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Methods and systems for transmitting audio sound

Field of the invention

The present invention relates to methods and systems for transmitting audio sound to one or more individuals.

5 Background of Invention

The audio environment is a key component of the environments that surround us in every day life. Unlike video, which requires for the line-of-sight transmission between a screen and an individual, sound can be heard even if
10 it is blocked by people or some other obstacles. In many situations, this omnidirectional spread of sound tends to annoy unwilling listeners. If two or more sounds are mixed together (for example, TV and radio sounds), each of the intended listeners will be unlikely to get correct information due to mutual interference. Thus, it is desirable that there are ways to separate sounds into
15 different "spaces".

The conventional way to realize separate sound spaces within a given area is to use sound absorbing materials to partition the area. This is however highly costly and sometimes not possible to implement (e.g. in a living room).
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Another possibility is to attempt to generate the audio sound only within limited spaces. Audio beam techniques are known, which attempt to generate a very narrow audio beam as compared with a conventional loudspeaker, and can be used to efficiently localize the sound space.
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However, if the listener is in motion, he will lose track of sound when he walks out the coverage area of a small fixed audio beam. This would make the listener feel uncomfortable as he is accustomed to enjoy listening (for

example to music) almost anywhere in his activity space with a conventional audio system which is omni-directional in sound propagation.

Of course, another common technique for providing sound only for one individual is by a headphone or earphone. The headphone or earphone has two functions: 1) to provide the listener with a continuous personal audio entertainment and 2) to avoid sound interference from other people. However, there are two problems associated with the usage of an earphone: 1) it is uncomfortable or even annoying to wear a headphone/earphone, especially for a long duration of time and in hot weather conditions, and 2) the headphone/earphone blocks or attenuates various sounds in its surroundings, thus impeding the listener's ability to react appropriately to events taking place around him. It would therefore highly desirable to create a personal audio system without using a headphone/earphone.

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It is suggested in USP 5,815,579 that a personal audio system without an earphone can be built by using a loudspeaker array attached to a person's garment or headband. Unfortunately, this may not be convenient since a person would still need to wear a loudspeaker as a garment or headband and the loudspeaker is required to be well-positioned.

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Another type of sound distribution system is suggested in USP 6,091,826. This is to be used in large places such as shopping malls or giant supermarkets for advertisement and guide purposes. In this system, the presence of customers around a loudspeaker system is detected, and when this happens useful information is broadcast to them through it. In such a system, a plurality of conventional loudspeakers are needed, and but it is still unavoidable that other people nearby will unwillingly hear the sound. Whereas conventional loudspeakers generate a sound field almost evenly in all directions, in recent years, there has been a great deal of interest in

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generating highly directional audio beams using the principle of ultrasonic demodulation in air [3]~[7]. By first modulating the audio signal onto an ultrasonic frequency signal and then generating the ultrasonic wave through a transducer in a narrow beam, the audible sound can be reproduced by demodulation caused by the nonlinearity of air. The consequent audio sound is limited to a very narrow beam. A common problem for such an audio beam system lies in the rather poor sound quality due to high distortion and low sound pressure level for low frequency components. However, a new way to generate high quality audio beam sound has been proposed in [7].

Another way to generate a relatively narrow audio beam is to use a large loudspeaker array in which both signal amplitude and phase for each loudspeaker are separately adjusted to form a beam [12].

Summary of the Invention

The present invention aims to provide new and useful ways to generate audio sound to individuals.

In general terms, the invention proposes that the location of an individual is tracked, and sound is generated in a beam having a location which is changed according to the position of the individual.

Thus, whereas a fixed audio beam system covers only a small stationary space, the invention makes it possible to provide a personal audio space such that the sound beam moves together with the listener. The system can create a personal audio space which covers only one person with the capability to follow his movement and redirect the audio space accordingly. It provides a continuous audio service to people and at the same time avoids the sound interference to others nearby.

Unlike an earphone or headphone, the present invention can be implemented without the listener needing to wear an earphone which could be uncomfortable under certain circumstances and may block other necessary sound sources to the listener.

Furthermore, unlike an earphone which can be used only by one individual, the present system can be used both for one person and a group of people if they stay together under the covering range of an audio beam.

Alternatively or additionally, multiple systems according to the invention may be provided, to as to provide different audio sounds to different people, in beams which move according to the positions of the individuals.

The audio sound which is transmitted in the beam may be input from any of a number of audio sources. For this purpose one or more such audio sources may be connected or connectable to the embodiment, such as a radio, a TV, an audio player, a PC, a telephone and other device providing personal voice signals.

Furthermore, the user may be capable of transmitting (preferably wirelessly) signals to the embodiment. In a first example, these may be control signals for controlling the embodiment.

In a second example, they may be signals generated by a microphone carried by the user, and used to implement bi-directional voice communication. In other words, a first individual whose position is being tracked by an embodiment of the invention is provided with a microphone and a mechanism to transmit wirelessly signals generated by the microphone to the embodiment, and these signals are transmitted to one or more other individuals (e.g. by telephone) who generate audio signals which are

transmitted to the first individual using the embodiment. For example, the output of the microphone may be output from an output of an embodiment of the invention into a bi-directional communication device such as a telephone, which also transmits signals into the embodiment encoding audio signals generated at a distance by the one or more other individual. The bi-directional communication made possible by some embodiments of the invention can be used to make a phone call or to provide point-to-point far distance secure talk. For example, the one or more other individual may also be provided with an embodiment of the invention.

- 10 Many techniques for determining the position of an individual have been proposed [8]~[11], and many of these are suitable for use in the present invention. One of the preferred embodiments is based on wireless local area network (WLAN) since it can provide both communication and positioning capability simultaneously. The WLAN architectures can be based on
- 15 IEEE802.11, Bluetooth, or UWB. In such a technique the user typically wears a transceiver or other device the position of which can be sensed by a WLAN. This may for example be integrated with the microphone device mentioned above.
- 20 As for the device generating the audio beam, it may include a conventional loudspeaker array which directly generates a beam of audio frequency waves, and/or ultrasonic parametric array which generates an ultrasonic beam modulated with audio sound. In this document both of these beams are referred to as "audio beams". An ultrasonic parametric array is preferred for its
- 25 low cost and small size. The audio beam generation device may have multiple audio beam transducers, of the same or different types.

In any case, based on the position information, the embodiment may select one or more of the audio beam transducers (if there are more than one)

and/or adjust the directions in which transducer(s) direct sound (e.g. by rotating it), to project an audio beam to a space including the listener. The embodiment may be arranged to be capable of generating an audio beam which reach at least some locations in the area within which the individual
5 moves through at least one reflection, e.g. from a ceiling or wall.

The derivation of the position of the individual(s) and the audio beam redirection technique may be performed by physically separate units, under the control of a control system. The control system may be integrated with
10 either of them, or be a further physically separate unit. For example, the control system may be a home server, of the kind generally expected to become common in future homes and which performs other tasks of home management such as environmental control.

As mentioned above, the embodiment may receive control signals wirelessly
15 (e.g. from the listener). Alternatively or additionally, the embodiment may accept control signals from either a control panel or over a communication link (e.g. from a remote location). In any of these cases, the control signals may be used to control the function of the embodiment such as selection of which audio source is used to obtain the audio signals, volume control of the audio
20 sound, initiation of bi-directional talk, etc.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

Fig. 1 illustrates schematically three components of an embodiment of
25 the invention;

Fig. 2 illustrates the configuration of the embodiment of Fig. 1;

Fig. 3 shows schematically as a system block diagram, the control module of the embodiment;

Fig. 4 illustrates several ways which may be employed by the embodiment to form and steer an audio beam to an individual;

Fig. 5 illustrates a WLAN positioning system which may be used by the embodiment to detect the position of an individual;

5 Fig. 6 illustrates a further positioning system which may be used by the embodiment, in a room environment.

Detailed Description of the embodiments

10 Referring firstly to Fig. 1, an embodiment of the invention is illustrated, including three parts. Firstly, there is an audio beam generation module 1 which generates a narrow audio beam 2 including (at least the ears of) an intended listener 3. Secondly, there is a listener position determination module 4 which can detect the position of the listener 3 (e.g. in an indoor
15 environment). Thirdly, there is a control module 5 which receives the position output by the listener position determination module 4 and controls the audio beam generation module 1 (the signals may be passed between units 1, 4 and 5 with or without a wire connection). In particular, based on the listener position determination the control module 5 dynamically steers the audio
20 beam. When the listener 3 is moving, the positioning sub-system continuously detects his location and feeds it to the control module 5. The control module 5 will continuously (or at short intervals) adjust the audio beam generation module 1 to ensure that the audio beam 2 always includes the ears of the listener. Thus, un-interrupted hearing is guaranteed for the listener. The beam
25 2 is sufficiently narrow (e.g. one 1 metre wide, or less) that it covers only the intended listener. The embodiment may permit the width of the beam to be tuned, according to the number of individuals who are expected to hear the same sound, and according to how far away other individuals who are not intended to hear the sound are expected to be.

The embodiment is illustrated in more detail in Figure 2. The control module 5 is implemented by a home server, of the kind which is expected to become a mainstay of the future home. It is easy to integrate the functions of the control module 5 into a home sever since the required computational load for the control module is very low. The home server 5 has an input section 6 which receives inputs from many different audio sources, such as a radio 10, a TV 11, an audio player (CD/DVD/MP3) 12, a PC 13, or a telephone 14, to provide the listener 3 with a multiple number of options to choose between.

Furthermore, the input section 6 includes an input for a signal encoding the voice of another person, which permits a point-to-point far distance talk between two individuals (e.g. using another embodiment 15 of the invention for generating a moving audio space for that other person). Only the person 3 within the audio beam 2 is able to hear the sound, so this embodiment can improve the security of voice communication in an open and public environment.

The information about the position of the listener 3 can be obtained in many different ways based on ultrasonic, infrared and electromagnetic waves. The use of WLAN is used in this embodiment, and is preferred since it will become more common in future. At the same time, WLAN can also be used to implement the communication between the listener 3 and the home server 5.

For example, a wireless transceiver may play the role of the listener position determination module 4, and furthermore optionally receive voice signals from the individual 3. It is connected to the home server 5, and the listener is equipped with a wireless transceiver 8 such as an IEEE802.11, Bluetooth, or UWB device. Information such as the listener's position, voice and control commands is obtained by the wireless transceiver 4, and input into the home server 5. In order for the listener's voice to be input into the wireless

transceiver 8, a microphone 7 is attached to the listener. Furthermore, if the embodiment includes a voice recognition function, the listener's voice may be used to provide a control function to the home sever 5.

- 5 More generally, the control commands used to operate the embodiment (for example, to select one of the audio sources 10 to 15, for volume change and for initiation of bi-directional communication) may employ the wireless link between the transceivers 4, 8 (e.g. using voice control as mentioned above, or by the transceiver 4 including or being linked to one or more buttons
10 operable by the listener 3), and/or they can be input into the home server 5 by means of keyboard (not shown) or a remote controller (also not shown).

A block diagram of the control system of the embodiment is shown in Figure 3. The transceiver 4 (e.g. having an aerial 20) receives signals from the
15 transceiver 8. These signals include voice signals from the listener's 3 voice, and also encode information on the position of the user. The position of the user is extracted by the unit 21, and the voice signals by a unit 22. The listener position data is transmitted by the unit 21 to a control logic 23, which will receive control commands either directly from the keyboard/remote
20 controller or indirectly from wireless link through transceiver 4. After receiving the commands, the control logic 23 will control a multiple-to-one input selection unit 25 to select one of the audio sources and connect it to the audio input of the audio beam system. If bi-directional voice communication is required, the control logic 23 will also control a one-to-multiple output
25 selection unit 24 which receives the output of the unit 22 and transmits it through a selected output of the embodiment. Since the voice information is normally encoded in the signal received by the transceiver 4, the unit 22 decodes it before it is sent out to a telephone, loudspeaker for another person or to another system corresponding to the present embodiment.

As mentioned the signals received by the wireless transceiver 4 also permit the position of the listener 3 to be determined (or alternatively, there may be a separate positioning system 4 from which the wireless transceiver receives position signals). In any case, upon receiving the position information, the control logic 23 will find the closest audio beam transducer (in case that multiple audio beam systems are deployed) and calculate the control parameters such as the rotation angles for both pitch and roll directions. These control parameters are sent to the audio beam system in real time to steer the transducer (by rotating the transducer in both pitch and roll directions) to make the audio beam always follow the listener.

Fig. 4 shows three different ways in which the audio beam can be generated in the embodiment of the invention. The three parts of the figure labelled 31, 32 and 33 indicate three separate realisations of the audio beam generation module 1. Note that optionally more than one of these types of module may be employed by the embodiment, e.g. covering different areas into which a listener 3 might move.

One form of the audio beam generation module 1 is a parametric array 31. This includes an ultrasonic transducer 34 to generate an audio signal modulated onto an ultrasonic wave which propagates through air. Since the ultrasonic carrier frequency is much higher than the audio frequency range, it can be easily focused into a narrow beam by a relatively small transducer. The audible sound is reproduced from the interactions among the ultrasonic frequency components, and the reproduced sound is confined to the ultrasonic beam. Therefore, a narrow audio beam can be formed. The ultrasonic transducer may be fixed on ceiling or wall to make the beam easily projected to the listener 3 without being blocked. Changes in the beam direction can be implemented by rotating the transducer. A two-joint rotation mechanism may be where one joint 35 rotates in a pitch direction and the

other joint 36 in a roll direction. Within one ordinary room (e.g. $<50\text{ m}^2$), one audio beam transducer may be sufficient.

Another possible type of audio beam generation module 1 is a conventional
 5 loudspeaker array 32 device, as proposed by 1 Ltd of the UK [12]. It uses a digital beam forming technique that controls the signal's phase and amplitude separately cell by cell. The sound from an array 37 of loudspeakers can be focused into a beam and steered as well based on phase and gain control signals 38. However, since this system is quite complex, it is highly costly and
 10 rather large in size. Consequently, it may be difficult to deploy in a home. On the other hand, when applied to some special environment like a luxurious office, it may be preferred owing to its high sound quality.

It is also possible to use one transducer to cover an area that is not on a line
 15 of sight with the listener 3, since the audio beam can be mirror reflected from a flat surface, wall and ceiling 39 if no direct path is not available. In Fig. 4, this is performed by the parametric audio beam generation module 33 (which may be of the same construction as the unit 31). Of course, the room geometry should be known to the home server 5 and be used to calculate the
 20 appropriate points of reflection.

In principle, any positioning method can be used to detect the listener's position in a room environment. The position can be measured by sound, light or electromagnetic waves. The present embodiment detects the position by a
 25 WLAN since this also enables communication between the listener 3 and the home server 5.

A first possible form of the positioning used by the embodiment is illustrated in Fig. 5, where multiple transceivers 4 are used to receive the signal from a
 30 mobile radio in the transceiver 8 (which is attached to the listener). By

measuring the time-difference-of-arrival (TDOA) of the signal transmitted from the mobile radio and received by these reference radios 4, the position of the mobile radio can be inferred based on geometric considerations. A preferred implementation is to feed the received signals of multiple reference radios 4
 5 directly to the home server 5 and to calculate the position information there.

Another possible form of the positioning method used by the embodiment is shown in Fig. 6 where only a single transceiver 8 with an omni-directional antenna is used. The transceiver 8 is attached to the listener 3 when in use.
 10 There is no other active reference in the room environment. The echoes reflected from the walls, objects and their multi-path copies are received by a transceiver (not shown) connected to the home server 5. The echoes from some known positions are first used in a learning phase to train a neural network (or other adaptive model) to record/identify the environment in the
 15 training phase. In the operation mode, the real time echoes are used to infer the position by making use of the already learnt parameters [11].

A concrete application of the embodiment is as follows. In the morning, you are busy brushing your teeth, washing your face, eating your breakfast,
 20 dressing your clothes, and so on and so forth before going to work. At the same time, however, you want to hear the morning news broadcast from a radio. Using the embodiment, you can always hear the news without interruption as you go through all the routine. There is no need for an earphone that would otherwise make it hard for you to wash your face and put
 25 on your clothes. Furthermore, you can still hear your baby's cry and respond to her. Your older children will not complain to you about the noise from the radio, since it is transmitted only to you and does not disturb them as they lie in bed or read a book.

Although only a single embodiment of the invention has been described in detail, many variations are possible within the scope of the invention as will be clear to a skilled reader.

For example, whereas the above embodiment is usually deployed in a room environment, other embodiments may be designed for application in other environments. Thus, the invention is applicable for use in any of homes, offices, meeting rooms, classrooms, etc.

Furthermore, although wireless positioning methods are preferred, other positioning methods are also possible. For example, instead of WLAN, a further preferred possibility is to use a UWB-based positioning system as this can provide more accurate positioning capability at relatively low cost.

References

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Claims

1. A sound generation system comprising:
position detection means for determining the position of at least one individual;
5 audio beam generation means for generating an audio beam propagating through a selected location; and
a control system for modifying the location through which the audio beam propagates according to the detected position of the at least one individual.
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2. A system according to claim 1 further comprising an input section for receiving multiple signals carrying respective audio sounds, the control system being operative to select one of the multiple signals for transmission to the individual using the audio beam.
- 15 3. A system according to claim 2 in which the multiple signals carrying audio sounds include signals derived from one or more of a radio, a TV, an audio player, a PC, or a telephone.
4. A system according to any preceding claim further including a wireless transmitter for transmitting wireless signals and for attachment to the
20 individual.
5. A system according to claim 4 in which the wireless transmitter operates according to one of the IEEE802.11, Bluetooth, or UWB standards.
6. A system according to claim 4 or claim 5 in which the transmitter is connected to a microphone and is arranged to transmit voice signals captured
25 by the microphone from the voice of the individual.
7. A system according to claim 6 when dependent on claim 2, having at least one output for transmitting a signal which is, or is derived from, the voice

signals, whereby the system permits bi-directional communication with at least one other individual with access to a communication system arranged to receive the voice signals, to generate second voice signals from the voice of the at least one other individual and transmit them to the input section.

5 8. A system according to claim 4 in which the position detection means determines the position of the individual based on signals transmitted by the wireless transmitter.

9. A system according to claim 8 in which the position detection means includes multiple receivers for the signal, the position of the individual being
10 obtained by a comparison of the time of arrival at the receivers of signals transmitted by the wireless transmitter.

10. A system according to claim 8 in which the position detection means is arranged to receive the signal transmitted by the wireless transmitter and additionally at least one reflected signal transmitted by the wireless transmitter
15 along a path including a reflection, the position detection means including an adaptive model to determine the position of the individual by a comparison of the times of arrival of the signal and the at least one reflected signal.

11. A system according to any preceding claim in which the audio beam generation means includes a parametric speaker for generating a beam of
20 ultrasonic waves modulated by an audio frequency.

12. A system according to claim 11 in which the parametric speaker is operative to redirect the beam of ultrasonic waves based on control signals received from the control system.

13. A system according to any preceding claim in which the audio beam
25 generation means includes an array of loudspeakers generating respective audio-frequency waves, the control system being operative to redirect the

audio beam by varying the amplitude and phases of the respective audio-frequency waves.

14. A system according to any preceding claim in which the audio beam generation means includes a plurality of devices operative to generate an audio beam, the control system selectively operating the devices according to the determined position of the individual.

15. A system according to any preceding claim in which the control system is a home server, operative to control at least one parameter of the environment containing the individual other than sound.

16. A system according to any preceding claim in which the audio beam generation means is operative to generate a plurality of audio beams carrying different audio signals, and the position detection means is arranged, for each beam, to determine the position of one or more individuals, the control system being arranged to direct the audio beams toward the detected position of the corresponding individual or individuals.

17. A method of transmitting audio sound to an individual the method comprising:

automatically tracking the position of the individual;
generating an audio beam in a selected direction; and
repeatedly redirecting the beam automatically according to the detected position of the individual to keep at least a head of the user within the audio beam.