proceedings of the 24th International Conference on Systems, Signals and Image Processing (IWSSIP)	Not Open Access	https://doi.org/10.1109/IWSSIP.2017.7965571	24.05.2017
C43	F. Ungureanu, R. G. Lupu, S. Caraiman and A. Stan	A Framework to Assess Cortical Activity of Visually Impaired Persons during Training with a Sensory Substitution Device	2017 21st International Conference on Control Systems and Computer Science (CSCS)	Not Open Access	https://doi.org/10.1109/CSCS.2017.34	31.05.2017
C44	A. Ciobanu, A. Morar, F. Moldoveanu, L. Petrescu, O. Ferche and A. Moldoveanu	Real-Time Indoor Staircase Detection on Mobile Devices	2017 21st International Conference on Control Systems and Computer Science (CSCS)	Green	https://doi.org/10.1109/CSCS.2017.46	31.05.2017
C45	A. Dragos B. Moldoveanu, I. Stanica, M.-I. Dascalu, C. N. Bodea, D. Flamaropol, F. Moldoveanu, B. Taloi and R. Unnthorsson	Virtual Environments For Training Visually Impaired For A Sensory Substitution Device	Zooming Innovation in Consumer Electronics International Conference (ZINC)	Green	https://doi.org/10.1109/ZINC.2017.7968654	01.06.2017
C46	M. Dascalu, A. Moldoveanu, O. Balan, R. Gabriel Lupu, F. Ungureanu and S. Caraiman	Usability Assessment of Assistive Technology for Blind and Visually Impaired	2017 E-Health and Bioengineering Conference (EHB)	Not Open Access	https://doi.org/10.1109/EHB.2017.7995476	24.06.2017
C47	M. Owczarek, P. Skulimowski and P. Strumiłło	A mobile system for interactive sonification of 3D scenes from “U-disparity” representation	XVI Krajowa Konferencja Elektroniki	Green	https://www.researchgate.net/publication/316551490_A_mobile_system_for_interactive_sonification_of_3D_scenes_from_U-disparity_representation	30.06.2017

C48	R. Tăerel, I. Mocanu, O. Bălan, A. Moldoveanu, Anca Morar	Active gaming to promote physical activity for elderly people	9th International Conference on Education and New Learning Technologies	Green	https://doi.org/10.21125/edulearn.2017.1378	05.07.2017
C49	A. Morar, F. Moldoveanu, L. Petrescu, O. Balan and A. Moldoveanu	Time-consistent segmentation of indoor depth video frames	2017 40th International Conference on Telecommunications and Signal Processing (TSP)	Green	https://doi.org/10.1109/TSP.2017.8076072	07.07.2017
C50	P. Skulimowski, M. Owczarek and P. Strumillo	Door detection in images of 3D scenes in an electronic travel aid for the blind	10th International Symposium on Image and Signal Processing and Analysis	Not Open Access	https://doi.org/10.1109/ISPA.2017.8073593	20.09.2017
C51	A. Morar, F. Moldoveanu, A. Moldoveanu, O. Balan and V. Asavei	GPU Accelerated 2D and 3D Image Processing	Proceedings of the 2017 Federated Conference on Computer Science and Information Systems	Green	https://doi.org/10.15439/2017F265	24.09.2017
C52	A. Morar, F. Moldoveanu, L. Petrescu and A. Moldoveanu	Real Time Indoor 3D Pipeline for an Advanced Sensory Substitution Device	Image Analysis and Processing - ICIAP 2017	Green	https://doi.org/10.1007/978-3-319-68548-9_62	13.10.2017
C53	S. Spagnol, S. Baldan and R. Unnthorsson	Auditory depth map representations with a sensory substitution scheme based on synthetic fluid sounds	2017 IEEE 19th International Workshop on Multimedia Signal Processing (MMSP)	Not Open Access	https://doi.org/10.1109/MMSP.2017.8122220	18.10.2017
C54	N. Botezatu, S. Caraiman, D. Rzeszotarski and P. Strumillo	Development of a versatile assistive system for the visually impaired based on sensor fusion	2017 21st International Conference on System Theory, Control and Computing (ICSTCC)	Green	https://doi.org/10.1109/ICSTCC.2017.8107091	19.10.2017
C55	A. Burlacu, A. Baciu, V. I. Manta and S. Caraiman	Ground geometry assessment in complex stereo vision based applications	Proc. of the 21 st Int. Conf. on System Theory, Control and Computing	Green	https://doi.org/10.1109/ICSTCC.2017.8107094	19.10.2017
C56	P. Herghelegiu, A. Burlacu and S. Caraiman	Negative obstacle detection for wearable assistive devices for visually impaired	Proc. of the 21 st Int. Conf. on System Theory, Control and Computing	Green	https://doi.org/10.1109/ICSTCC.2017.8107095	19.10.2017
C57	O. Balan, A. Moldoveanu, F. Moldoveanu, A. Morar and S. Ivascu	Perceptual feedback training for improving spatial acuity and resolving front-back confusion errors in virtual auditory environments	2017 40th International Conference on Telecommunications and Signal	Green	https://doi.org/10.1109/TSP.2017.8075999	23.10.2017

			Processing (TSP)			
C58	S. Caraiman, A. Morar, M. Owczarek, A. Burlacu, D. Rzeszotarski, N. Botezatu, P. Herghelegiu, F. Moldoveanu, P. Strumillo and A. Moldoveanu	Computer Vision for the Visually Impaired: the Sound of Vision System	2017 IEEE International Conference on Computer Vision Workshops (ICCVW)	Gold	https://doi.org/10.1109/ICCVW.2017.175	28.10.2017
C59	M. Janeczek, P. Skulimowski, M. Owczarek and P. Strumillo	Adaptive edge-based stereo block matching algorithm for a mobile Graphics Processing Unit	2017 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA)	Not Open Access	https://doi.org/10.23919/SPA.2017.8166864	07.12.2017

Notably, the latest and strongest results of the projects, achieved during last months of 2017, are being prepared for publication and will be submitted to journals during the first part of 2018.

List of dissemination and communication activities

This section provides a summary of the dissemination and communication activities conducted during project implementation. For each activity, we present details such as: name, date, location, participating partners, the number of persons participating to the event (who have thus come in contact with various information about the Sound of Vision project), as well as the attendant profile.

Activity	Date	Location	Partner	Attendance	Attendant profile
Engineering Day	2015.04.10	University of Iceland	UoI	250	Students, general public
Federated Conference on Computer Science and Information Systems	2015.0913	Lodz, Poland	TUL	300	Scientific community
European Researcher's Night	2015.09.25	Széchenyi István University	SZE	100	Local community, grown-ups
White Cane Safety Day	2015.10.15	Győr, Hungary	SZE	30	Children, young adults, parents
Science Day	2015.10.31	University of Iceland	UoI	3500	Children, young adults, parents
Special Conference Dedicated to Innovation	2015.11.12	University of Iceland, School of Health and Science	UoI	N/A	Students, general public
Workshop for innovation and technique in welfare	2015.11.18	Icelandic Ministry of Welfare	UoI	50	Welfare services employees
Scientific Lecture for the elderly	2015.11.23	Széchenyi István University	SZE	1000	Local community, the elderly
DAFx-15 Conference	2015.12.2	Trondheim, Norway	UoI	100	Scientific community
Presentation of SoV for the local blind community	2015.12.2-5	Leipzig, Germany	SZE	20	Local blind adults
Local newspaper article presenting the SOV project	2015.12.28	Iasi, Romania	TUI	N/A	General public
Demonstration of Sound Localization	2016.01.15	Reykjavík, Iceland	UoI	25	Academy of Arts students & engineering students
Interactive demonstration for children and young adults	2016.01.16	Széchenyi István University	SZE	30	Children, young adults, parents
National Job Orientation Day and Industrial Fare Zalaegerszeg	2016.03.03	Zalaegersze, Hungary	SZE	2000	Children, young adults, industrial partners

Krakow Integration Days	2016.04.19	Krakow, Poland	FIRR	N/A	Students, people with visual impairments, caretakers
nextEHealth 2016	2016.04.21	Bucharest, Romania	UPB	N/A	Authorities, researchers, practitioners
2nd Healthy Ageing Research Centre (HARC) Conference on Translational Research in Healthy Ageing	2016.05.13	Lodz	TUL	200	Scientific community, engineers and medical personnel
Prototype presentation at IMC 2016	2016.06.29	Dublin, Ireland	UoI	N/A	Scientific community
15th International Conference on Computers Helping People with Special Needs	2016.07.14	University of Linz, Austria	TUL	N/A	Scientific community
HCI International 2016	2016.07.21	Toronto, Canada	ISI	3500	Scientific community
Contest for the blind, organized by the Romanian Association for the Visually Impaired	2016.09.?	Iasi, Romania	TUI	30	Local blind community, adults
European Researcher's Night	2016.09.30	Gyor, Hungary	SZE	N/A	Local community, grown-ups
DAFx-16 Conference	2016.09.08	Brno, Czech Republic	UoI	100	Scientific community
ICT Proposers' Day 2016	2016.09.16	Bratislava	UPB	250	Researchers in eHealth
21st CIM	2016.10.01	Cagliari, Italy	UoI	N/A	Scientific community
EEG Theory and Applications workshop	2016.10.21	Reykjavík, Iceland	ISI	300	Scientific community
Science Day	2016.10.29	University of Iceland	UoI	3500	Children, young adults, parents
International Conference on Multimodal Interaction	2016.11.12	Tokyo, Japan	ISI	1000	Scientific community
Interactive Sonification Workshop (ISon 2016)	2016.12.15	Bielefeld University, Germany	TUL	100	Scientific community
News on Romanian national television channel presenting the SOV project	2017.04.13	Iasi, Romania	TUI	N/A	General public
142nd International AES Convention	2017.05.20 -23	Berlin, Germany	all	75	Audio scientific community
News story presenting the SOV project on a Romanian national television channel	2017.05.24	Iasi, Romania	TUI	N/A	General public
Keynote at WearMMe (in conjunction with ICMR 2017)	2017.06.06	Bucharest, Romania	ISI	100	Scientific community

XVI Krajowa National Conference of Electronics	2017.06.08	Darlowko Wschodnie, Poland	TUL	100	Scientific community
Presentation at ENVITER	2017.09.28	Duren, Germany	UoI	N/A	Scientific community
10th International Symposium on Multimedia Applications and Processing (MMAP'17)	2017.09.03	Prague, Czech Republic	TUL	300	Scientific community
10th International Symposium on Image and Signal Processing and Analysis (ISPA 2017)	2017.09.19	Ljubljana, Slovenia	TUL	100	Scientific community
21st Conference SPA 2017	2017.09.21	Poznan, Poland	TUL	100	Scientific community
Sound of Vision — Result In Brief, CORDIS (Record no. 203292)	2017.02.27	Luxembourg, Luxembourg	UoI	>1million readers	General public, Scientific community
IEEE MMSP 2017 Conference	2017.10.16	Luton, UK	UoI	100	Scientific community
Invited session on Human Computer Interaction at ICSTCC'17	2017.10.20	Sinaia, Romania	TUI, UoI, TUL, UPB		Scientific community
"Equal opportunities - better future" Conference	2017.10.27	Lodz, Poland	TUL	100	Blind and visually impaired students, scientific community
ICCV'17 - International Conference on Computer Vision	2017.10.28	Venice, Italy	TUI	3000	Scientific community
Platinum Business Magazine, Research & Innovation	2017.11.01	Italy & European Union	ISI	>1million readers	Business and Entrepreneurs, distributed in Businesses around Europe
Project Dissemination Event	2017.11.27	Bucharest, Romania	IW	60	Target group representatives, authorities, policy makers, researchers
Lecture: "How to show the world to the visually impaired people?" at Children's University of Lodz	2017.11.04	Lodz, Poland	TUL	500	Children aged 8-12
Project Dissemination lecture and demo at the ERASMUS 30th anniversary day	2017.11.08	Leipzig, Germany	SZE	30	Students, researchers from Germany
H2020 InfoDay	2017.12.11	Lodz, Poland	TUL	200	University staff, PhDs, students
How soundscapes and vibrations are helping blind people see the world, Horizon magazine	2017.12.12	EU	UoI	>1million readers	General public, Scientific community

ESTIMATION OF NUMBER OF PERSONS REACHED

In order to allow estimating the number of people reached using the communication activities undertaken during the project, we tracked all communication activities and recorded estimated attendant numbers and profile for all of them. The dissemination KPI table from the previous section illustrates that over 20.000 people were reached during offline project communication activities. For the purposes of estimation, we defined *direct recipients* as persons directly impacted by the project's main result - the Sound of Vision assistive device. We count these as the blind, visually impaired as well as their direct caregivers. *Indirect recipients* are people who do not benefit from the project directly, but who can further our mission by making it known via word of mouth or dissemination through electronic channels, such as social media.

The total number of people reached via our offline dissemination activities is around 21.000 people. In addition, we estimate that over 1 million persons had the opportunity of learning about the project from at least one of the news reports that appeared in national print or TV media, as the project had media appearances within all project countries. Of the people reached via offline activities, we estimate around 1.000 to be direct beneficiaries, with the rest of them being indirect beneficiaries. The project had also very good reach in the online medium, for which we cannot make accurate estimations.

Conclusions

SoV system is a wearable device, that perceives the environment through 3D scanning, both indoors and outdoors and in various illumination conditions, and that can convey to the visually impaired user a rich environmental representation, based on an original solution of combining audio and haptic stimulations. We therefore conclude that the main objective of the project has been successfully achieved.

Wearability was one of the most important aspects considered during the development of the SoV system. The emphasis on wearability sets the development of the SoV system apart when compared to other computer vision based sensory substitution devices for the visually impaired.
We conclude that the development of the ergonomic aspects of the SoV device was highly successful and that the SoV system is both comfortable and clearly conveys the intended information to users.

The main challenges associated with development of the 3D reconstruction, segmentation and classification algorithms emerged from the combination of three essential requirements for the SoV system: wearability, pervasiveness and real time operation. Wearability imposed major constraints on the 3D acquisition devices that could be integrated in the SoV headgear - especially the weight constraint on the headgear. Nonetheless, the consortium managed to successfully meet all 3D reconstruction and segmentation objectives. The final SoV prototype performs complex detections of many types of objects, in various environments (indoor, outdoor, various illumination conditions) using wearable hardware for acquiring the 3D information from the environment and fully and efficiently exploiting the processing power of the device.

The work on the development of the audio rendering system was highly complex and encompassed two important sub-objectives; The development of sound synthesis solutions that lead to very good sound localisation accuracy and the design of audio model able to encode rich information about the environment.

For the **development of the sound synthesis solution**, the consortium identified and developed the most suitable headphone-based solutions for spatial sound rendering. The main consideration was prevent blocking naturally occurring environmental sounds and to spatially render virtual sound sources. Localization tests results showed that good quality off-the-shelf and in-ear headphones are a valid alternative to reference headphones for horizontal localization. An advantage of using in-ear hear-through solution was the possibility to enable audio signals transmission through bluetooth (wireless) channel with minimal latency (units of milliseconds), improving the ergonomics and the aesthetics of the device (eliminating the non-comfortable use of cables).

For the **design of the audio models able to encode rich information about the environment**, the consortium explored various alternatives in rendering 3D information through sound signals and identifying and developing the most promising sonification solutions to be implemented in the prototype device of the SoV project. Test results showed superior performances of the developed sonification algorithms compared to state-of-the-art algorithms in terms of task accuracy as well as intuitiveness and pleasantness of the delivered sounds.

Importance and effectiveness of haptics. At the beginning of the project, haptics was regarded as a secondary channel for conveying information about the environment to the user. As the research and development continued it became apparent that the haptic modality was important for conveying important information that was not easily conveyed through audio. This led to the design of the haptic vest and subsequently the haptic belt. The haptic presentation has proved to be highly successful and an an essential addition to the rendering of the environment through the SOV device, a view typically shared by the end users who have tested the system.

Training. As part of its the SoV system's design, the consortium placed particular emphasis on training. The goal was for the SoV system to be usable and helpful to some extent even without advanced training. Yet, it is expected that a user's most effective adaptation to the system's audio and haptic environmental representations will require training procedures for users to become proficient in using the system. Based on usability test results and the study into the effects of training - both using our training procedures - we conclude that we have well-defined procedures for training - both in real-life training environments and in the special training mode

One of the main goals of Sound of Vision was to carry out **research on cognitive, affective and perception aspects** to support the design of the SOV system. While in the initial formulation of this objective the emphasis was put on monitoring of cortical activations, it soon became apparent that psychophysical tests of perceptual mechanisms would be best suited to supporting the design of the system (later the GA was amended to reflect this). The psychophysical studies on vibrotactile perception were used to improve the design of the haptic belt both in terms of the position and spacing of the tactors and in selecting tactor types. Moreover, psychophysical tests were employed in the usability evaluation of the three SoV prototypes and resulted in valuable feedback for the iterative improvement up to the Final System. In sum, we conclude that the design of the SOV device has benefitted from this research, in particular the psychophysical tests of vibrotactile sensitivity, since so far there has been little research into this.

The extensive final tests of the final SOV prototype were highly promising, boding well for continued development of the SOV system. Blind and visually impaired participants are able to use the system to navigate in difficult environments, in some cases reaching performance levels similar to their performance levels of the white cane after only a few hours of training, even though they have used the white cane for years or decades.

Hence, the SoV system has the potential to make a huge socio-economic impact. With the SoV system visually impaired persons will be able to dramatically increase their mobility and face-to-face interactions with other persons. This will lead to more active and healthier life-style which in turn will facilitate social integration, prevention of health issues (physical and mental) and improved general wellbeing. As a result, the society will benefit from less healthcare costs, increased workforce and increased productivity.

The project has to be considered a great success, achieving all its goals. In the end, test participants using the final prototype were able to move around in environments, with their performance improving strongly within only a few hours of training. Participants reported that the information about the environment was understandable and useful for mobility. Additionally, users reported that the device was relatively comfortable. Many participants, in particular the younger ones, reported that they would prefer to use the SOV system to aid with their perception and mobility, by itself or in conjunction with the white cane.

FURTHER RESOURCES

- Information about the project an up-to-date list of links to all published papers is available on the project's website: www.soundofvision.net
- Demonstration videos of visually impaired participants using the final prototype are available on the project's YouTube channel.