October 24, 2017

Differential Sonar

Honglei Wu

DIFFERENTIAL SONAR

Abstract:
Sonar is used to track in-room activity. A sonar device provides acoustic location and tracking of multiple objects that are co-present in a room. A sender/receiver in the sonar device directs a sound wave toward the multiple objects and collects the reflected sound waves from the multiple objects over multiple time intervals. The echo characteristics of the co-present multiple objects in the reflected sound waves collected over the multiple time intervals are differentially analyzed to determine the locations of, and track movement of, individual objects of the multiple objects.

The word "sonar" is an abbreviation for "Sound, Navigation and Ranging."

FIG. 1 illustrates the principle of active sonar.

In active sonar, a sound transmitter (or sender) transmits a sound wave pulse, and then a sound receiver listens for a pulse (echo) that is reflected by an object. The transmitted sound wave pulse is generally created electronically using a sonar transmitter that includes a signal generator, a power amplifier and an electro-acoustic transducer. The time lapse or delay between the transmitted sound wave pulse and the received echo is detected or measured. An electronic analyzer (not shown in FIG. 1) coupled to the sender and receiver can determine the time delay, for example, by temporal correlation of a transmitted train of sound wave pulses and the train of reflected sound wave pulses. The time delay is converted into a distance or range of the object using the known speed of sound (e.g., approximately 343 meters per second in air).

In a traditional sonar device, distance determination and motion tracking is based on information carried in the "first to arrive" reflected sound wave pulse. A traditional sonar device cannot track multiple objects directly because of a line-of-sight limitation. In other words, a traditional sonar device only “sees” the first object in its direct line-of-sight and does not see any objects that are blocked by the first object. A traditional sonar device also suffers from a “number of objects” limitation. If multiple reflected sound waves are received from the multiple objects (e.g., in response a sound wave pulse transmitted by the sender), the sound receiver in a traditional sonar device may merely recognize the first reflected sound wave pulse received from the closest of the multiple objects as being the echo. In other words, a traditional sonar device only "sees" the closest one object of multiple objects and cannot track the multiple objects individually. Thus, a traditional sonar device cannot be used to track, for example, in-room activity, when multiple objects (e.g., a chair and person) are co-present in a room.

A sonar device, as described herein, can be configured for distance determination and motion tracking of individual objects in multiple object scenarios. The distance determination and motion tracking of individual objects of the multiple objects is based on analysis of information in multiple reflected sound waves that are received over diverse time intervals, and not merely the information carried in the "first to arrive" reflected sound wave.

FIG. 2 is an illustration of the sonar device, which may be deployed to track in-room activity when multiple objects (e.g., a chair and a person) are co-present in a room. As shown in FIG. 2, the sonar device may transmit a sound wave pulse in the room. Each of the multiple objects (e.g., the chair and the person) that are co-present in the room can return a respective reflected sound wave pulse to the sonar device. The reflected sound wave pulses from individual objects amongst the multiple objects (e.g., the chair and the person) are received at different times corresponding to the different distances of the individual objects from the sonar device.

FIG. 3 schematically illustrates the reflected sound wave received by the sonar device that includes idealized (for purposes of illustration) reflected sound wave pulses from the chair and the person in the room.

In actual room conditions, the reflected sound waveforms can be more complex than shown in FIG. 3, for example, because the reflecting objects may have reflecting surfaces that extend over distance or the reflecting objects may block each other, and because the reflecting objects and other objects (e.g., walls of the room) may multiply reflect or bounce the sound waves off each other.

Because the reflected sound waveforms of multiple objects can be complex, a traditional sonar device may fail to distinguish or track individual objects based on the sound wave reflected in the room, or may merely distinguish or track the closest object (the chair) by recognizing only the “first to arrive” sound wave (i.e., the reflected sound wave from the chair).

In contrast, the sonar device of FIG. 2, as described herein, provides acoustic location and tracking of individual objects of the set of multiple objects that are co-present in a room. The sonar device selects one or more characterizing features or attributes of the complex waveform of the sound wave reflected in the room, which features or attributes may be sensitive or responsive to movement or repositioning of an individual object in the set of multiple objects. Values of these one or more characteristics or attributes may change when individual objects (e.g., the person) move or are geometrically repositioned relative to the other objects in the set of multiple objects. The sonar device collects samples of the entire sound wave reflected in the room over different time intervals, and compares at least two different temporal samples to determine changes in the values of these one or more characteristics or attributes. The sonar device can determine distance and track movement of individual objects based on the determined changes.

FIG. 4 illustrates an example implementation of a sonar device that can analyze complex reflected sound waveforms to track the movement of individual objects in the set of multiple objects. The sonar device includes an interface (e.g., acoustic transducer interface) between the sender/receiver of the sonar device and an analyzer unit that includes an attribute extractor, a memory, and a temporal difference data processing unit.

The attribute extractor is configured to select one or more characterizing features or attributes of an individual object in the complex waveform of the sound wave reflected by the set of multiple objects. Values of one or more characterizing features or attributes of the individual object in the complex waveform may be susceptible to change because of movement or repositioning of the individual object in the set of multiple objects. Further, the attribute extractor can, for example, extract the selected characterizing features or attributes from different temporal samples of the complex waveform of the sound wave reflected by the a set of multiple objects. The different temporal samples obtained over different time intervals and or the extracted attributes can, for example, be stored in memory, for example, for analysis by the temporal difference data processing unit of the analyzer unit.

The temporal difference data processing unit in the analyzer unit can temporally compare two different temporal samples to determine if there are changes in the selected characterizing features or attributes with time, and accordingly infer movement or repositioning of the individual object in the set of multiple objects.

One version of the attribute extractor used in the sonar device of FIG. 4 can be configured to select one or more characterizing features or attributes of an individual object based on in-phase information and quadrature information of the complex waveform of the sound wave reflected by the set of multiple objects. FIG. 5 illustrates an example configuration of an attribute extractor for extracting in-phase information and quadrature information from an input signal. As shown in FIG. 5, the attribute extractor includes an in-phase/quadrature clock generator whose in-phase clock and quadrature clock outputs are multiplied with the input signal, and passed through respective low-pass filters to obtain the in-phase information and quadrature information.

The received reflected sound waveforms can be "preconditioned" by extracting the attributes using the attribute extractor, and then data processing can be performed on the extracted attributes, instead of the raw reflected sound waveforms. For example, instead of directly comparing the received reflected sound waveforms, the sonar device can extract the in-phase information and quadrature information and compare the in-phase information and quadrature information.

A second version of the attribute extractor used in the sonar device of FIG. 4 can be configured to select one or more characterizing features or attributes of an individual object based on amplitude information and phase information of the complex waveform of the sound wave reflected by the set of multiple objects. FIG. 6 illustrates an example configuration of an attribute extractor for extracting in-amplitude information and phase information from an input signal. As shown in FIG. 6, the attribute extractor includes a band pass filter to limit the frequency range of the input signal, followed an amplitude detector and a phase detector that obtain the amplitude information and phase information from the output of the band pass filter, respectively.

In this case also, the received reflected sound waveforms can be "preconditioned" by extracting the attributes using the attribute extractor, and then data processing can be performed on the extracted attributes, instead of the raw reflected sound waveforms. For example, instead of directly comparing the received reflected sound waveforms, the sonar device can extract the amplitude information and phase information and compare the amplitude information and phase information.

With reference to the example of the chair and the person co-present in a room, FIG. 7 is an illustration of the changes in the reflected sound waveform that may be caused when an object (e.g., the person) moves or is repositioned. Two temporal samples (e.g. Sample 1 and Sample 2) of the reflected sound waveform corresponding to two different positions of the person are shown in FIG. 7. In Sample 1, the reflected sound waveform includes a contribution of the reflected pulse from the chair and a contribution of the reflected pulse from the person at a first position. In Sample 2, the reflected sound waveform includes the same contribution of the reflected pulse from the chair (because the chair has not moved in the room). However, in Sample 2, the contribution of the reflected pulse from the person is at different time point because of the movement and changed position of the person in the room.

FIG. 8 is an illustration of an example algorithm that may be used in the sonic device of FIG. 4 in conjunction with the temporal difference data processing unit to compare two different temporal samples and infer movement or repositioning of the individual object in the set of multiple objects.

As shown in FIG. 8, the sonar device transmits a first sound wave pulse, and copies the reflected sound wave received over a first time interval, after attribute extraction, to memory as Sample 1. Sample 1 is stored as a baseline sample in memory. The sonar device then transmits a second sound wave pulse, and copies the reflected sound wave received over a second time interval, after attribute extraction, to memory as Sample 2. Next, the temporal difference data processing unit looks for significant differences between Sample 1 and Sample 2 in the characteristic features of an individual object. If a significant difference is found, the temporal difference data processing unit computes a movement distance of the individual object based on the time location of the significant difference. The movement distance is the distance that the individual object may have moved in the time between the times Sample 1 and Sample 2 were obtained.

To continue tracking the objects in time, as further shown in FIG. 8, the sonar device may iteratively update the baseline sample in memory by copying Sample 2 as Sample 1 in memory, and obtain a new Sample 2 for comparison with the baseline sample.

FIG. 9 visually shows an example determination by the sonar device of significant differences between two temporal samples (e.g., Sample 1 and Sample 2) of the reflected sound waveform.

Sample 1 and Sample 2, as shown in FIG. 9, include waveforms for two extracted attributes (e.g., Attribute 1 and Attribute 2) characterizing features or attributes of an individual object (e.g., a person) in the complex waveform of the sound wave reflected by the set of multiple objects. Attribute 1 and Attribute 2 may, for example, be the amplitude and phase of the reflected sound waveform, respectively. As shown visually in FIG. 9, the waveforms of the two attributes in Sample 1 and Sample 2 are significantly different at about 10 milliseconds. This significant difference is detected by the temporal difference data processing unit in the sonar device using, for example, the algorithm described above (FIG. 8). The time difference of 10 milliseconds at the speed of sound corresponds to a distance of about 5 feet. Thus, the sonar device may track the individual object (e.g., the person) as having moved by about 5 feet in the time from Sample 1 to Sample 2.

The sonar devices described herein may be used, for example, in conjunction with Internet-of-Thing (IOT) devices and systems. Human-to-device distance information provided by the sonar devices may be used by the IOT devices and systems to, for example, prompt a user interaction, turn appliances on-or-off, activate home security systems and smart home systems, etc.

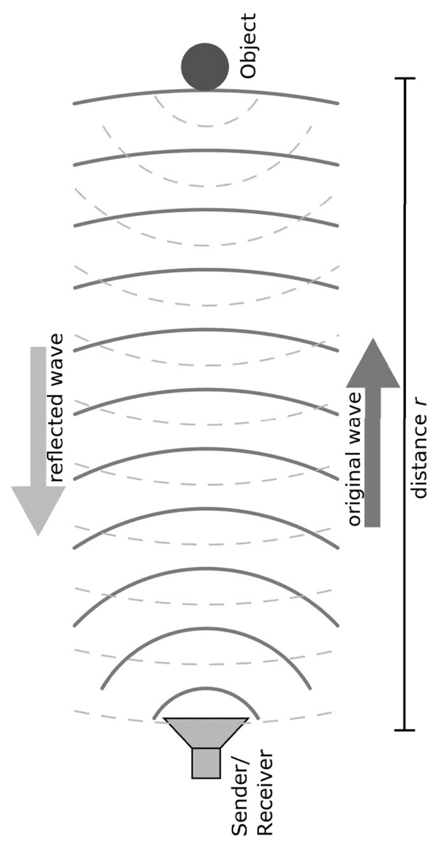
Object
reflected wave
original wave
distance r
Sender/
Receiver

FIG. 1

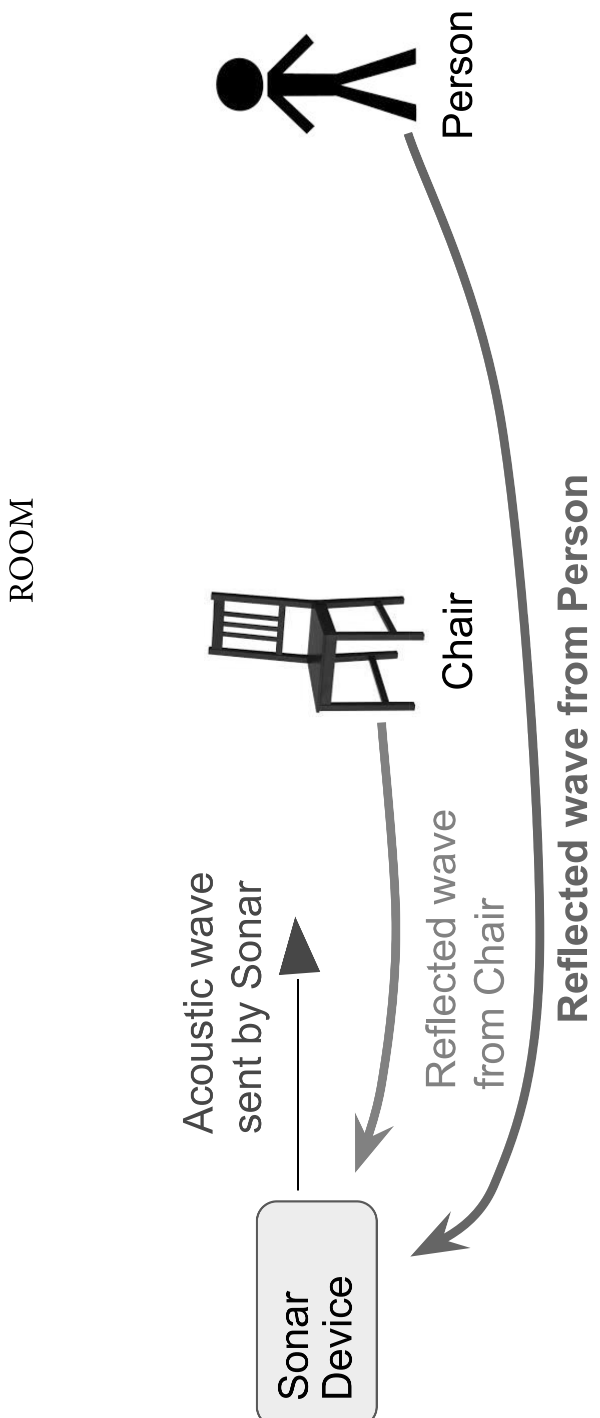
ROOM
Person
Chair
Acoustic wave sent by Sonar
Reflected wave from Chair
Reflected wave from Person
Sonar Device

FIG. 2

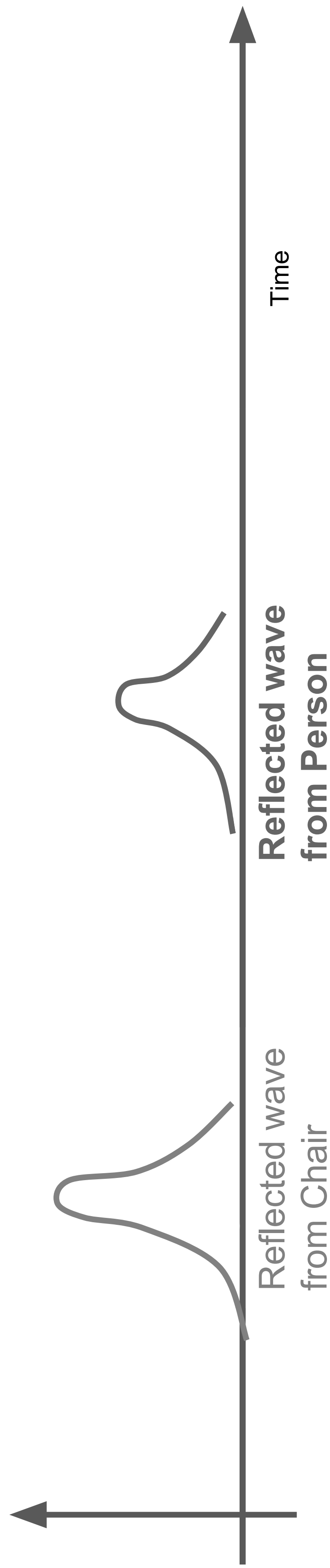

FIG. 3

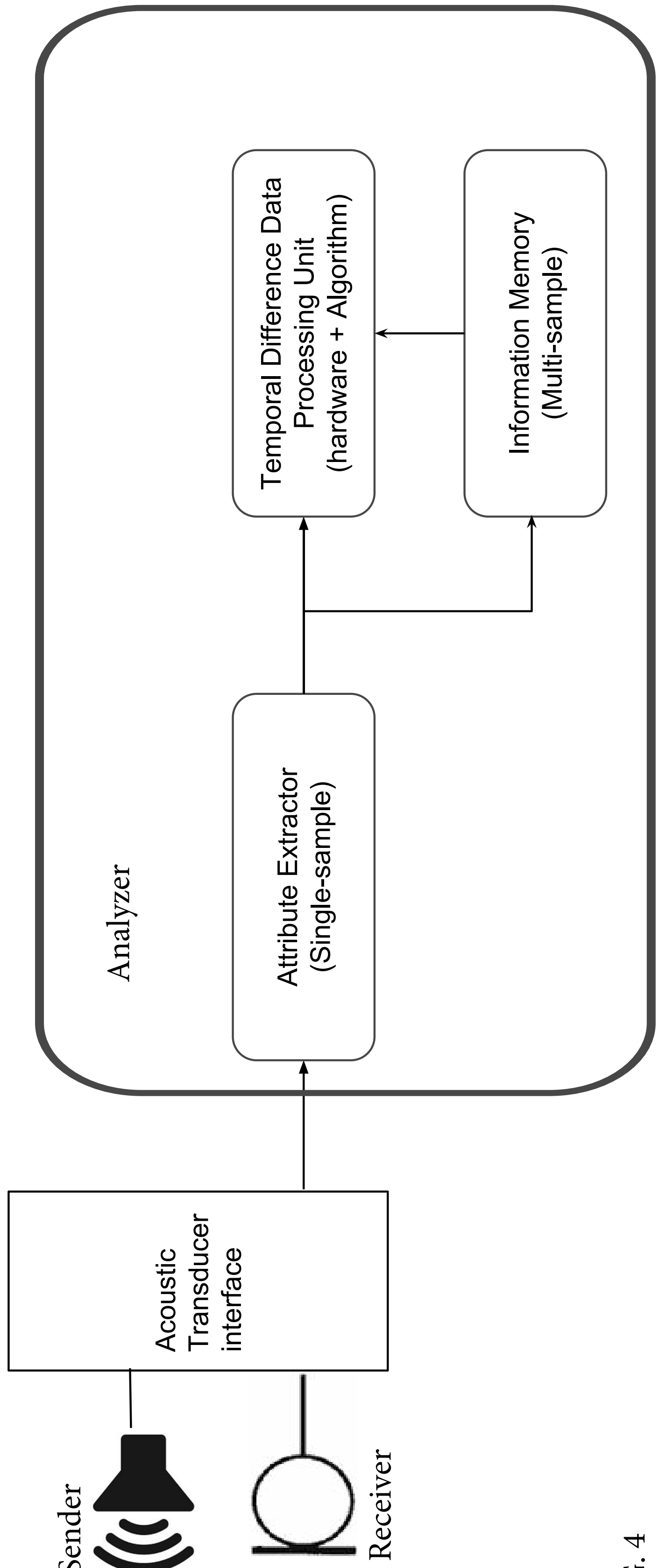
Analyzer
Attribute Extractor
(Single-sample)
Temporal Difference Data
Processing Unit
(hardware + Algorithm)
Information Memory
(Multi-sample)
Acoustic
Transducer
interface
Sender
Receiver

FIG. 4

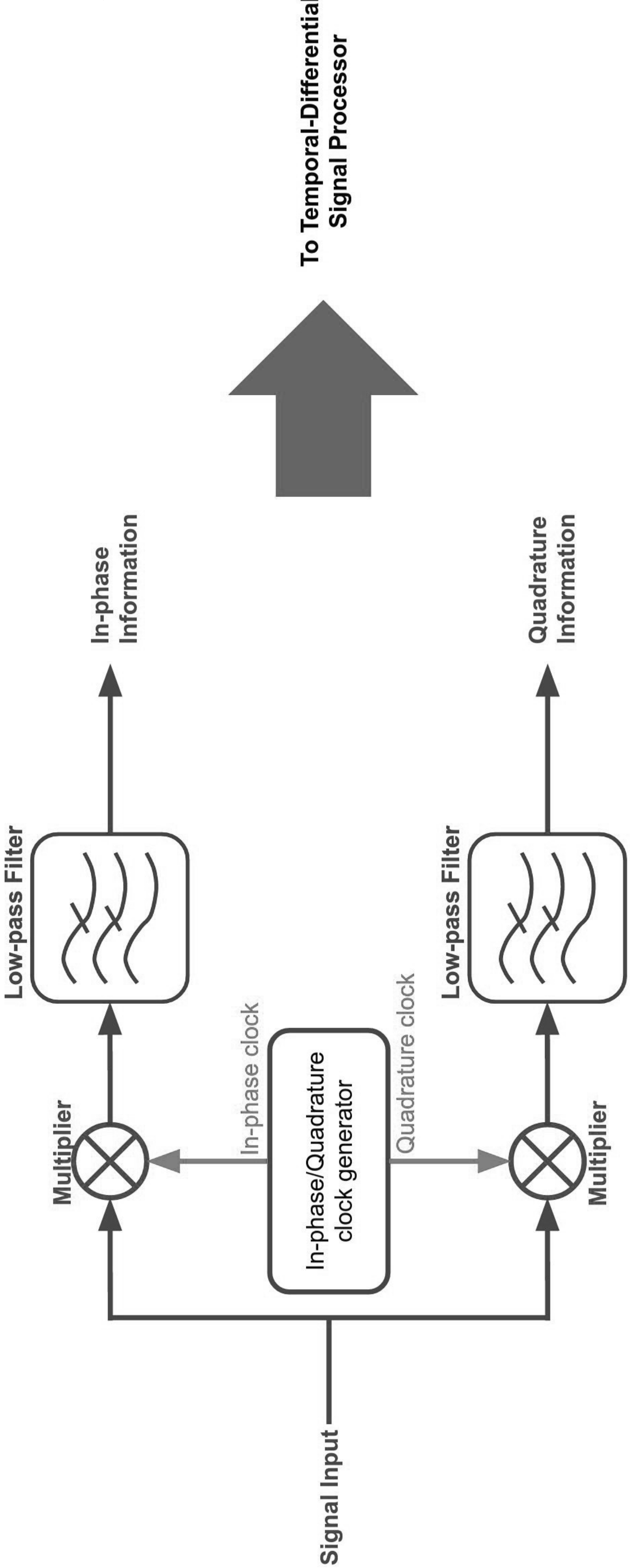
To Temporal-Differential
Signal Processor
In-phase
Information
Quadrature
Information
Low-pass Filter
Low-pass Filter
In-phase clock
Quadrature clock
In-phase/Quadrature
clock generator
Multiplier
Multiplier
Signal Input

FIG. 5

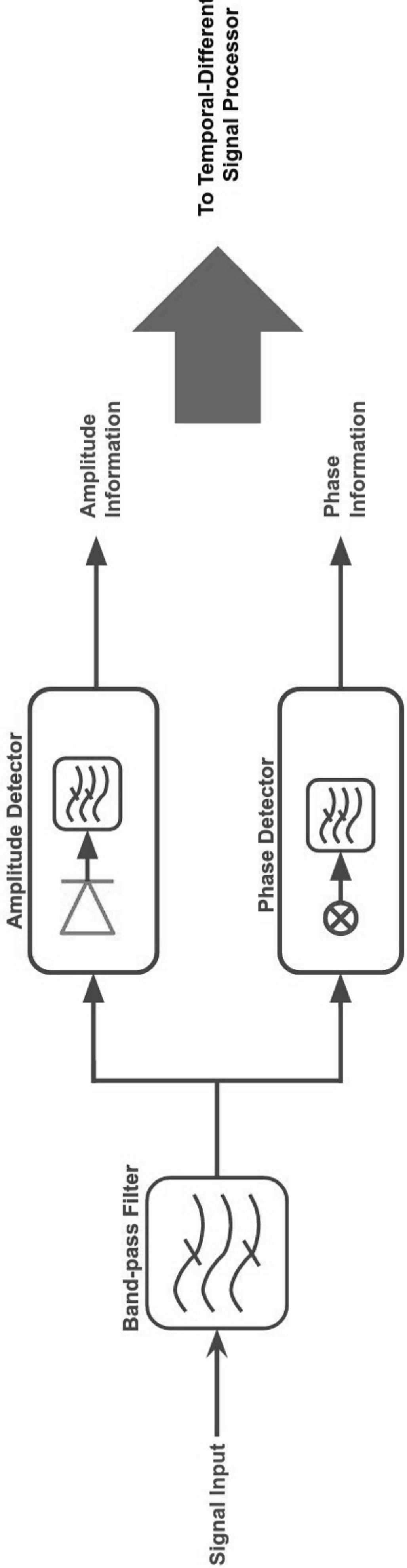
Signal Input
Band-pass Filter
Amplitude Detector
Phase Detector
Amplitude Information
Phase Information
To Temporal-Differential Signal Processor

FIG. 6

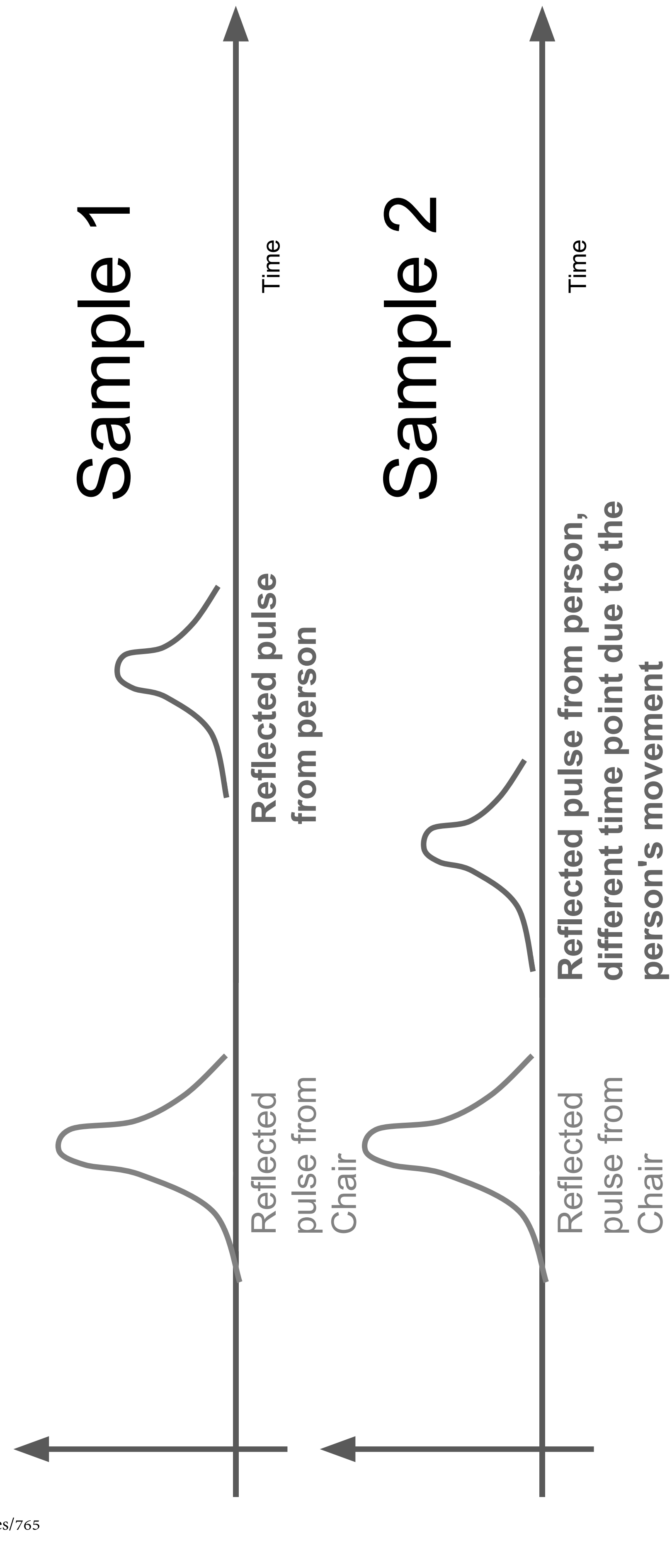
Sample 1
Time
Reflected pulse from person
Reflected pulse from Chair
Sample 2
Time
Reflected pulse from person, different time point due to the person's movement
Reflected pulse from Chair

FIG. 7

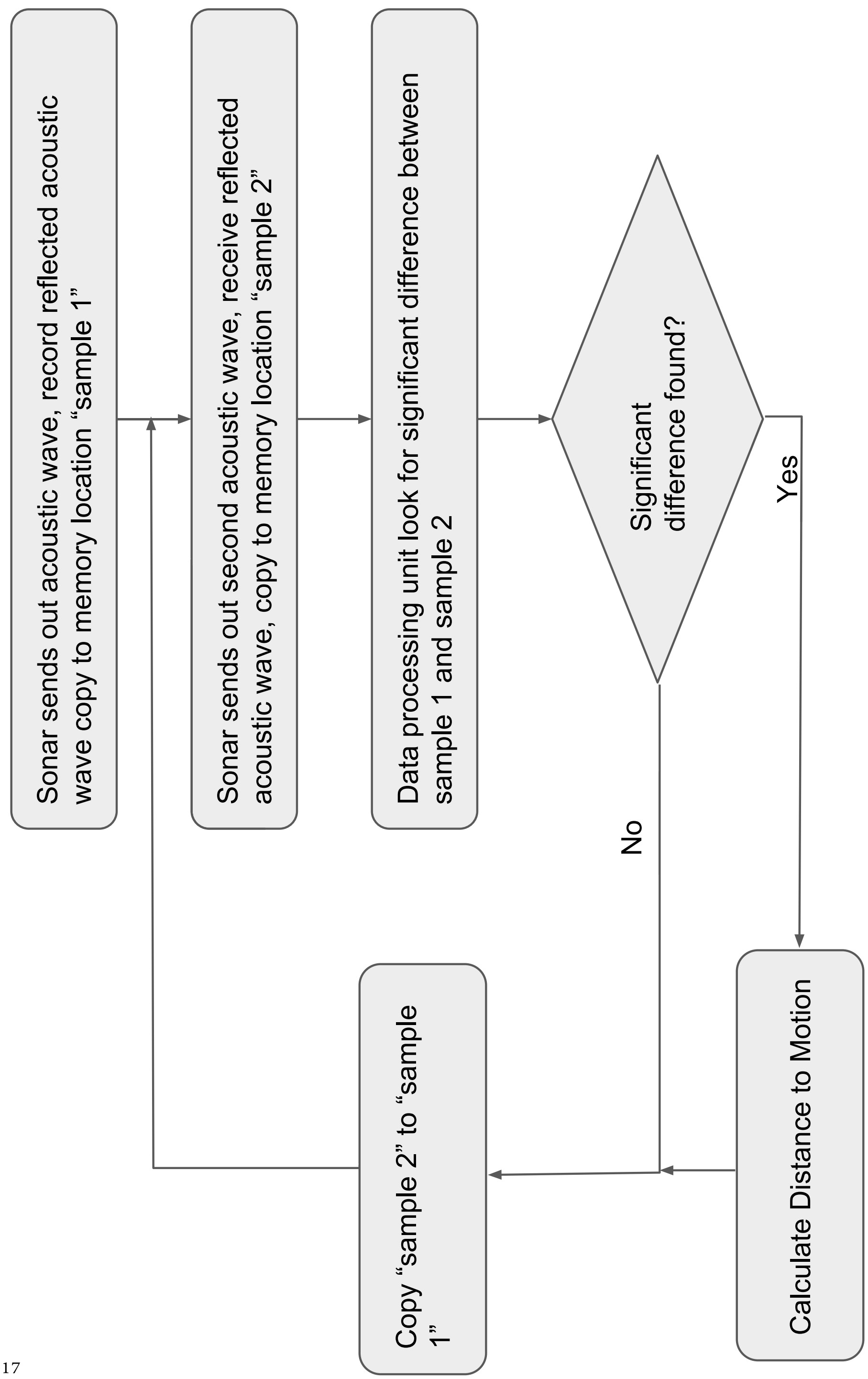
Sonar sends out acoustic wave, record reflected acoustic wave copy to memory location “sample 1”
Sonar sends out second acoustic wave, receive reflected acoustic wave, copy to memory location “sample 2”
Data processing unit look for significant difference between sample 1 and sample 2
Significant difference found?
Yes
No
Calculate Distance to Motion
Copy “sample 2” to “sample 1”

FIG. 8

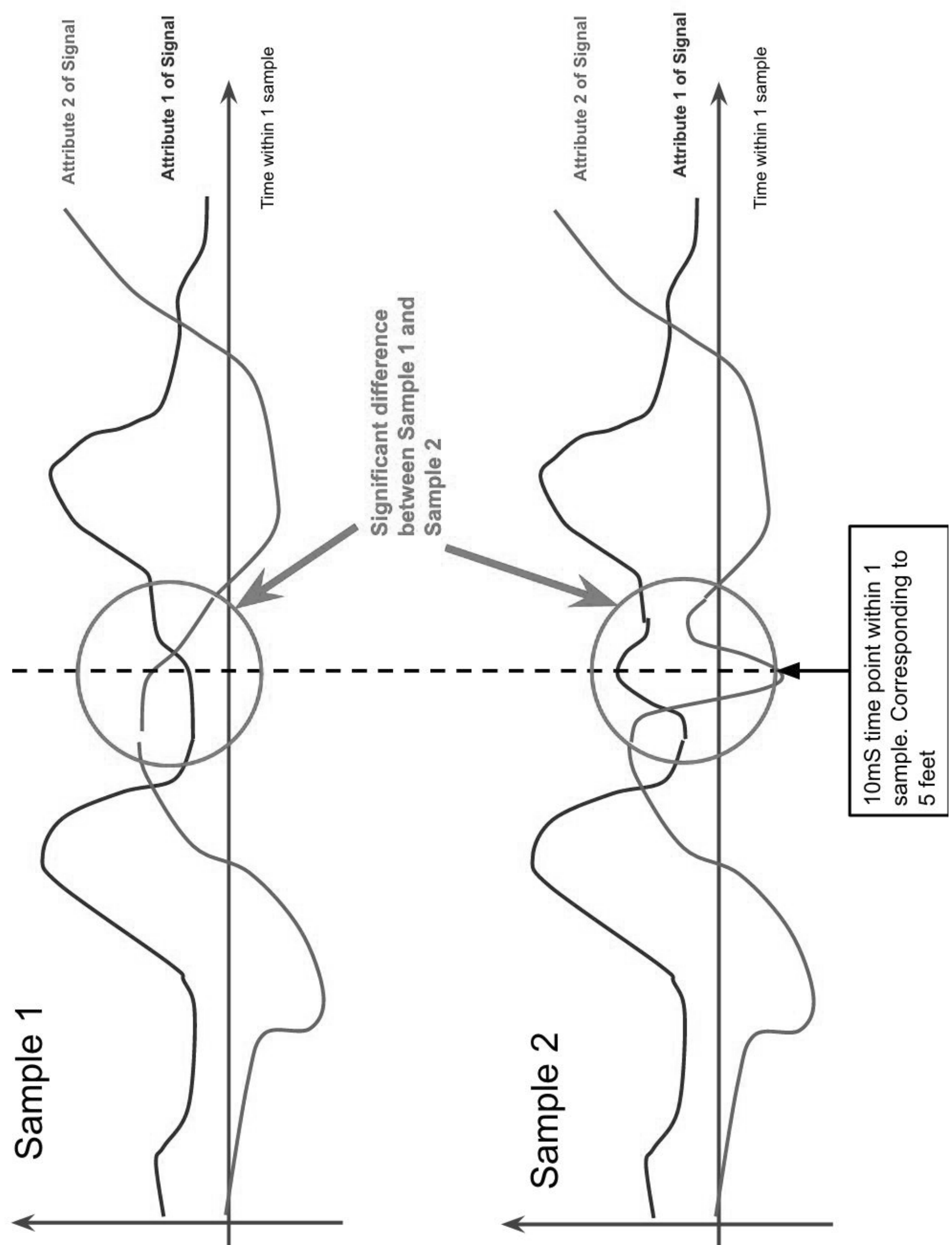
Sample 1
Attribute 2 of Signal
Attribute 1 of Signal
Time within 1 sample
Significant difference between Sample 1 and Sample 2
Sample 2
Attribute 2 of Signal
Attribute 1 of Signal
Time within 1 sample
10mS time point within 1 sample. Corresponding to 5 feet

FIG. 9