Training technology for auditory orientation by the persons with visual impairment

— Toward practical use in rehabilitation facilities —

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People with visual impairments require training to perceive their surroundings from ambient sounds. The author developed a system, introduced to rehabilitation facilities, that allows training to be conducted in a safe virtual environment. To realize this system, the author carried out fundamental research on the mechanism of auditory orientation; developed basic technologies to simulate 3-D sound; and designed hardware and software to calculate 3-D sound, as well as head position and direction. A training curriculum was also developed. The effectiveness of the training system was evaluated, and certified as being more effective than the existing real-environmental training system. However, some problems with calculating head position and direction must be addressed before this system can be completely introduced to rehabilitation facilities. While we are currently working to resolve this problem, the training system in its present state is being distributed as a simplified version to the people concerned since September, 2010, and is being actively used.

Keywords **:** Visual impairment, auditory orientation, rehabilitation, 3-D sound, position and direction measurement

1 Training in the past

It is essential for people who have lost their sight, due to injuries, disorders, or other reasons, to develop an ability to recognize their surroundings based on sound (auditory spatial orientation), instead of light, and improve their ability to walk and daily living skills. Auditory spatial orientation required by visually impaired people includes both "sound localization," the ability to identify the location of a sound-producing object such as a car, and "obstacle perception,[Term 1]" the ability to determine the position of an object that does not produce sound such as a wall or pillar, using reflected sound.

Practice to improve auditory spatial orientation currently implemented in education and rehabilitation settings for visually impaired people only focuses on training in which they are repeatedly tested for their ability to recognize their surroundings by listening to auditory information while actually walking in a real-life environment.[1] However, training in an actual environment with moving vehicles poses a risk to visually impaired people "who have just started undergoing training." It may also be very difficult for them to distinguish auditory clues required for auditory spatial orientation from a mixture of noises in the actual environment. Training in auditory spatial orientation should be conducted in a safe and structured manner to improve its safety and efficiency and shorten the rehabilitation period, instead of only emphasizing training to distinguish different sounds in the actual environment. In this context, a few studies were conducted in Japan and other countries to develop systems designed to help implement training in auditory spatial orientation in a structured manner.[2] Most of these training systems created virtual reality environments for auditory training, using acoustic technology. However, these systems were only designed to help conduct training in sound localization and not obstacle perception, and no findings of the studies were put into practical use.

On the other hand, during the period between 1998 and 2002, the authors developed a training method focusing only on basic training to improve obstacle perception, which was put into practice.[3] As people who have just started undergoing training have difficulty identifying an approach to learn obstacle perception, the training method, which involves creating a virtual environment using acoustic technology, aimed to help visually impaired people understand and learn it. However, the method does not cover training to improve sound localization, which suggests that there is no appropriate system for training in auditory spatial orientation.

In this context, I conducted research to develop a system for training in auditory spatial orientation, including sound localization and obstacle perception, and put it into practice. The present paper presents the results of a series of studies conducted to develop the system for auditory spatial orientation training.

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2 Constructive scenario required to develop the training system

As described in the previous chapter, currently, there is no method to implement training in auditory spatial orientation in a safe and structured manner, and people with visual impairment undergo training in a real-life environment to add to their experience of distinguishing different sounds. It is desirable that they receive training and learn in a safe, virtual environment. To conduct training in a structured manner, the level of difficulty of training materials should be changeable. The most realistic approach is the adoption of virtual reality technology, which can simulate factors associated with sounds to be learned in auditory spatial orientation training. However, to implement this training method, knowledge on the mechanism of auditory spatial orientation in terms of acoustics is required, and the use of virtual reality technology requires techniques to produce three-dimensional sound and monitor the movement of the heads of trainees.

To develop the training system, it is necessary to create a scenario by integrating elements of interdisciplinary studies in a structured manner, as described in previous paragraphs. To this end, I created the following scenario: clarify the mechanism of auditory spatial orientation, develop a training method based on the mechanism (which simulates safe, virtual training environment), seek ways to reduce costs, and introduce the method to rehabilitation and education settings for visually impaired people.

This scenario consists of the following elements:
1) Knowledge on the mechanism of auditory spatial orientation required by visually impaired people while walking (psychoacoustics)
2) Three-dimensional acoustic technology to simulate the above-mentioned mechanism (acoustic technology)
3) Hardware/software to conduct real-time calculations required for 3-D acoustics (signal processing technology)
4) Technology to monitor and record the position and direction of the head, used to create a virtual reality environment based on 3-D acoustic technology (sensor technology)
5) Training schedule implemented using the developed training system (rehabilitation science)

Figure 1 shows the principle of the training system. A trainer in charge of conducting training for visually impaired people first develops a training schedule, and then creates a training environment required to implement it. For example, “a training environment in which automobiles drive on roads” should be designed, if a trainee is to “develop the ability to recognize the position and direction of a road by listening to the sound of a vehicle passing on it.”

Following this, the training system simulates the stereophonic environment designed by the instructor for the trainee, using the 3-D acoustic technology, hardware, and software. It ensures that even trainees with little experience of undergoing the training can clearly hear and understand sound information, a part of the mechanism of the system, when the environment is simulated. The system allows trainees to feel as if they are in the actual environment, hear sounds coming from the surroundings more clearly than in the actual environment, and effectively learn the mechanism of auditory spatial orientation.

When the head of a trainee turns or moves in the training environment, changes in the position and direction will be identified by the system for monitoring them and conveyed to the 3-D acoustic system, and, based on this information, the sound images will be changed. When trainees move their heads in the training environment, they can experience changes in the sound similar to those in the real environment.

3 Solutions to problems in the development of a training system

3.1 Development of a prototype training system

A prototype training system was developed based on findings acquired by clarifying the mechanism of auditory spatial orientation required by visually impaired people while walking (Fig. 2).[8] Research and development were conducted in collaboration with the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities, with the support of a Grant-in-Aid for Scientific Research from the Ministry of Health, Labour and Welfare.

3.1.1 Development of training methods based on perception of obstacles

Between the 1990s and early 2000s, I conducted

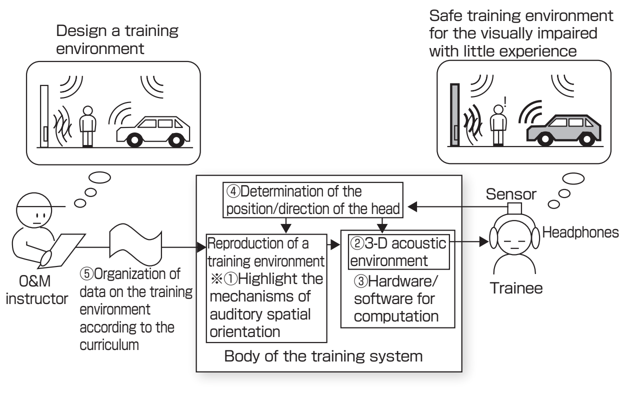

Fig. 1 Concept of the auditory spatial orientation training system

A trainer first develops a training schedule, and then creates a training environment required to implement it. Following this, the training system simulates the stereophonic environment for the trainee, using the 3-D acoustic technology, and ensures that even trainees with little experience in rehabilitation can clearly hear and understand sound information. The technology to determine the head position/direction moves the position of the sound image when the trainee moves or turns his/her head in the training environment. The trainee feels as if he/she is in the actual environment.

psychoacoustic research and experiments, involving human subjects, to examine the mechanisms of "obstacle perception" included in "auditory spatial orientation," which had not been clarified.[3]-[7] In the process of the study, it became clear that people involved in rehabilitation and education for visually impaired people had to rely on experience-based training methods because the mechanisms of obstacle perception had not been clarified, and that it was necessary to develop training methods based on the clarified mechanisms. The results suggested that visually impaired people used the following acoustic phenomena as "clues" in obstacle perception: changes in the image[4][5] and tone[6] of direct and reflected sounds, and decays[7] of sound due to sound insulation and diffraction. When these "clues" were simulated using acoustic technology, people who had developed obstacle perception skills felt as if specific objects were present.[3] Figure 3 shows an example of an examination of obstacle perception training. In this example, speakers positioned in front of and behind a person produced direct and reflected sounds similar to those heard in the actual environment, and the body movements were examined when the virtual walls approached the person. The subjects in the experiment, who had developed obstacle perception skills, involuntarily moved to avoid the virtual wall when it approached them. This demonstrates that factors associated with obstacle perception can be identified by simulating direct and reflected sounds using speakers. The finding is the basis for obstacle perception training in the system. Factors associated with obstacle perception are highlighted in the training system, so that even trainees with little experience of undergoing the training can clearly understand them. For example, fully-reflected sound was used (no decrease in the sound pressure level); sound was completely insulated when obstacles were placed; direct sound vertically striking the reflecting surface of an obstacle was used; and there was no noise, excluding direct and reflected sounds.

3.1.2 Technology to create a 3-D acoustic environment

As the auditory system of humans has a mechanism that allows them to perceive three-dimensionally-formed sounds, the training system adopted a technology that produces a variety of 3-D sounds based on this mechanism[9] and presents them to trainees wearing headphones. The technology assigns a sound image to a position in 3-D space by convolving the head-related transfer function (HRTF), which represents the acoustic transfer characteristics of the head, auricle, and ear canal, into signals transmitted by the original sound. It creates a 3-D virtual auditory environment for trainees wearing stereo headphones. However, the technology has a drawback: the position of the sound image produced in 3-D space varies depending on the person due to individual differences in the HRTF. Therefore, the technology cannot be used to accurately simulate an auditory environment unless calibration is conducted for each person. The training system developed based on the scenario should be used as an educational material to help trainees with little experience of undergoing this type of training learn the basics of auditory spatial orientation, and not for official training.

To create the above-mentioned 3-D acoustic environment, hardware and software designed for high-speed computing were needed that can convolve the HRTF and signals transmitted by the original sound on a real-time basis; therefore, sound effectors with integrated circuits for digital signal processing (DSP) were commonly used in the early 2000s. The prototype training system was operated by ten

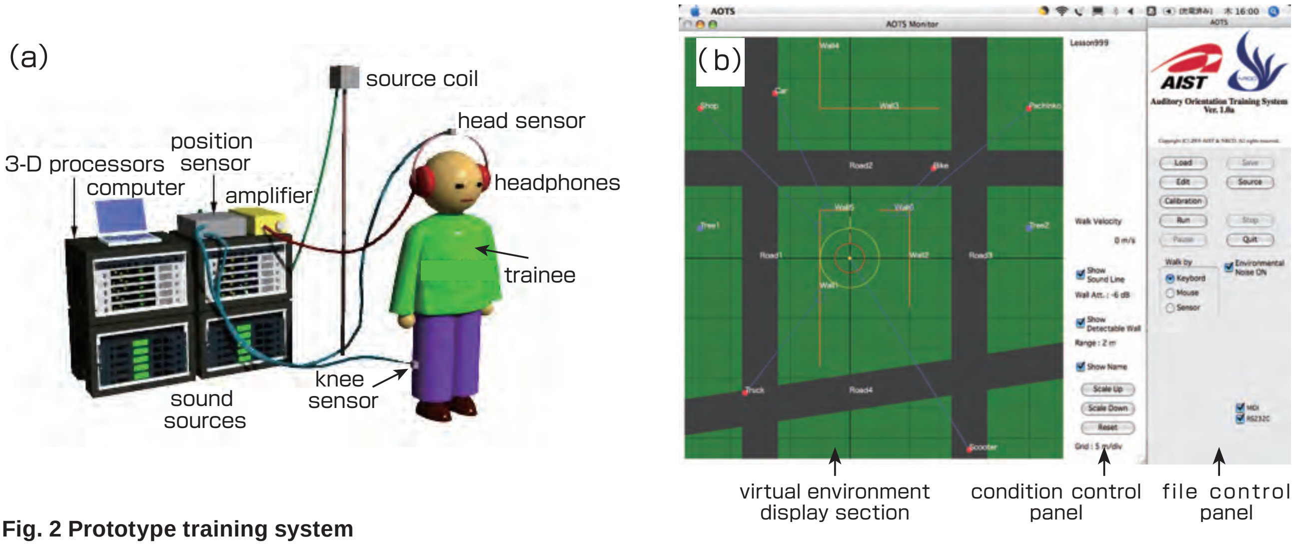

Fig. 2 Prototype training system
(a) Structure of the system
(b) Training environment displayed on the screen
Positions of the trainee (at the center of the circle), sound sources (such as cars, trucks, stores), walls, roads, and landmarks are displayed in the virtual environment display section on the left of the screen. The condition control panel in the center of the screen is for setting conditions regarding the virtual environment (e.g., with or without noise) and the display mode (e.g., enlarge and reduce). The file control panel on the right of the screen is for operating files regarding the virtual environment and starting/stopping its display.

commercially available 3-D sound effectors (RSS-10 by Roland) connected in parallel, equipped with dedicated DSP integrated circuits, to create a 3-D acoustic environment for ten sound sources.

3.1.3 Technology to identify the position and direction

In the development of the prototype training system, commercially available magnetic position sensors (3SPACE Fastrak, Polhemus) were adopted to monitor and record the position and direction of the head. The magnetic position sensor identifies the position and direction of an object with high accuracy; the sensor coil attached to an object detects a magnetic field generated by the source coil. Although its price is over one million yen, the sensor is used for research purposes, and readings can be obtained with an accuracy of 1 mm (position) and 1 degree (direction). As the position and direction were identified only within an approximately one-meter area, or the magnetic field was generated by the source coil, trainees could not walk in the actual environment. Therefore, they marched in place without moving forward in the training environment. The sensor coils were attached to both the head and knees of a trainee to detect stepping movements. Vertical movements of the knee detected by the knee sensor were determined as steps made by a trainee; the walking rate was determined according to the speed and range of vertical movements.

3.1.4 Training schedule

In the training schedule, four components were positioned in the training environment: 1) sound sources, 2) walls, 3) roads, and 4) landmarks. Point sources of sound (1) were used as components to represent sound-producing objects in the training environment such as automobiles and stores. Therefore, "sound sources" could be used for training to identify their positions. In addition to this, environmental sound was produced by four sources in the training environment, which were equivalent to north, south, east, and west, so that trainees could feel as if they were in a real outdoor environment. (2) "Walls," which do not produce any sound, were used to reflect and insulate sound produced by the above-mentioned sources. "Walls" were prepared to be used for obstacle perception training. Although the third and fourth elements, "roads" and "landmarks," had no acoustic function, they were added so that an instructor designing the training environment could use them to create an image of streets as real as possible. Finally, I asked an instructor from the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities, to create a common environment to be used for walking training, using the four above-mentioned components. As the prototype training system is equipped with an interface that allows users to freely edit a training environment, the instructor customized the environment using it.

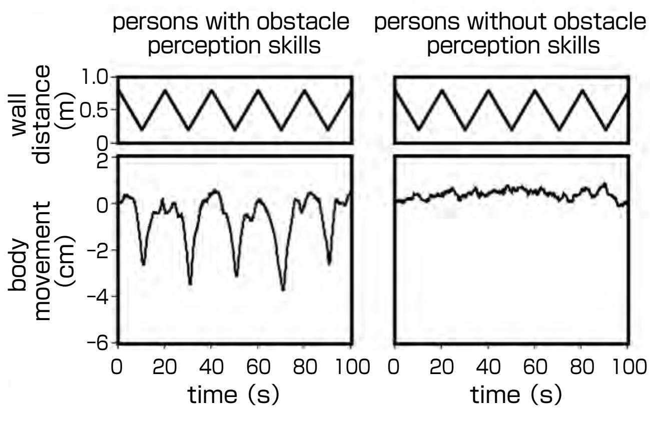

Fig. 3 An example of validation of obstacle perception training
The body movement of the trainee when he/she thinks he/she is approaching a virtual wall created by reflected sounds (left: person who has acquired obstacle perception orientation, right: person who has not). The upper figures show the movement of the wall. Persons who had acquired obstacle perception involuntarily moved to avoid the virtual wall when it approached them.

3.2 Effectiveness of the training system

In 2005, when the prototype training system was completed, an experiment to examine its effectiveness was conducted in the National Rehabilitation Center for Persons with Disabilities.[10]

To simulate visually impaired people with no or little experience of rehabilitation, the researcher recruited 30 sighted people without knowledge of auditory spatial orientation, rather than those with visual impairment, and asked them to wear eye masks and participate in the experiment. The subjects were divided into three groups, each consisting of ten people. The first group underwent no training, and the second group underwent training conducted using the present system. The third group underwent conventional training. Forty-minute training sessions were conducted by a skilled walking trainer for five days. Assessment items as the effects of the training were reduction of the following: (a) veering[Term 2] while walking (unable to walk in a straight line), and (b) stress while walking (psychological burden experienced by being unable to see while walking). Two objective assessment tests from the viewpoints of the subjects were also conducted: (c) skill assessment[Term 3] (consisting of 50 self-assessment items on walking skills) and (d) assessment on anxiety[Term 3] (consisting of 50 self-assessment items on anxiety while walking). In Assessment (a), the trajectory recorded by GPS and the walking routes were compared to calculate the maximum and mean differences. In Assessment (b), the stress pulse ratio (SPR), rate of increase in the heart rate, was calculated. In Assessments (c) and (d), surveys on walking skills and anxiety while walking were conducted using questionnaires consisting of 50 items each developed by the National Rehabilitation Center for Persons with Disabilities.

Regarding (b), (c), and (d), there were no significant differences in the effects of training between Group II (prototype training system) and Group III (actual environment), although the effects for the two groups were significantly higher compared to Group I (no training) (Fig. 4 (b), (c), and (d)). This suggests that the effects of training conducted in safe virtual training environments were comparable to those of training implemented in the real environment associated with risks. Regarding (a), the effects of training conducted under the present training system were significantly higher, compared to the other two groups. This suggests that walking training using sound as clues conducted in the virtual environment was more effective than training in the actual environment (Fig. 4 (a)). These results support the effectiveness of the training system developed by the researcher.

The training system was patented in 2010 in Japan.[11]

3.3 Obstacles to the practical use of the training system (problems)

The efficacy of the developed prototype training system has been established in the preceding paragraphs. However, some challenges remained to be overcome "to introduce the system to rehabilitation settings for visually impaired people," the final part of the scenario.

The first obstacle was the cost of the system. The price of the effector equipped with dedicated DSP integrated circuits to simulate a 3-D acoustic environment was approximately 300,000 yen at that time, and the prototype training system used ten effectors for ten sound sources; the cost of these components alone amounted to approximately three million yen. The magnetic sensors used to identify the position and direction of the head were over one million yen, and the total cost of the system, including equipment to record the original sound and controlling computers, was approximately five million yen. Different from medical settings, "sections involved in welfare services," including rehabilitation for visually impaired people, cannot afford to purchase expensive systems. Efforts to reduce the cost of the system were essential to introduce it to welfare settings.

Furthermore, the body of the system was too large to be carried. Some visually impaired people attend training facilities to undergo rehabilitation, while others receive "home-visit-based training" or rehabilitation at home with trainers. As the system, being too heavy to be carried, could not be used for home-visit-based training, it was necessary to develop a downsized system.

As explained in the preceding paragraphs, the magnetic

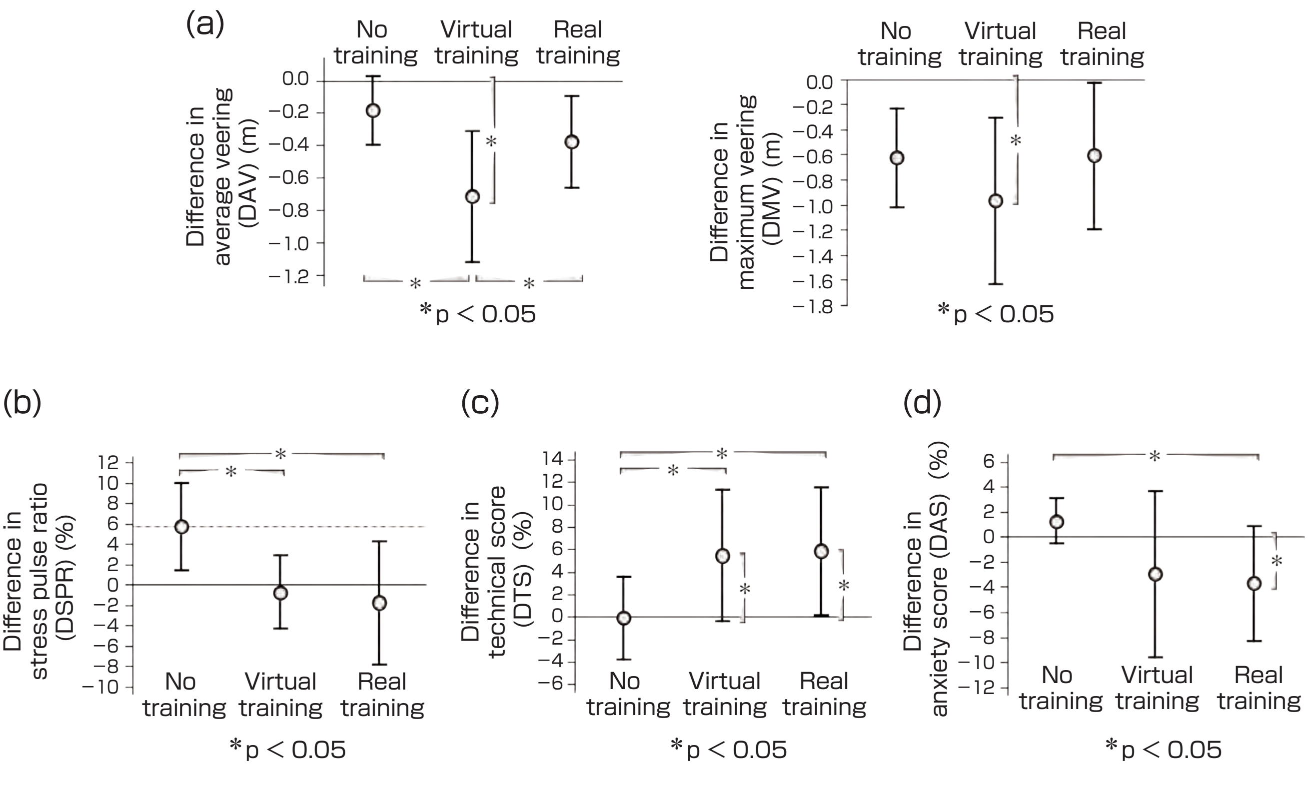

Fig. 4 Results of an experiment to assess the training system (Seki *et al*., 2011[10])

(a) Changes in veering while walking as a result of training (left: mean value, right: maximum value). The smaller the value on the vertical axis, the higher the veering-reducing effect of training.

(b) Changes in stress while walking as a result of training. The smaller the value on the vertical axis, the higher the stress-reducing effect of training.

(c) Changes in skills as a result of training. The larger the value on the vertical axis, the greater the effect of training to improve skills.

(d) Changes in anxiety as a result of training. The smaller the value on the vertical axis, the greater the anxiety-reducing effect of training.

positional/directional sensor used in the prototype training system only reacts to an object placed within approximately one meter of it, trainees were asked to march in place without moving forward. Therefore, trainees in this experiment did not feel that they accelerated, a feeling they would have experienced while actually walking. It was necessary to expand the area covered by the sensor so that trainees could actually walk and move forward.

New approaches were implemented to address the above-mentioned difficulties and to put the system into practical use.

3.4 Reexamination to put the training system into practical use

The development of a practical training system was initiated in 2006, including reexaminations of some elements of the scenario. Research and development were conducted in collaboration with the Research Institute of Electrical Communication, Tohoku University, Tohoku Fukushi University, and other research institutions with the support of research grants from Tohoku University Research Institute of Electrical Communication (Collaborative Project Research) and the Okawa Foundation for Information and Telecommunications.

Regarding hardware/software employed in this type of system, dedicated DSP integrated circuits were mainly used in the early 2000s when I developed the prototype training system. However, due to the advancement of computer technology, even the central processing unit (CPU) of a general-purpose computer can now perform convolution integral calculations, or convolve the head-related transfer function (HRTF) on a real-time basis.[12] Since most rehabilitation facilities for visually impaired people had already adopted general-purpose PCs as a tool to ensure information accessibility, these institutions did not have to purchase new equipment if general-purpose PCs could be used for calculations. Moreover, the body of the system, which was too large and heavy to be carried, could be downsized using laptop PCs. For a practical training system, it was decided to introduce SiFASo (simulative environment for 3-D acoustic software) [13] for general-purpose PCs, developed by a research group of Tohoku University Research Institute of Electrical Communication. SiFASo has an excellent capability to reproduce sound, although the number of sound sources that can be produced depends on the processing speed of the CPU. Up to eight sounds can be reproduced using Pentium IV 2 GHz or other CPUs of a similar class, and the present mainstream CPUs of Core 2 Duo 2 GHz class are expected to produce an even larger number of sound sources. This means that the new system was expected to deliver the same level of performance as the prototype training system.

As a technology to identify the position and direction of the head, the introduction of commercially available, or mass-produced, GPS equipment and MEMS gyro acceleration sensors into the practical training system was decided to replace expensive and high-precision magnetic sensors that covered narrow areas. As these were low-priced costing thousands to tens of thousands of yen, they could reduce financial burdens. Furthermore, since there were no restrictions on the area covered by the sensor, trainees would not have to march in place, as they did with the prototype training system, and the new system would allow them to actually walk in the real environment. The new system helps conduct safe training and allows trainees to walk around a large area without buildings, such as the grounds of a school for the visually impaired, while feeling that they are accelerating the walking speed. However, commercially available, low-priced sensors, which cover wide areas, are usually inaccurate, often produce noise, and measurements using them include significant errors. Therefore, to adopt these sensors into the training system, it is necessary to introduce new technologies to improve their accuracy. Currently, methods for reducing noise-induced errors are being considered.[14] It has been suggested that a Kalman filter-based algorithm is effective for reducing noise-induced errors, and that low-priced sensors covering wide areas may be adopted into the system.

4 A simplified version of the training system

A practical training system was developed based on the above-mentioned reexamination results (Fig. 5).

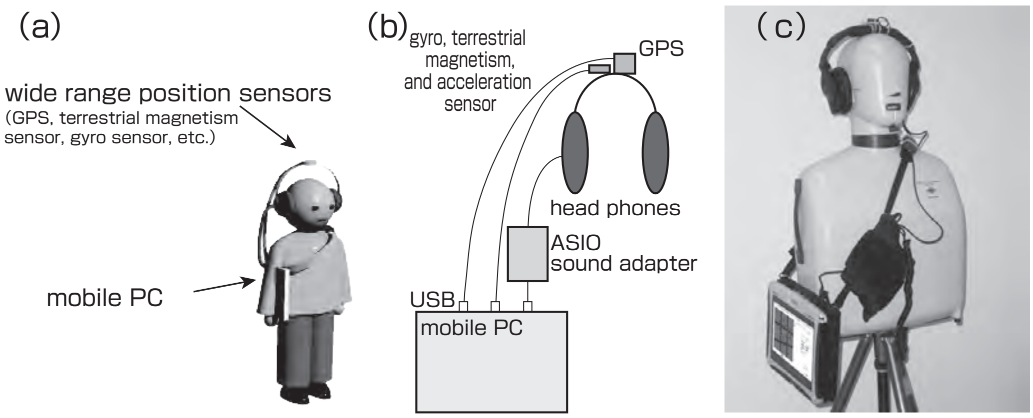

Fig. 5 Practical training system
(a) Structure of the system
(b) Diagram of components (blocks)
(c) A picture of a model with the equipment

The practical training system consists of a laptop PC, headphone set (and a sound adapter), and position/direction sensors. The small and light body of the system (the weight of the PC and headphone set together is approximately 3 kg) allows trainees to walk while carrying it.

The simplified version of the practical training system is currently available, although the accuracy of the sensors for identifying the position and direction of the head has not yet been improved. The simplified version, which has not adopted GPS equipment and gyro acceleration sensors, allows users (e.g. instructors) to operate the image of a trainee displayed on the PC screen while the trainee is moving around in the training environment (Fig. 6). Although the simplified version still has a drawback that trainees cannot walk around in a real environment, a problem also shared by the prototype training system, people involved in rehabilitation can afford to introduce the system because of its low price and small size. The table shows a comparison of the prototype and practical training systems and the simplified version. In September 2010, we started to distribute the simplified version of software free of charge (AIST Intellectual Property Management Number: H22PRO1182) to the visually impaired and relevant people in Japan and other countries to obtain feedback for improvement. The software system consists of the core 3-D acoustic technology and other software to determine the position and direction of the head, to generate data on the training environment and reproduce it, and to control the user interface for trainers. In 2010, the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities introduced the software system to its instructor training course. The introduction of the training system to the instructor training course has increased efficiency in teaching, including simulating a variety of walking environments in the classroom.

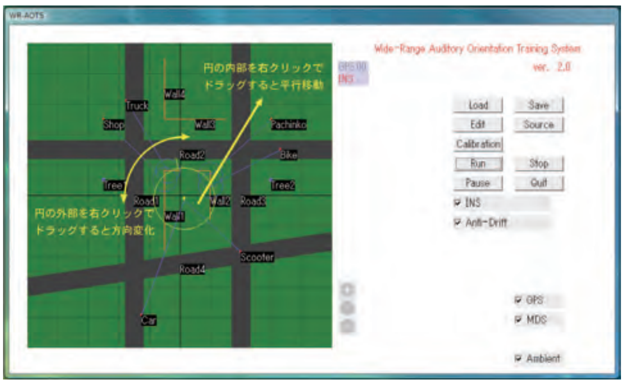

Fig. 6 User interface of the simplified version of the practical training system
Instead of a sensor to identify the position and direction of the head, the operator can use the mouse to move the image of a trainee around in the training environment.
- Right-click in the circle and drag the image in the direction you want it to move
- Right-click outside the circle and drag the image in the direction you want it to turn

Table. A comparison of the prototype and practical training systems and simplified version

	Prototype training system	Practical training system	Simplified version of the practical training system
Price (excluding that of the PC)	Five million yen	Tens of thousands of yen	Tens of thousands of yen
Size	Large (four times the size of the 0.6 m (H) x 0.6 m (W) x 0.6 m (D) rack)	Small (Laptop PC + headphones)	Small (Laptop PC + headphones)
Portability	Stationary-type	Portable	Portable
Determination of the position /direction of the head	High accuracy (direction: 1 degree, distance: 1 mm)	Low accuracy (direction: 10 degrees, distance: several dozen centimeters to a few meters)	Replaced by a mouse
	Narrow range (with an approximately one-meter radius)	Wide range (unlimited)	
	Expensive (one million yen or higher)	Inexpensive (a few thousand to tens of thousands of yen)	

5 Summary and future development

The present paper has described the development of a system for auditory spatial orientation training and research to put it into practical use.

To develop the training system, it was necessary to integrate the following elements of interdisciplinary studies in a structured manner: 1) mechanisms of auditory spatial orientation, 2) 3-D acoustic technology to reproduce the mechanisms, 3) hardware/software for computation regarding 3-D acoustic environments, 4) technology to determine the position/direction of the head, and 5) a training schedule. Therefore, research and development were conducted according to the following scenario: clarify the mechanism of auditory spatial orientation, develop a training method based on the mechanism (which simulates a safe, virtual training environment), seek ways to reduce costs, and introduce the method to rehabilitation and education settings for visually impaired people.

In the 1990s, I started a study to clarify the mechanisms of obstacle perception in humans. In 2003, I considered the introduction of 3-D acoustic technology, hardware and software to reproduce a 3-D acoustic environment, technology to determine the position and direction of the head of a trainee, and a training curriculum including training procedures, and a prototype training system was developed in 2005. Although the results of experiments supported the validity of the training system, some obstacles to its practical use still remained to be overcome. Following reexaminations of hardware/software to reproduce 3-D acoustic environments and technology to determine the position/direction of the head, the practical training system was completed. It is necessary to establish the validity of the system in practical settings as soon as possible. Since 2010, the simplified version of software has been distributed to the visually impaired and relevant people and used in courses to train instructors.

I plan to improve the technology to determine the position/direction of the head and publish a paper on the revised version. As the controller of a commercially available home video game device was considered to be best suited for the sensor to determine the position/direction of the head in terms of the balance between the cost and positioning performance, I am hoping to publish a paper on a revised version of the system adopting an algorithm to reduce errors in measurements obtained from the sensor. I am also planning activities to further promote the training system. I will distribute the training system software free of charge through the website of the National Institute of Advanced Industrial Science and Technology (AIST), and ask academic organizations involved with visual impairment to distribute it. I also plan to teach training methods using the newly developed training system to people on instructor training courses, and develop a system to assess the training results.

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Terminology

Term 1. Obstacle perception: An auditory ability to identify objects that do not produce sound, including walls and pillars, using clues such as reflected sound from objects, sound insulation, and their changes. An important environmental perception for the visually impaired.

Term 2. Veering: A visually impaired person's behavior of walking off a predetermined route

Term 3. Assessment of skills and anxiety while walking: Assessment using a questionnaire consisting of 50 items developed by the National Rehabilitation Center for Persons with Disabilities. Question items for assessment of skills include, "You can walk without veering much," "You can walk while touching the side of a wall or building," and "You can walk in parallel with automobiles running on the road." Question items for assessment of anxiety include, "You worry about being hit by a car," "You feel uneasy when walking in an unfamiliar place," and "You worry about hitting a sign board."

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Author

Yoshikazu SEKI

Complete the doctorate course at the Graduate School of Engineering, Hokkaido University in 1994. Doctor of Engineering. Entered the National Institute of Biosciences and Human-Technology of the Agency of Industrial Science and Technology in 1994. Principal researcher of Special Division for Human Life Technology, AIST, currently involved in clarification of the mechanisms of auditory spatial perception by the visually impaired and the development of technologies to implement training for them to learn spatial perception. Part-time instructor at the National Rehabilitation Center for Persons with Disabilities, Department of Visual Impairment, teaching trainers specializing in life training for the visually impaired based on the research results.

Discussions with Reviewers

1 Overall structure

Comment (Hideto Taya: Public Relations Department, AIST)

The present paper describes research on a training system for auditory spatial perception, developed and implemented using 3-D acoustic, signal processing, sensor, and other element technologies, and a training schedule, based on the author's knowledge of the mechanisms of auditory spatial perception, the subject of his long-term study. The paper is worthy of publishing in this journal.

Comment (Yasushi Kubo: Evaluation Department, AIST)

The present scientific study is excellent, and I think this paper complies with the objectives of *Synthesiology*.

2 Obstacle perception

Question (Hideto Taya)

Please describe problems that were solved in the development of methods for basic training in obstacle perception, and how the solutions have been utilized in the training system.

A description of the examination results of "obstacle perception" training for the visually impaired may be required.

Answer (Yoshikazu Seki)

Regarding "problems that were solved in the development of methods for basic training on obstacle perception," they are described in the paper as follows: "When these "clues" were simulated using acoustic technology, people who had developed obstacle perception skills felt as if specific objects were present." The description, "Fully-reflected sound was used (no decrease in the sound pressure level)" in the paper explains "how the solutions have been incorporated into the training system."

As the examination results of "obstacle perception" training for the visually impaired, records of visually impaired people's movements to avoid virtual walls (data shown in Fig. 3) created using 3-D auditory technology were added.

3 Experiment for validation

Question (Yasushi Kubo)

As the experiment for validation described in "3.2 Effectiveness of the training system" is very important to establish the effectiveness of the system, shouldn't actual data be included?

Since the effects are considered to vary depending on the number of training sessions implemented, it is necessary to state the number, isn't it?

Answer (Yoshikazu Seki)

Yes, it is. Experimental data, quoted from Reference 10, are in Figs. 4 (a) to (d). Information on the number of training sessions has also been added to the second paragraph of 3.2.

Additional question (Yasushi Kubo)

Figure 4 adds to the objectivity of assessment of the developed system. On the other hand, it may be difficult for non-specialists to understand the meaning of the labels on the vertical axis. Can supplemental descriptions be added to explain what an increase or decrease in the number indicates?

Answer (Yoshikazu Seki)

Captions to Figs. 4 (a) to (d) state the meanings of positive and negative numbers and an increase or decrease in the number.

Question (Hideto Taya)

The subjects of the experiment for validation were sighted people, instead of the visually impaired.

—Do you think that the validation experiment has limitations because the subjects were sighted people?

—Has a validation experiment involving the visually impaired been established?

Answer (Yoshikazu Seki)

I do not think that the validation experiment has limitations because the subjects were sighted people; in fact, I consider that the system has satisfied stricter criteria. If the system was designed for the visually impaired who had already learned daily life skills, the assessment using blindfolded sighted people as subjects would have been inadequate. However, as the system is used to conduct training for visually impaired "people who have not learned those skills," an assessment involving those with much experience of living as visually impaired people would have been rather inappropriate.

The effectiveness of the system when "the subjects are actual visually impaired people with little experience of rehabilitation" has not been established. This is because it is difficult to conduct an experiment involving people who have lost their sight recently to examine the validity of a system under development from an ethical point of view.

These are also explained in Reference 10.

4 Future challenges

Question (Hideto Taya)

I think there are technological development and promotional issues in promoting the system in the future. Please explain these two issues. What activity plan for promotion do you have?

Answer (Yoshikazu Seki)

As challenges in technological development, descriptions on the results of reexamination of the balance between cost reduction and positioning performance were added. As for promotion activities, the training system software will be distributed, free of charge, through the website of AIST, and I will also ask academic organizations related to visual impairment to distribute or help distribute it. I plan to teach training methods using the newly developed training system to people taking instructor training courses. I implemented the promotion of a CD called "Acoustic environment for obstacle perception training," a training material developed ten years earlier than this training system, and it was adopted by more than 300 facilities.