IN-VEHICLE ULTRASONIC MONITORING SYSTEM

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IN-VEHICLE ULTRASONIC MONITORING SYSTEM

ABSTRACT

An in-vehicle monitoring system may use various vehicle speakers and various microphones to determine the presence and location of occupants within a vehicle (e.g., an automobile, a motorcycle, a bus, a recreational vehicle (RV), a semi-trailer truck, a tractor or other type of farm equipment, a train, a plane, a boat, a helicopter, a personal transport vehicle, etc.) using ultrasonic sound frequencies. The in-vehicle monitoring system may include a vehicle head unit, audio system, or other device, which may in turn cause vehicle speakers, such as one or more speakers built into the vehicle, other speakers located within the vehicle, etc.) to output one or more ultrasonic frequencies within the vehicle. Various microphones included within the vehicle (e.g., one or more microphones built into the vehicle, one or more microphones included in devices, such as smartphones, located within the vehicle, etc.) may detect reflections of the ultrasonic frequencies from objects within the vehicle. The vehicle head unit, mobile device (e.g., smartphone, tablet, etc.), or a remote server (e.g., a cloud computing system) may analyze or process the detected ultrasonic frequencies (e.g., by using cross-correlation and envelope-detection) to determine whether one or more occupants are located within the vehicle and whether any of the occupants are moving within the vehicle. In various instances, different speakers within the vehicle may output different ultrasonic frequencies to determine the position of any occupants within the vehicle. The in-vehicle monitoring system may use (e.g., by the vehicle head unit) such information about any occupants detected in the vehicle to automatically adjust audio settings, automatically start and/or stop an engine, automatically lock and/or unlock the vehicle, etc.
DESCRIPTION

The present disclosure describes a system for in-vehicle monitoring of drivers and passengers using ultrasound that can be implemented without requiring hardware redesign. The system may use one or more existing in-vehicle speakers at various locations (e.g., alongside the doors, windshield, dashboard, or rear of the passenger compartment of the vehicle) as a transmitter to transmit one or more (e.g., a series of) ultrasonic frequencies (hereinafter, “transmitted ping”). The system may be further configured to use one or more microphones included within the vehicle (e.g., one or more microphones built into the vehicle, one or more microphones included in devices, such as smartphones, located within the vehicle, etc.) as a receiver to receive reflections of transmitted pings (hereinafter, “received ping”). The system may process discrepancies (e.g., due to reflection characteristics of objects in the vehicle changing due to a change in the position or velocity of the objects) between the transmitted ping and the received ping (e.g., by a machine learning algorithm) to determine the position and/or velocity of one or more occupants.

FIG. 1 (below) is a conceptual diagram illustrating a side view of an interior of a vehicle 100 in which an example system 110 is configured to transmit and receive pings in accordance with one or more aspects of the present disclosure. FIG. 1 shows a cross-sectional view of an interior of vehicle 100 having vehicle computing system 110. In FIG. 1, vehicle 100 is illustrated as an automobile, but vehicle may be a motorcycle, a bus, a RV, a semi-trailer truck, a tractor or other type of farm equipment, a train, a plane, a helicopter, a truck, a boat, a personal transport vehicle, etc.
In general, system may include processing circuitry 112, one or more transmitters 114, and one or more receivers 116. Processing circuitry 112 may be included in a vehicle head unit, a mobile device (e.g., smartphone, tablet, etc.), and/or a remote server (e.g., a cloud computing system). Processing circuitry 112 may execute various computational functions. For example, processing circuitry 112 (e.g., included in a vehicle head unit, a mobile device, a remote server, etc.) may cause one or more transmitters 114 (e.g., one or more speakers built into the vehicle) to
transmit a series of pings. Processing circuitry 112 may then cause one or more receivers 116 (e.g., one or more microphones built into the vehicle, one or more microphones included in devices, such as smartphones, located within the vehicle, etc.) to receive reflections of the transmitted pings (i.e., received pings). Processing circuitry 112 may then process the transmitted pings and the received pings to determine the position and/or velocity of one or more occupants 120.

In some examples, processing circuitry 112 of system 110 may also interact with applications 118 (e.g., entertainment, navigation apps, smart voice assistant apps, etc.) on behalf of one or more occupants 120. For example, processing circuitry 112 may input the information about the position and/or velocity of one or more occupants to a smart driving companion application (e.g., Android Auto, etc.) to facilitate processes such as automatically unlocking and/or locking the vehicle, automatically starting and/or stopping an engine, automatically adjusting vehicle speaker settings (e.g., volume, balance, equalization, fader, treble, bass, etc.), etc.

In some examples, system 110 may be implemented using in-vehicle speakers 114 and in-vehicle microphones 116 to create an active sonar framework (e.g., an area that system 110 can monitor to determine the position and/or velocity of one or more occupants 120). For example, the in-vehicle speakers 114 may transmit (e.g., emit) one or more pings (e.g., a linearly frequency-modulated (LFM) ultrasonic ping). The in-vehicle microphones 116 may receive (e.g., record) the reflections of the ping.

Processing circuitry 112 may process the transmitted ping and the received ping (e.g., by performing cross-correlation, envelope-detection, etc.) to determine an ultrasonic time-resolved waveform with signals from non-vacuum materials in certain time-of-flight bins. As used herein,
time-of-flight may refer to the amount of time required to send the signal and receive the reflection, and bin may refer to a segment of an axis (e.g., time axis) that includes information about the signal (e.g., amplitude, magnitude, or energy from a specific range of frequencies). As such, a time-of-flight bin may be a segment of a time axis that includes information about the amplitude, magnitude, or energy of the transmitted ping and/or the received ping.

As discussed above, processing circuitry 112 may process the transmitted ping and the received ping by performing cross-correlation, envelope-detection, and/or any other signal processing technique. For example, processing circuitry 112 may perform envelope-detection to determine an envelope of a time-of-flight bin for the transmitted ping and an envelope of a time-of-flight bin for the received ping, each envelope including information about the amplitude, magnitude, or energy of the corresponding ping at various times in the time-of-flight bins. Additionally, or alternatively, processing circuitry 112 may process the transmitted ping and the received ping using a machine learning algorithm. For example, the machine learning algorithm may include a feature extraction module (e.g., a range-frequency transform module) that computes the frequencies of each bin of a frequency axis using fast Fourier transform (FFT) to produce machine-interpretable image data. The machine learning algorithm may then classify the image data to determine the presence of one or occupants.

As indicated above, the system may be configured to transmit, receive, and process more than one ping, such as a series of pings. Processing circuitry 112 may process one or more transmitted pings and one or more received pings to determine an ultrasonic time-resolved waveform with signals from non-vacuum materials in certain time-of-flight bins using the following equations:

\[ c = s \ast r \]
where the variables $s$ and $r$ are the waveforms of the transmitted ping and received ping respectively, and the star symbol is the cross-correlation. Processing circuitry 112 may perform cross-correlation to reject all frequencies other than the ultrasonic frequency band of interest during back-end processing. Processing circuitry 112 may perform envelope detection using any envelope detector, (e.g., asynchronous half-wave envelope detector, synchronous full-wave envelope detector, asynchronous real square-law envelope detector, asynchronous complex envelope detector, asynchronous complex square-law envelope detector, synchronous real envelope detector, etc.).

The amplitude of a received ping (e.g., as indicated by the envelope of the time-of-flight bin for the received ping) of a passenger compartment of a vehicle 100 without any occupants 120, may be smaller than the amplitude of a received ping of a passenger compartment of a vehicle 100 with one or more occupants 120. As such, processing circuitry 112 may process the amplitudes, magnitudes, or energies represented in one or more time-of-flight bins for the respective transmitted ping and received ping (e.g., by implementing a foreground extractor) to determine whether one or more occupants 120 are occupying the passenger compartment of a vehicle 100. For example, system 100 may compute the background using an exponential filter and subtract the output of the exponential filter from incoming data about the one or more transmitted pings and the one or more received pings using the above equations to determine whether one or more occupants 120 are occupying the passenger compartment of a vehicle 100.

In some examples, system 100 may be configured to determine the position and/or velocity of more than one occupant. For example, the active sonar framework may include multiple transmitters 114 (e.g., in-vehicle speakers alongside the doors, windshield, dashboard,
or rear of the passenger compartment of the vehicle, etc.) that, independently or collectively, transmit one or more pings that covers multiple seats. The active sonar framework may further include one or more receivers 116 (e.g., an in-vehicle microphone, a mobile phone, etc.) that, independently or collectively with one or more other receivers 116, receives the one or more transmitted pings. In this way, the active sonar framework may be extended to cover multiple seat locations within the vehicle.

To mitigate ultrasonic interference (e.g., multiple simultaneous transmissions confusing receivers), transmitters 114 of the active sonar framework may each be configured to transmit pings encoded with modified ultrasonic frequency bands uniquely identifying each transmitter 114. As a result, one or more receivers 116 may perform multiple, different cross-correlations and determine the occupancy state of each seat covered by the active sonar framework.

In some examples, system 100 may determine one or more of the number, position, velocity, etc., of occupants 120 occupying the vehicle, and at least some of that data may be inputted into a variety of applications 118 (e.g., entertainment, navigation apps, smart voice assistant apps, etc.), including smart driving companion application (e.g., Android Auto, etc.) to enhance or streamline the user experience. For example, user 120 may, from a distance, use an application on user’s mobile phone (e.g., Android Auto), in conjunction with system 100 to detect the occupancy state of the vehicle, to authenticate user’s identity and proximity to user’s vehicle to unlock user’s vehicle. Upon user 120 entering and sitting in a seat of the vehicle, system 100 may detect the presence of user 120 and start the engine of the vehicle. Additionally or alternatively, user 120 may leave the vehicle. Upon user 120 leaving the passenger compartment of vehicle 100, system 110 may detect that user 120 has been absent for a pre-determined period of time and shut off the engine and lock the vehicle. In another examples,
system 100 may be configured to detect the positions of multiple occupants 120 in the vehicle 100 and spatially-adapt speaker sounds to provide better audio quality. For example, system 100 may automatically adjust vehicle speaker settings (e.g., volume, balance, equalization, fader, treble, bass, etc.) based on the number of occupants in the vehicle, the positions (e.g., seats occupied) of the one or more occupants, etc.

The example systems 110 have numerous advantages. By their nature, ultrasonic frequencies (e.g., greater than about 20 kilohertz) are outside the upper limit of the audible range for humans. Therefore, the pings emitted by the one or more transmitters 114 should be inaudible to occupant 120. Further, system 110 may be implemented without requiring hardware redesign by the original equipment manufacturer. For example, system 110 may be implemented via an update to the software of vehicle 100, potentially reducing the cost of scaling ultrasonic in-vehicle state monitoring. System 110 may also preserve privacy because it does not need to include an optical sensor such as a camera. However, it is to be understood that system 110 may be adapted to further include an optical sensor if such a configuration is desirable.

It is noted that the techniques of this disclosure may be combined with any other suitable technology or combination of technologies, including those listed as references below.

REFERENCES

1. US Patent No. 7134687
2. US Patent No. 7734061
3. US Patent No. 7801570
4. US Patent No. 9008854
5. FR Patent No. 2877279