US012386024B2

(12) **United States Patent**
Oldfeldt et al.

(10) **Patent No.: US 12,386,024 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **SYSTEM AND METHOD FOR DETERMINING A DISTANCE BETWEEN NETWORKED ELECTRONIC DEVICES EACH COMPRISING A LOUDSPEAKER AND A MICROPHONE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 182 days.

(21) Appl. No.: **18/481,562**

(22) Filed: **Oct. 5, 2023**

(65) **Prior Publication Data**

US 2024/0133998 A1 Apr. 25, 2024

(30) **Foreign Application Priority Data**

Oct. 13, 2022 (EP) 22201258

(51) **Int. Cl.**
G01S 5/18 (2006.01)

(52) **U.S. Cl.**
CPC ***G01S 5/18*** (2013.01)

(58) **Field of Classification Search**
CPC G01S 5/18; G01S 7/52004; G01S 7/539; G01S 15/36; G01S 7/003; G01S 15/74; G01S 11/14
See application file for complete search history.

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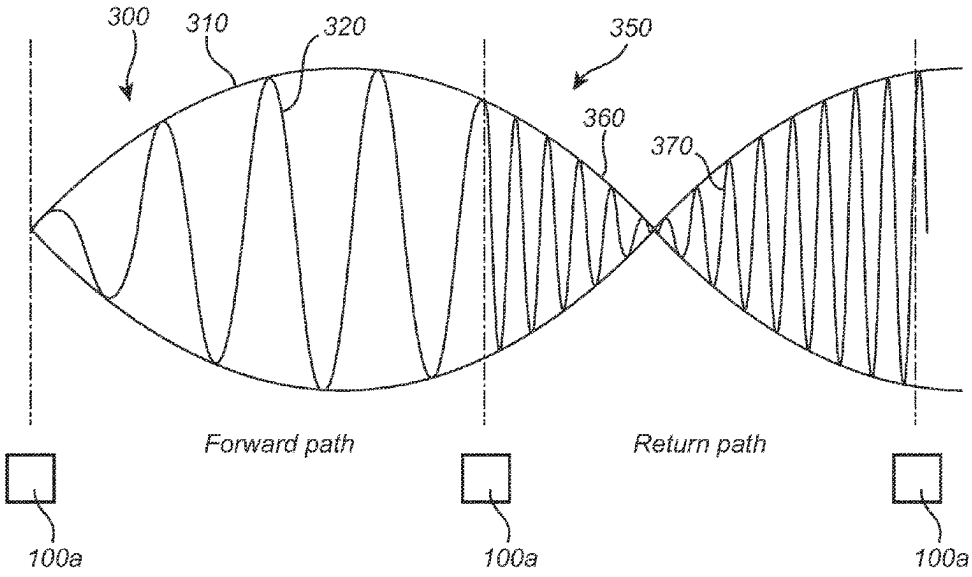
(57) **ABSTRACT**

A system determines a distance between networked electronic devices. A first sound signal comprising a first measuring wave having a first frequency carried on a first carrier wave having a first carrier frequency higher than the first frequency is emitted by a first device. A second device receives the first sound signal, and defines a second sound signal comprising a second measuring wave having the first frequency carried on a second carrier wave having a second carrier frequency different from the first carrier frequency. A phase of the second measuring wave is set such that it simulates a reflection of the first measuring wave on the second device. The second sound signal is emitted by the second device and received by the first device. The distance between the first and second devices is calculated based on a phase shift between the emitted first, and received second measuring waves.

8 Claims, 3 Drawing Sheets



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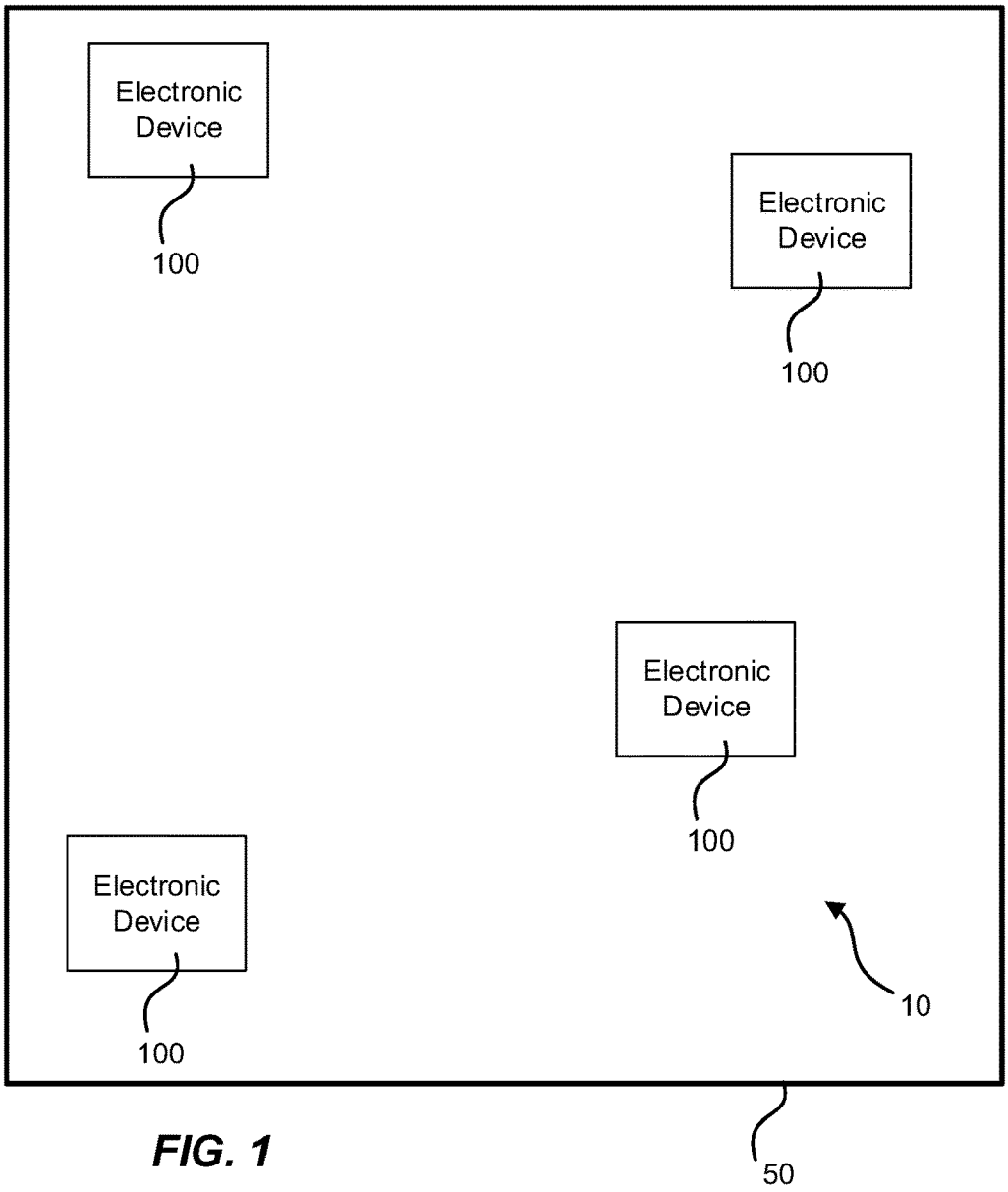
Electronic Device
100
Electronic Device
100
Electronic Device
100
Electronic Device
100
10
50

FIG. 1

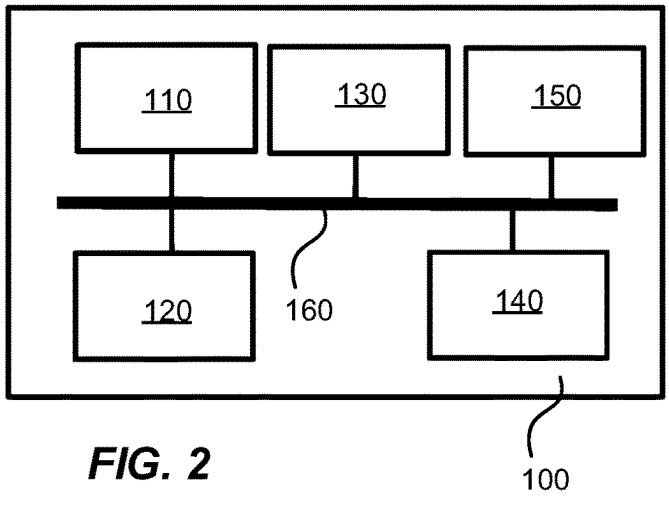
110
130
150
120
160
140
100

FIG. 2

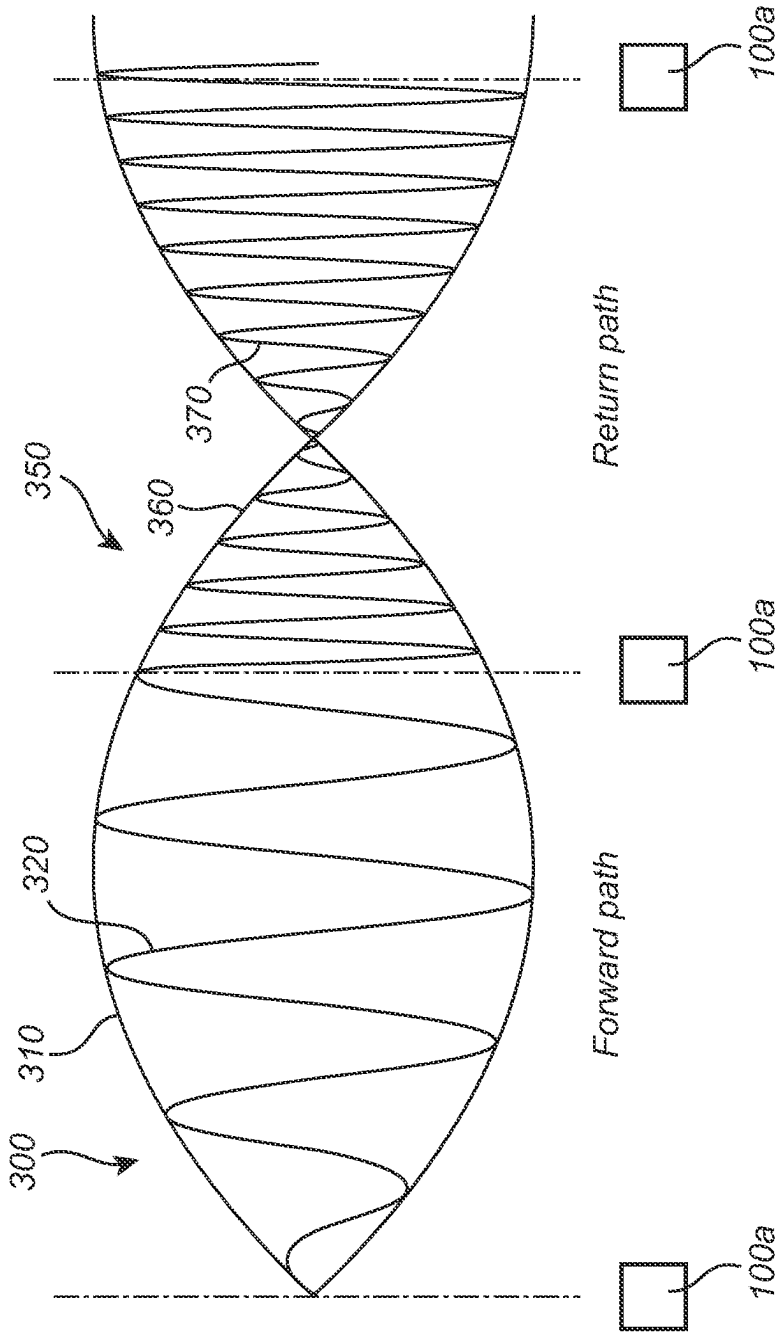
300
310
320
350
360
370
Forward path
Return path
100a
100a
100a

Fig. 3

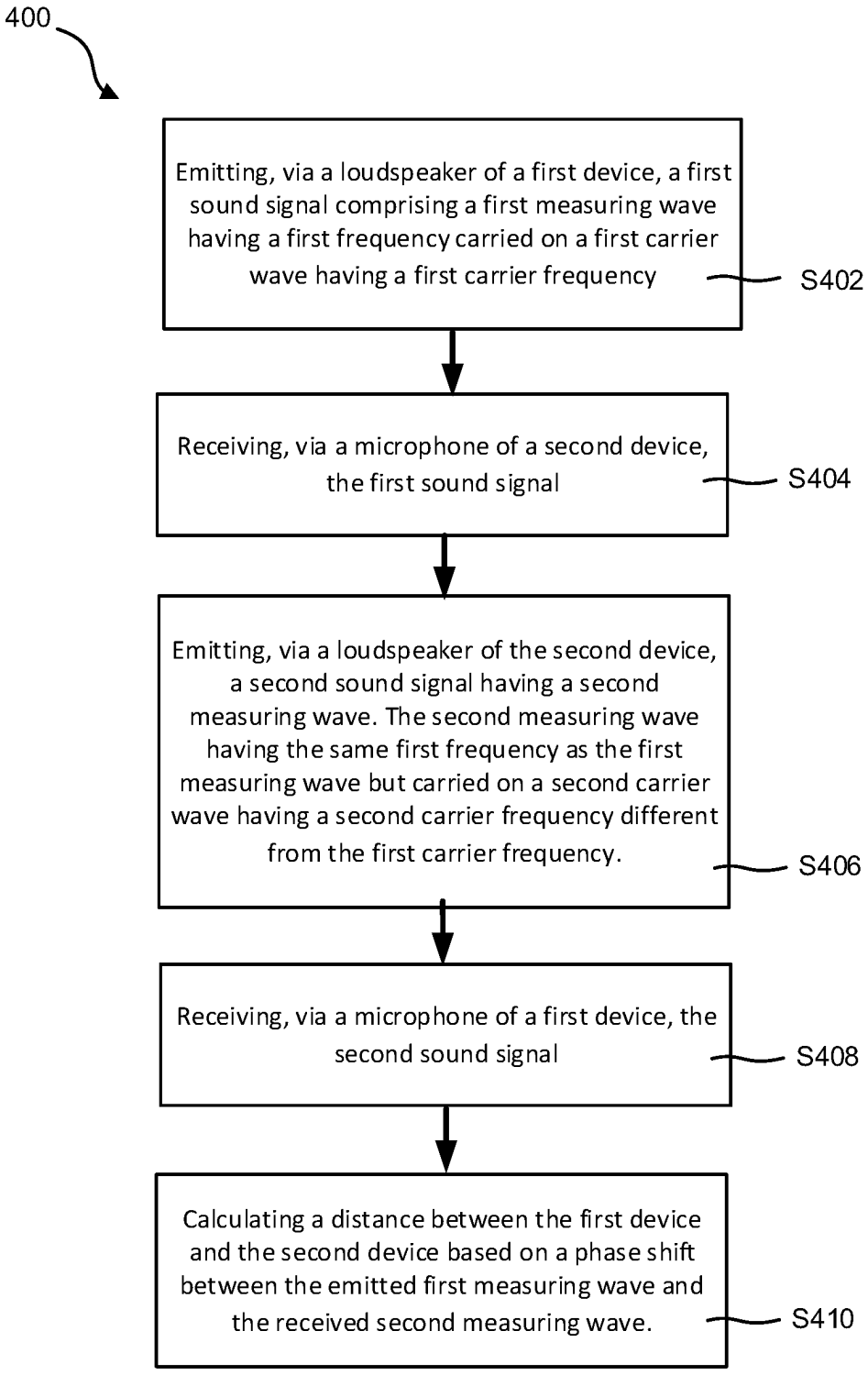
400
Emitting, via a loudspeaker of a first device, a first sound signal comprising a first measuring wave having a first frequency carried on a first carrier wave having a first carrier frequency
S402
Receiving, via a microphone of a second device, the first sound signal
S404
Emitting, via a loudspeaker of the second device, a second sound signal having a second measuring wave. The second measuring wave having the same first frequency as the first measuring wave but carried on a second carrier wave having a second carrier frequency different from the first carrier frequency.
S406
Receiving, via a microphone of a first device, the second sound signal
S408
Calculating a distance between the first device and the second device based on a phase shift between the emitted first measuring wave and the received second measuring wave.
S410

FIG. 4

SYSTEM AND METHOD FOR DETERMINING A DISTANCE BETWEEN NETWORKED ELECTRONIC DEVICES EACH COMPRISING A LOUDSPEAKER AND A MICROPHONE

TECHNICAL FIELD

The present invention relates to determining a distance between networked electronic devices. Especially, it relates to determining such a distance using properties of sound emitted and received by the networked electronic devices using loudspeakers and microphones of the networked electronic devices.

BACKGROUND

In many applications there is a need to determine a distance between a first device and a second device. It is, e.g., known to perform distance measurements using different methods such as using a tape-measure, a laser-based range finder, or a sonar. The different methods have their pros and cons.

The inventors of the present invention have realized that there is a need for an additional method of determining a distance between a first device and a second device, especially for the case of determining a distance between devices of a system of devices mounted in a building.

SUMMARY OF THE INVENTION

In view of the above, it is an object of the present invention to provide a method of determining a distance between a first device and a second device.

According to a first aspect a method for determining a distance between a first networked electronic device and a second networked electronic device is provided. The first networked electronic device has a first loudspeaker and a first microphone. The second networked electronic device has a second loudspeaker and a second microphone. The method comprises emitting, using the first loudspeaker, a first sound signal. The first sound signal comprises a first measuring wave having a first frequency carried on a first carrier wave having a first carrier frequency. The first carrier frequency is higher than the first frequency. The method further comprises receiving, using the second microphone, the first sound signal. The method further comprises defining, at the second electronic device, a second sound signal. The second sound signal comprises a second measuring wave carried on a second carrier wave. The second measuring wave has the same frequency as the first measuring wave. Hence, the second measuring wave has the first frequency. The second carrier wave has a second carrier frequency different from the first carrier frequency. A phase of the second measuring wave is set such that it simulates a reflection of the first measuring wave on the second networked electronic device. The method further comprises emitting, using the second loudspeaker, the second sound signal. The method further comprises receiving, using the first microphone, the second sound signal. The method further comprises calculating the distance between the first networked electronic device and the second networked electronic device based on a phase shift between the emitted first measuring wave and the received second measuring wave.

In line with the above, the inventors have realized that by using properties of sound, a distance between two devices each equipped with a loudspeaker and a microphone can be determined. This by looking at a phase shift of a low frequency periodic measuring wave carried on a sound-based carrier wave. The low frequency periodic measuring wave might even be below 20 Hz. In order to determine distances in the range of 1 m to 50 m the frequency of the measuring wave needs to be 3-160 Hz. That since the wavelength of the measuring wave needs to be longer than half the distance between the two devices. Most loudspeakers cannot reproduce waves having such low frequencies. By using a carrier wave emitting a measuring wave having as low frequency as discussed above is provided for.

The first and second carrier waves may have a carrier frequency in a range of 200-20 000 Hz.

Defining the second sound signal may comprise setting the phase of the second measuring wave to be same as a phase of the first measuring wave of the by the second microphone received first sound signal.

Setting the phase of the second measuring wave may comprises determining the phase of the second measuring wave based on a processing time of a circuitry at the second networked electronic device analyzing the first sound signal in order to determine the phase of the received first measuring wave.

Defining and emitting the second sound signal may comprise emitting a candidate second sound signal; shifting, while listening with the second microphone, the phase of the second measuring wave of the candidate second sound signal until the phases of the received first measuring wave and the second measuring wave of the candidate second sound signal match up; and upon the phases of the received first measuring wave and the second measuring wave of the candidate second sound signal matching up, emitting the second sound signal as having the matched-up phase.

According to a second aspect a system for determining a distance between a first networked electronic device and a second networked electronic device is provided. The system comprises: the first networked electronic device having a first loudspeaker and a first microphone; and the second networked electronic device having a second loudspeaker and a second microphone. The first networked electronic device further comprises first circuitry configured to: define a first sound signal comprising a first measuring wave having a first frequency carried on a first carrier wave having a first carrier frequency being higher than the first frequency; and drive the first loudspeaker to emit the first sound signal. The second networked electronic device further comprises second circuitry configured to: analyze the first sound signal upon its registration by the second microphone; define a second sound signal comprising a second measuring wave having the first frequency carried on a second carrier wave having a second carrier frequency being higher than the first frequency and different from the first carrier frequency, wherein a phase of the second measuring wave is set such that it simulates a reflection of the first measuring wave of the first sound signal on the second networked electronic device; and drive the second loudspeaker to emit the second sound signal. The first circuitry of the first networked electronic device is further configured to: analyze the second sound signal upon its registration by the first microphone; determine a phase shift between the emitted first measuring wave and the received second measuring wave; and calculate the distance between the first networked electronic device and the second networked electronic device based on the determined phase shift.

The above-mentioned features of the method, when applicable, apply to this second aspect as well. In order to avoid undue repetition, reference is made to the above.

A further scope of applicability will become apparent from the detailed description given below. However, it should be understood that the detailed description and specific examples are given by way of illustration only.

It is to be understood that the terminology used herein is for purpose of describing particular embodiments only, and is not intended to be limiting. It must be noted that, as used in the specification and the appended claim, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements unless the context clearly dictates otherwise. Thus, for example, reference to "a unit" or "the unit" may include several devices, and the like. Furthermore, the words "comprising", "including", "containing" and similar wordings does not exclude other elements or steps.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects will now be described in more detail, with reference to appended figures. The figures should not be considered limiting; instead they are used for explaining and understanding.

As illustrated in the figures, the sizes of layers and regions may be exaggerated for illustrative purposes and, thus, are provided to illustrate the general structures. Like reference numerals refer to like elements throughout.

FIG. **1** schematically illustrates a system of networked electronic devices mounted in a building.

FIG. **2** schematically illustrates a networked electronic device.

FIG. **3** schematically illustrates a method of using properties of sound for determining a distance between two networked electronic devices.

FIG. **4** is a block diagram of a method for determining a distance between the first electronic device and the second electronic device.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which currently preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for thoroughness and completeness, and to fully convey the scope of the invention to the skilled person.

FIG. **1** illustrates a system **10** of networked electronic devices **100** mounted in a building **50**. Such a networked electronic device is schematically illustrated in FIG. **2**. Each networked electronic device **100** has a loudspeaker **110** and a microphone **120**. Examples of such networked electronic devices **100** are networked loudspeakers, networked monitoring cameras and/or networked access control devices. In addition to the loudspeaker **110** and a microphone **120**, the networked electronic device **100** may comprise circuitry **130**, a memory **140** and a communication module **150**. The communication module **150** is configured to send and/or receive data via a communication network to which the networked electronic device **100** is connected. The circuitry **130** is configured to carry out overall control of functions and operations of the networked electronic device **100**. The circuitry **130** may include a processor, such as a central processing unit (CPU), microcontroller, or microprocessor. The processor is configured to execute program code stored in the memory **140**, in order to carry out functions and operations of the networked electronic device **100**. The memory **140** may be one or more of a buffer, a flash memory, a hard drive, a removable medium, a volatile memory, a non-volatile memory, a random access memory (RAM), or another suitable device. In a typical arrangement, the memory **140** may include a non-volatile memory for long term data storage and a volatile memory that functions as system memory for the networked electronic device **100**. The memory **140** may exchange data with the circuitry **130**, the loudspeaker **110**, the microphone **120** and/or the communication module **150** over a data bus **160**. Functions and operations of the networked electronic device **100** may be embodied in the form of executable logic routines (e.g., lines of code, software programs, etc.) that are stored on a non-transitory computer readable medium (e.g., the memory **140**) of the networked electronic device **100** and are executed by the circuitry **130** (e.g., using the processor). Furthermore, the functions and operations of the networked electronic device **100** may be a stand-alone software application or form a part of a software application that carries out additional tasks related to the networked electronic device **100**. The functions and operations may be considered a method that the networked electronic device **100** is configured to carry out. Also, while the functions and operations may be implemented in software, such functionality may as well be carried out via dedicated hardware or firmware, or some combination of hardware, firmware and/or software.

For some applications, such as during commissioning of the system **10** of networked electronic devices **100**, distances between the different networked electronic devices **100** are to be determined. Various methods for determining distance exist as of today, e.g., tape-measure, a laser-based range finder, or a sonar. However, none of them are optimal for determining a distance between two networked electronic devises **100** being mounted in a building **50**.

The inventors of the present invention have realized that properties of sound can be used in determining a distance between two networked electronic devices **100***a*, **100***b* each equipped with a loudspeaker and a microphone. This will now be discussed in connection with FIGS. **3** and **4**. FIG. **3** schematically illustrates using properties of sound for determining a distance between two networked electronic devices **100***a*, **100***b* and FIG. **4** is a block diagram of a method for determining a distance between the first electronic device **100***a* and the second electronic device **100***b*.

A first networked electronic devices **100***a* is instructed to emit S**402**, via its loudspeaker, a first sound signal **300** comprising a first measuring wave **310** having a first frequency carried on a first carrier wave **320** having a first carrier frequency. The first sound signal **300** is illustrated along the "Forward path" in FIG. **3**.

A second networked electronic device **100***b*, within earshot of the first sound signal **300**, is set to, via its microphone, listen to the first sound signal **300**. Hence, the second networked electronic device **100***b* is set to receive S**404** the first sound signal.

Upon receipt of the first sound signal **300**, the second networked electronic device **100***b* is set to, via its loudspeaker, emit S**406** a second sound signal **350** having a second measuring wave **360**. The second measuring wave **360** has the same first frequency as the first measuring wave **310** but carried on a second carrier wave **370** having a second carrier frequency different from the first carrier frequency. The second sound signal **350** is illustrated along the "Return path" in FIG. **3**. By using the second carrier

frequency different from the first carrier frequency the second sound signal **350** may be differentiated from echoes of the first sound signal **300** from other structures.

Further, the second networked electronic device **100***b* is set to shift a phase of the second measuring wave **360** so that it simulates a reflection of the first measuring wave **310** on the second networked electronic device **100***b*. That is, the phase of the second measuring wave **360** is to be set to be same as a phase of the first measuring wave **320** at the second networked electronic device **100***b*. Hence, the second networked electronic device **100***b* is set to define the second sound signal **350** such that a phase of the second measuring wave **360** is set such that it simulates a reflection of the first measuring wave **310** on the second networked electronic device **100***b*. The second sound signal **350** may be defined using circuitry of the second networked electronic device **100***b*. Hence, the second networked electronic device **100***b* is set to answer with a second sound signal **350** comprising a second measuring wave **360** having the same phase as the first measuring wave **310** of the incoming first sound signal **300**. That is, the second networked electronic device **100***b* is set to simulate a reflection of the first measuring wave **310**. However, in order to distinguish the simulated reflection from real reflections on other structures, the second networked electronic device **100***b* is set to carry the second measuring wave **360** on a second carrier wave **370** having a carrier frequency different from the carrier frequency of the first sound signal **300**. In other words, defining the second sound signal **350** comprises setting the phase of the second measuring wave **360** to be same as a phase of the first measuring wave **310** of the by the second microphone of the second networked electronic device **100***b* received first sound signal **300**. Setting the phase of the second measuring wave **360** may comprise determining the phase of the second measuring wave **360** based on a processing time of a circuitry at the second networked electronic device **100***b* analyzing the first sound signal **300** in order to determine the phase of the received first measuring wave **310**. Doing so the phase of the second measuring wave **360** can be timed with the phase of the received first measuring wave **310**. Alternatively, or in combination, defining and emitting the second sound signal **350** may comprise: i) emitting a candidate second sound signal, ii) shifting, while listening with the second microphone of the second networked electronic device **100***b*, the phase of the second measuring wave of the candidate second sound signal until the phases of the received first measuring wave **310** and the second measuring wave of the candidate second sound signal match up, and iii) upon the phases of the received first measuring wave **310** and the second measuring wave of the candidate second sound signal matching up, emitting the second sound signal **350** as having the matched-up phase.

The first networked electronic device **100***a* is then set to, via its microphone **120***a*, listen to the second sound signal **350**. Hence, the first networked electronic device **100***a* is set to receive S**408** the second sound signal.

A distance between the first networked electronic device **100***a* and the second networked electronic device **100***b* can then be determined based on a phase shift between the, at the first networked electronic device **100***a*, emitted first measuring wave **310** and the, at the first networked electronic device **100***a*, received second measuring wave **360**. This since such a phase shift will depend on the distance between the first and second networked electronic devices **100***a*, **100***b*. The distance, D, between the first and second networked electronic devices **100***a*, **100***b* can be expressed as:

$$D = \frac{\Delta\Phi}{\pi} \cdot \lambda$$

where $\Delta\Phi$ is the phase shift [expressed in radians] and λ is the wavelength of the measuring wave defined as:

$$\lambda = \frac{\text{speed of sound}}{f}$$

where f is the frequency of the measuring waves **310**, **360**, i.e., the first frequency discussed above. This under the assumption that the distance between the first and second networked electronic devices **100***a*, **100***b* is within half a wavelength. Hence, the distance D between the first networked electronic device **100***a* and the second networked electronic device **100***b* is calculated S**410** based on a phase shift between the emitted first measuring wave **310** and the received second measuring wave **360**. The calculating S**410** is preferably made by circuitry of the first networked electronic device **100***a*. However, the calculating S**410** can be made at any other device having computational capabilities and being connected to the first networked electronic device **100***a* so that the phase shift or information for calculating the phase shift may be communicated thereto.

Assuming the workable range for the distance one would want to measure is between 1 m and 50 m, then the first frequency should be in the range of 160 Hz and 3.3 Hz. The frequency for the first and second carrier waves **320**, **370** shall be higher than the first frequency, hence typically above 200 Hz. An upper limit for the frequency of the first and second carrier waves **320**, **370** is typically 20 000 Hz. As mentioned above, the first and second carrier waves **320**, **370** are set to have different carrier frequencies. By using different carrier frequencies for the different carrier waves **320**, **370** the second sound signal **350** may be differentiated from echoes of the first sound signal **300** from other structures in the building. Further, an identity of the networked electronic devices **100** can be encoded by assigning a specific carrier frequency to a specific networked electronic device. Typically, the first and second sound signals **300**, **350** are sinusoidal amplitude modulated signals. However, any periodic signal that can be carried by a carrier wave would work.

The person skilled in the art realizes that the present invention by no means is limited to what is explicitly described above. On the contrary, many modifications and variations are possible within the scope of the appended claims.

For example, in some applications both the first and the second networked electronic devices are fixedly mounted in the building. In other applications the first electronic device may be a portable electronic device, such as a mobile phone.

Additionally, variations can be understood and effected by the skilled person in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

The invention claimed is:

1. A method for determining a distance between a first networked electronic device having a first loudspeaker and a first microphone and a second networked electronic device having a second loudspeaker and a second microphone, the method comprising:

emitting, using the first loudspeaker, a first sound signal comprising a first measuring wave having a first fre-

quency carried on a first carrier wave having a first carrier frequency being higher than the first frequency, wherein the first sound signal is sinusoidal amplitude modulated;

receiving, using the second microphone, the first sound signal;

defining, at the second electronic device, a second sound signal comprising a second measuring wave having the first frequency carried on a second carrier wave having a second carrier frequency different from the first carrier frequency, wherein the second sound signal is sinusoidal amplitude modulated and wherein defining the second sound signal comprises setting the phase of the second measuring wave to be the same as a phase of the first measuring wave of the first sound signal received by the second microphone thereby a phase of the second measuring wave is set such that it simulates a reflection of the first measuring wave on the second networked electronic device;

emitting, using the second loudspeaker, the second sound signal;

receiving, using the first microphone, the second sound signal; and

calculating the distance between the first networked electronic device and the second networked electronic device based on a phase shift between the emitted first measuring wave and the received second measuring wave.

2. The method according to claim **1**, wherein the first frequency of the first and second measuring waves is in a range of 3-160 Hz.

3. The method according to claim **1**, wherein the first and second carrier waves have a carrier frequency in a range of 200-20,000 Hz.

4. The method according to claim **1**, wherein setting the phase of the second measuring wave comprises determining the phase of the second measuring wave based on a processing time of a circuitry at the second networked electronic device analyzing the first sound signal in order to determine the phase of the received first measuring wave.

5. The method according to claim **1**, wherein defining and emitting the second sound signal comprises:

emitting a candidate second sound signal,

shifting, while listening with the second microphone, the phase of the second measuring wave of the candidate second sound signal until the phases of the received first measuring wave and the second measuring wave of the candidate second sound signal match, and

upon the phases of the received first measuring wave and the second measuring wave of the candidate second sound signal matching, emitting the second sound signal as having the matched phase.

6. A system for determining a distance between a first networked electronic device and a second networked electronic device, the system comprising:

the first networked electronic device having a first loudspeaker and a first microphone; and

the second networked electronic device having a second loudspeaker and a second microphone,

wherein the first networked electronic device further comprises first circuitry configured to:

define a first sound signal comprising a first measuring wave having a first frequency carried on a first carrier wave having a first carrier frequency being higher than the first frequency, wherein the first sound signal is sinusoidal amplitude modulated, and

drive the first loudspeaker to emit the first sound signal;

wherein the second networked electronic device further comprises second circuitry configured to:

analyze the first sound signal upon its registration by the second microphone,

define a second sound signal comprising a second measuring wave having the first frequency carried on a second carrier wave having a second carrier frequency being higher than the first frequency and different from the first carrier frequency, wherein the second sound signal is sinusoidal amplitude modulated and wherein defining the second sound signal comprises setting the phase of the second measuring wave to be the same as a phase of the first measuring wave of the first sound signal received by the second microphone thereby a phase of the second measuring wave is set such that it simulates a reflection of the first measuring wave of the first sound signal on the second networked electronic device, and

drive the second loudspeaker to emit the second sound signal;

wherein the first circuitry of the first networked electronic device is further configured to:

analyze the second sound signal upon its registration by the first microphone,

determine a phase shift between the emitted first measuring wave and the received second measuring wave, and

calculate the distance between the first networked electronic device and the second networked electronic device based on the determined phase shift.

7. The system according to claim **6**, wherein the first frequency of the first and second measuring waves is in a range of 3-160 Hz.

8. The system according to claim **6**, wherein the first and second carrier waves have a carrier frequency in a range of 200-20,000 Hz.

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