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(54) ULTRASONIC SENSOR

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(57) **ABSTRACT**

An ultrasonic sensor, that transmits probe waves which are ultrasonic waves and acquires detection waves including reflected waves which have been reflected from surrounding objects, includes a transmitter/receiver that transmits the probe waves and acquires the detection waves, a detection wave processing section that executes processing for passing a predetermined frequency band which includes the frequency of the probe waves, an amplitude measurement section which measures the amplitude of the detection waves, and a judgement section which judges whether there is adherence of foreign matter on the transmitter/receiver, based on a relationship between a time axis and values of the amplitude of the detection waves during a reverberation interval following the termination of transmitting the probe waves.

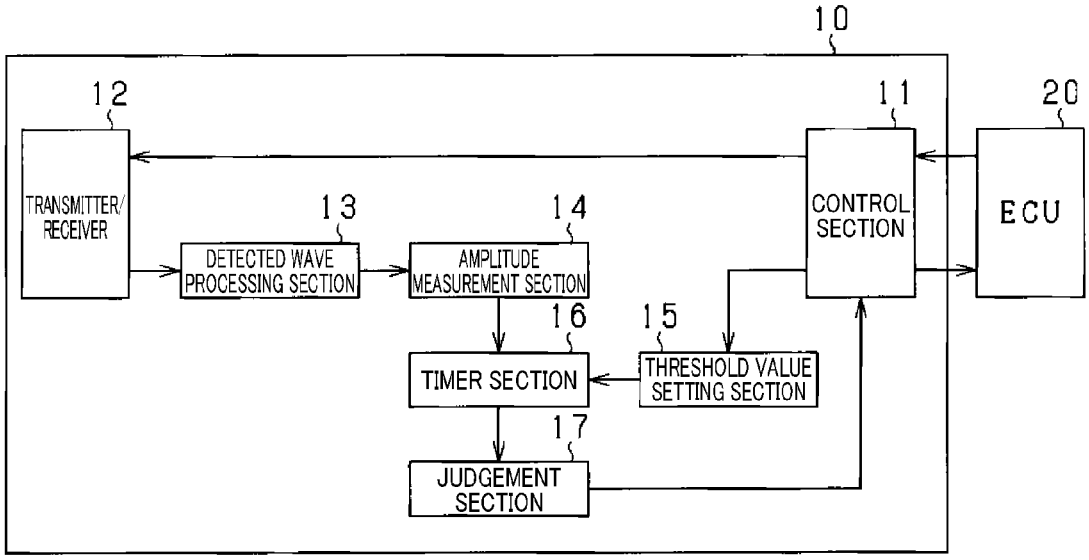


FIG.1

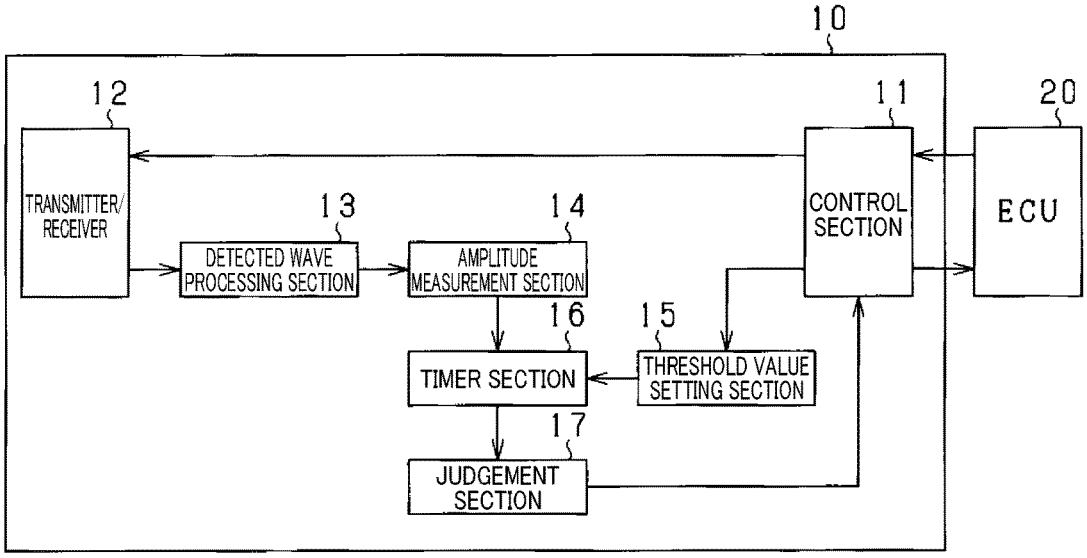

10
12
11
20
TRANSMITTER/
RECEIVER
13
14
DETECTED WAVE
PROCESSING SECTION
AMPLITUDE
MEASUREMENT SECTION
CONTROL
SECTION
ECU
16
15
TIMER SECTION
THRESHOLD VALUE
SETTING SECTION
17
JUDGEMENT
SECTION

FIG.2

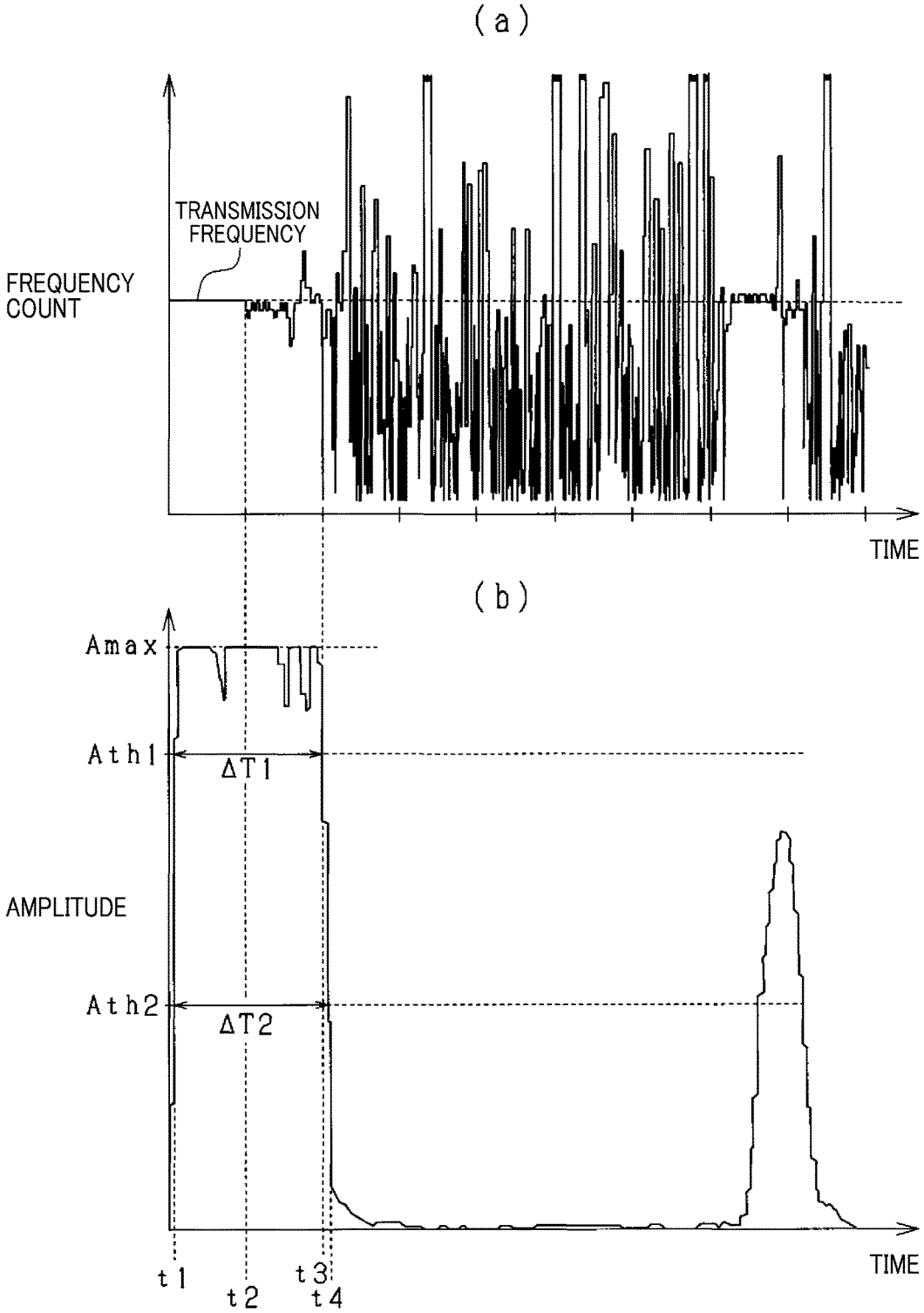

(a)
TRANSMISSION FREQUENCY
FREQUENCY COUNT
TIME
(b)
Amax
Ath1
ΔT1
AMPLITUDE
Ath2
ΔT2
t1
t2
t3
t4
TIME

FIG.3

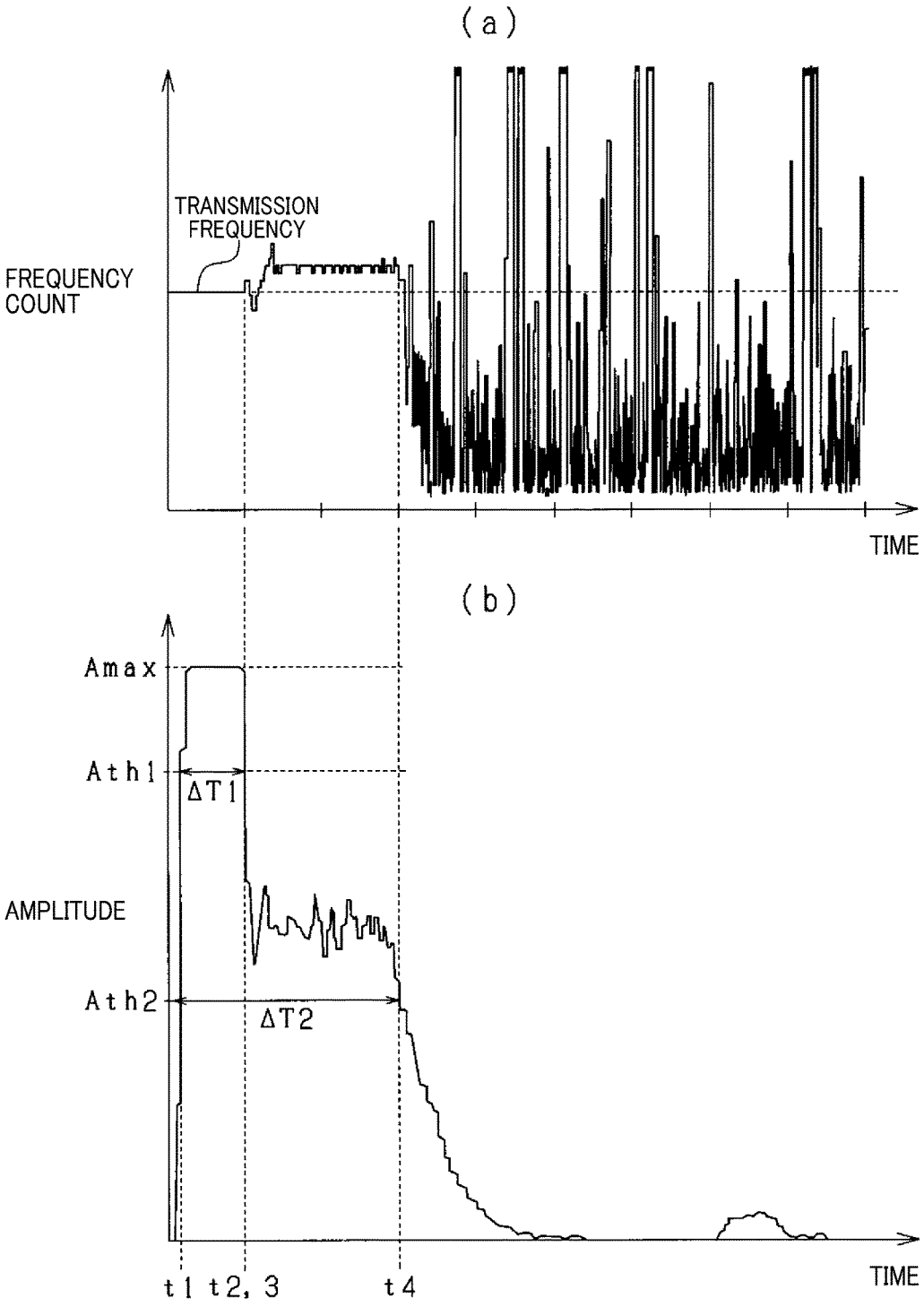

(a)
TRANSMISSION FREQUENCY
FREQUENCY COUNT
TIME
(b)
Amax
Ath1
ΔT1
AMPLITUDE
Ath2
ΔT2
t1
t2, 3
t4
TIME

FIG.4

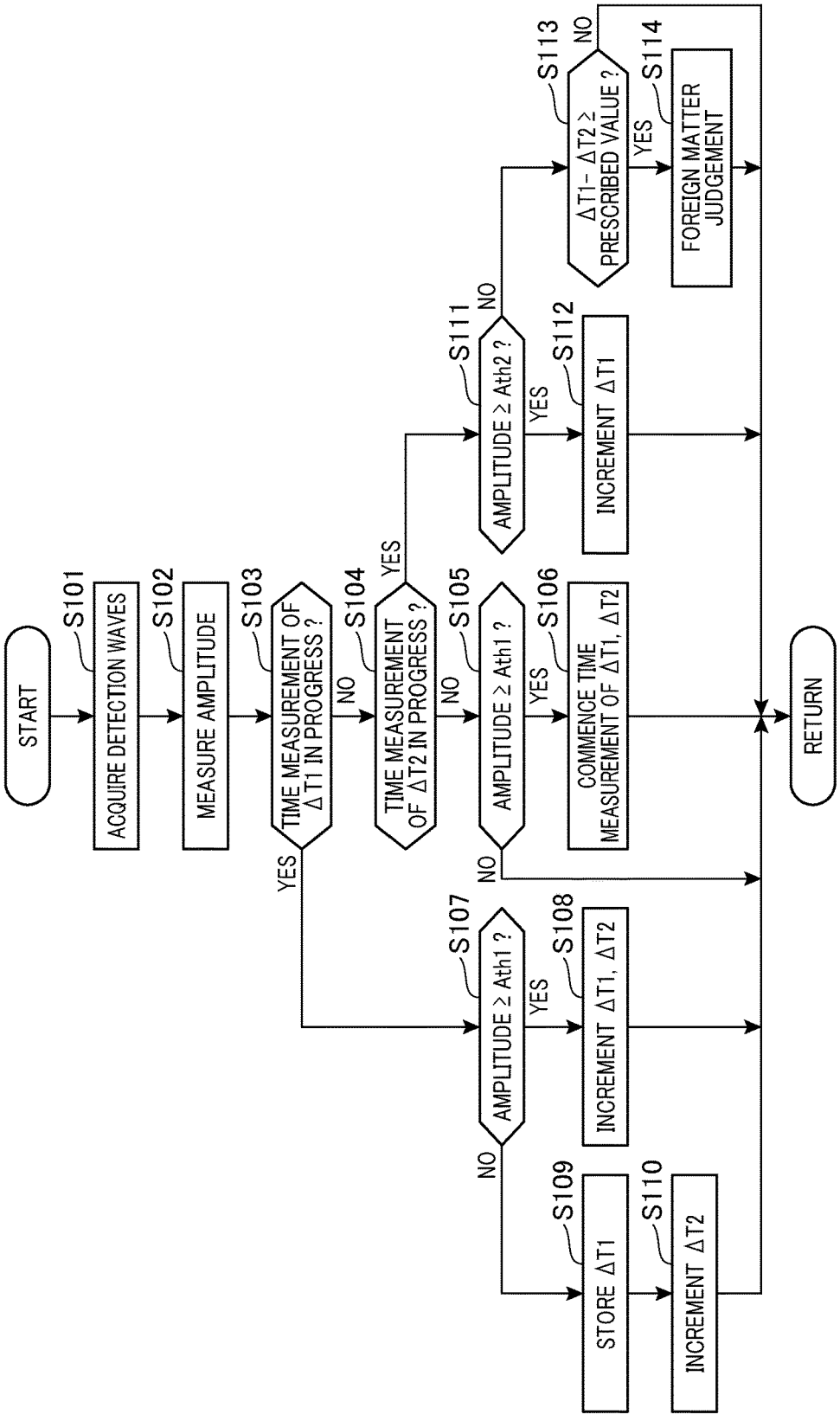

START
S101
ACQUIRE DETECTION WAVES
S102
MEASURE AMPLITUDE
S103
TIME MEASUREMENT OF ΔT1 IN PROGRESS ?
YES
NO
S104
TIME MEASUREMENT OF ΔT2 IN PROGRESS ?
YES
NO
S105
AMPLITUDE ≥ Ath1 ?
YES
NO
S106
COMMENCE TIME MEASUREMENT OF ΔT1, ΔT2
S111
AMPLITUDE ≥ Ath2 ?
YES
NO
S112
INCREMENT ΔT1
S113
ΔT1− ΔT2 ≥ PRESCRIBED VALUE ?
YES
NO
S114
FOREIGN MATTER JUDGEMENT
S107
AMPLITUDE ≥ Ath1 ?
YES
NO
S108
INCREMENT ΔT1, ΔT2
S109
STORE ΔT1
S110
INCREMENT ΔT2
RETURN

FIG.5

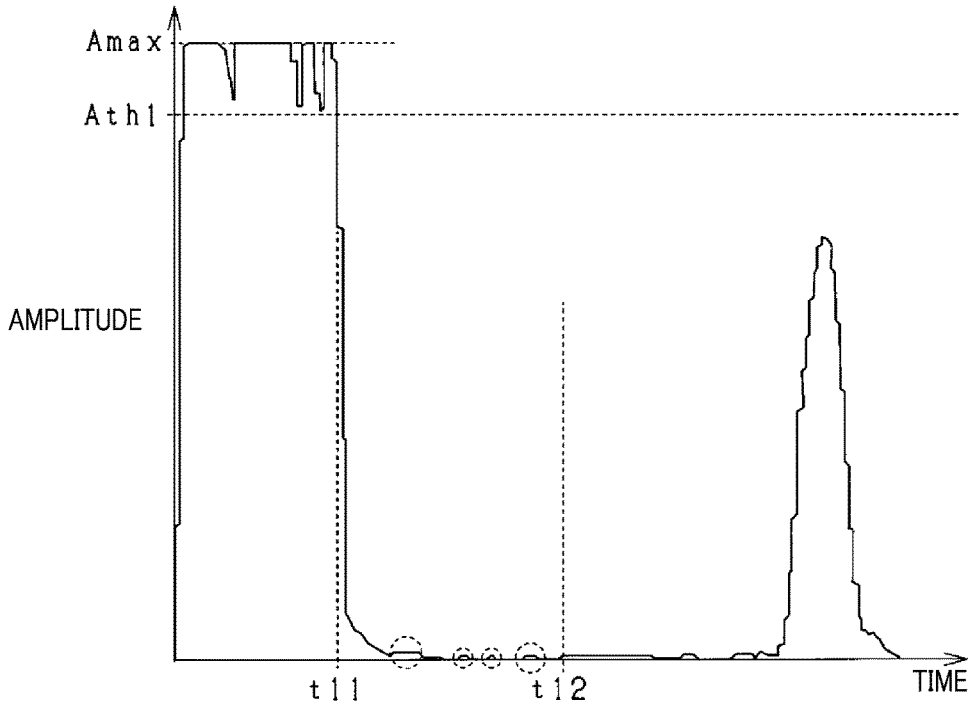

Amax
Ath1
AMPLITUDE
t11
t12
TIME

FIG.6

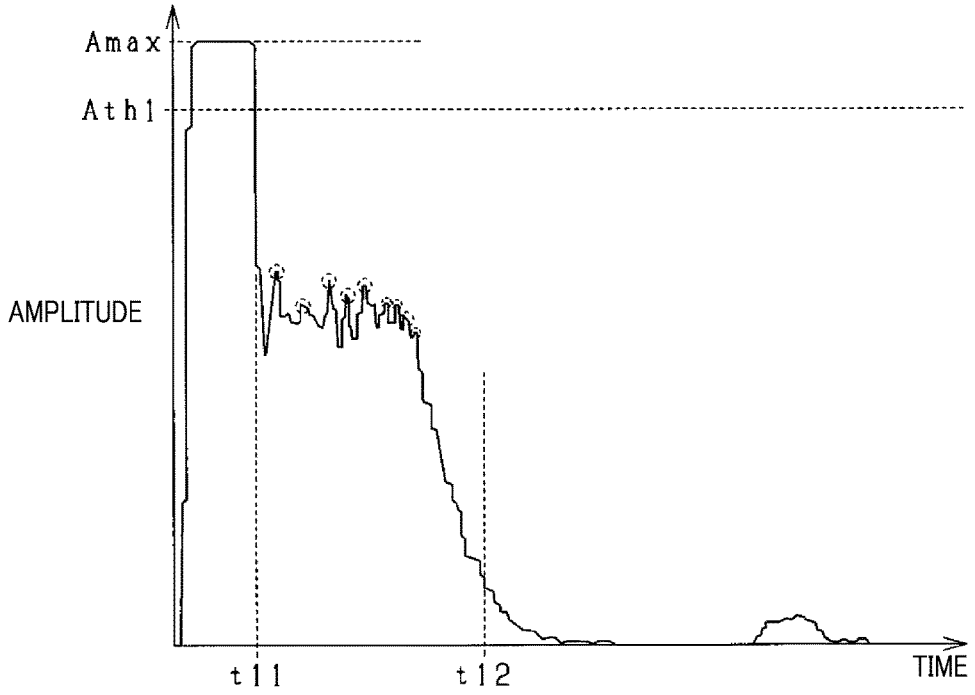

Amax
Ath1
AMPLITUDE
t11
t12
TIME

FIG.7

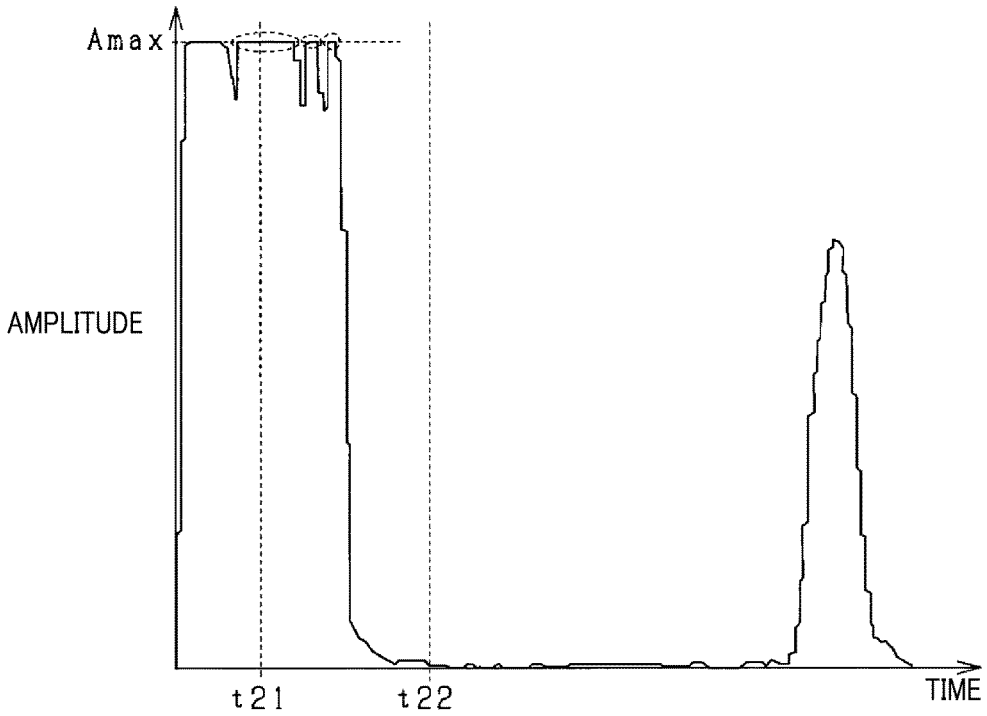


FIG.8

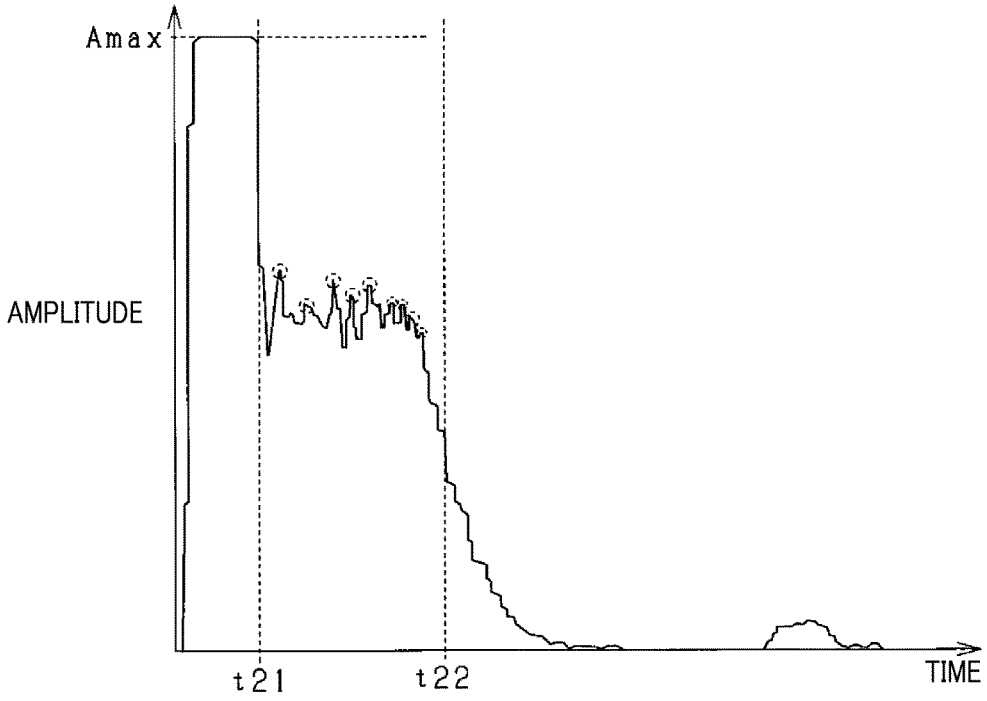


FIG.9

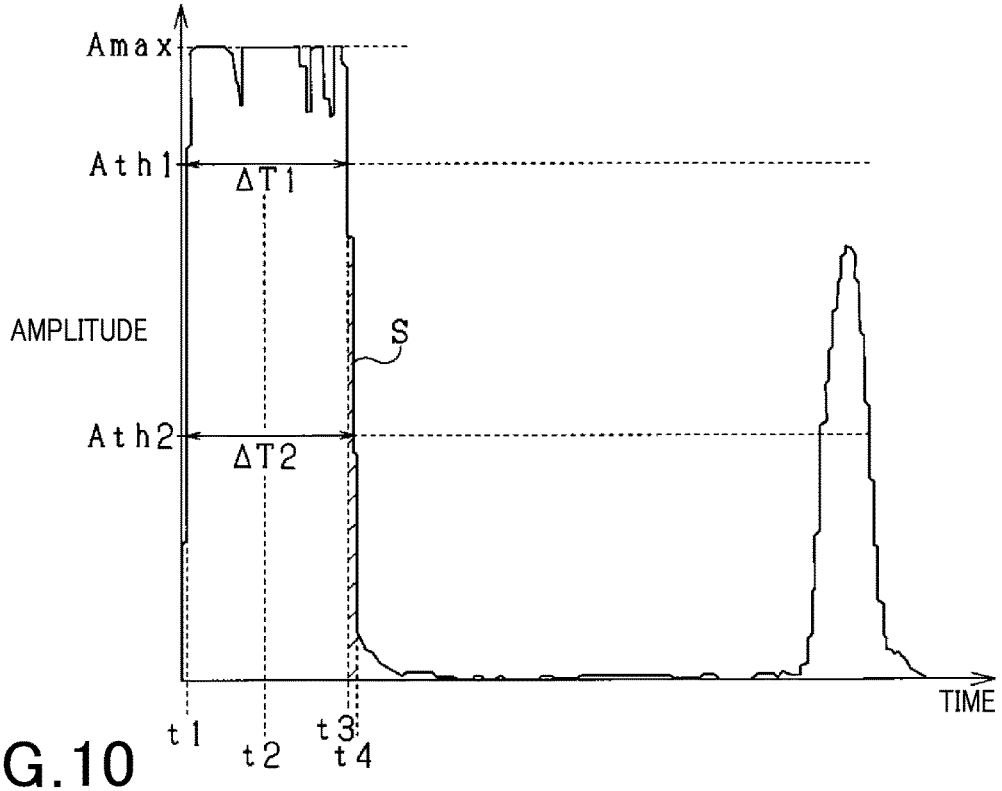

Amax
Ath1
ΔT1
AMPLITUDE
S
Ath2
ΔT2
TIME
t1
t2
t3
t4

FIG.10

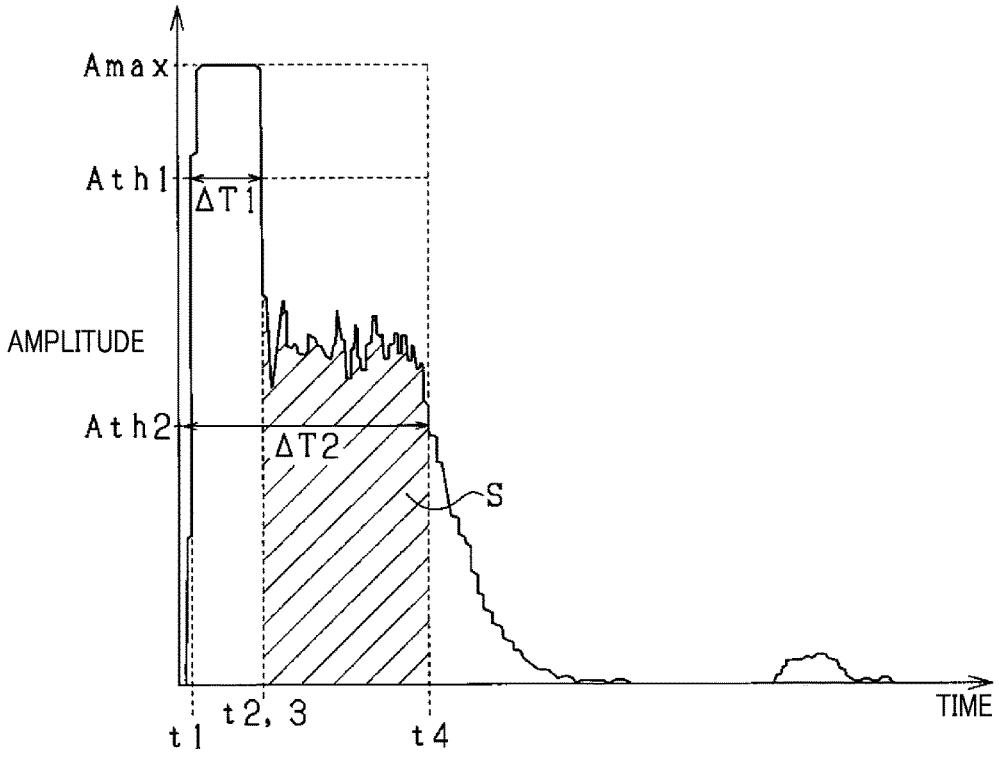

Amax
Ath1
ΔT1
AMPLITUDE
Ath2
ΔT2
S
TIME
t1
t2, 3
t4

FIG.11

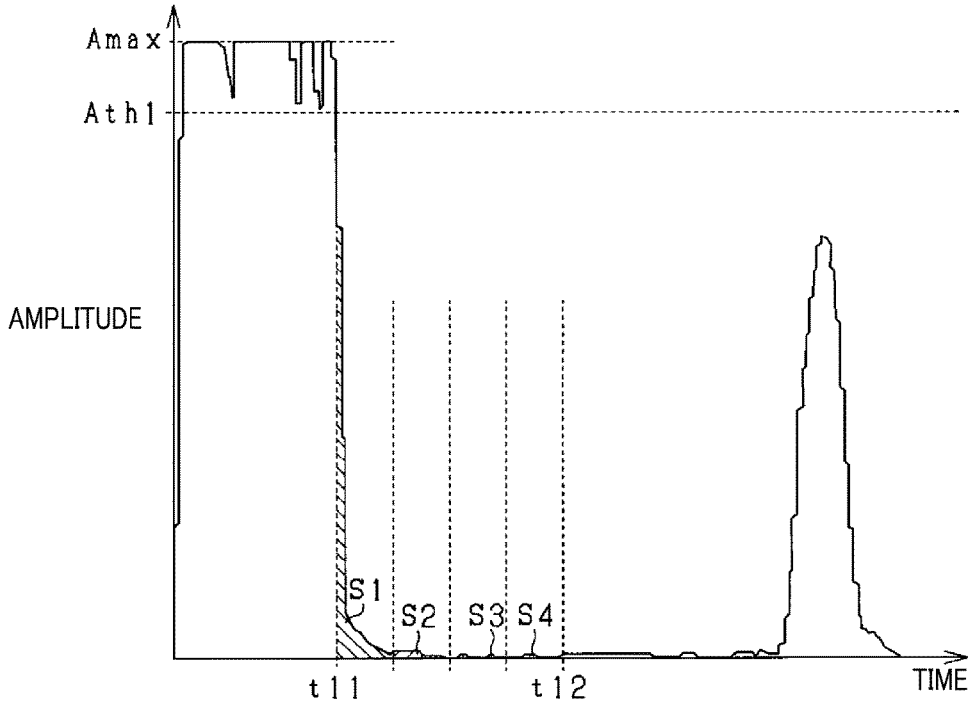
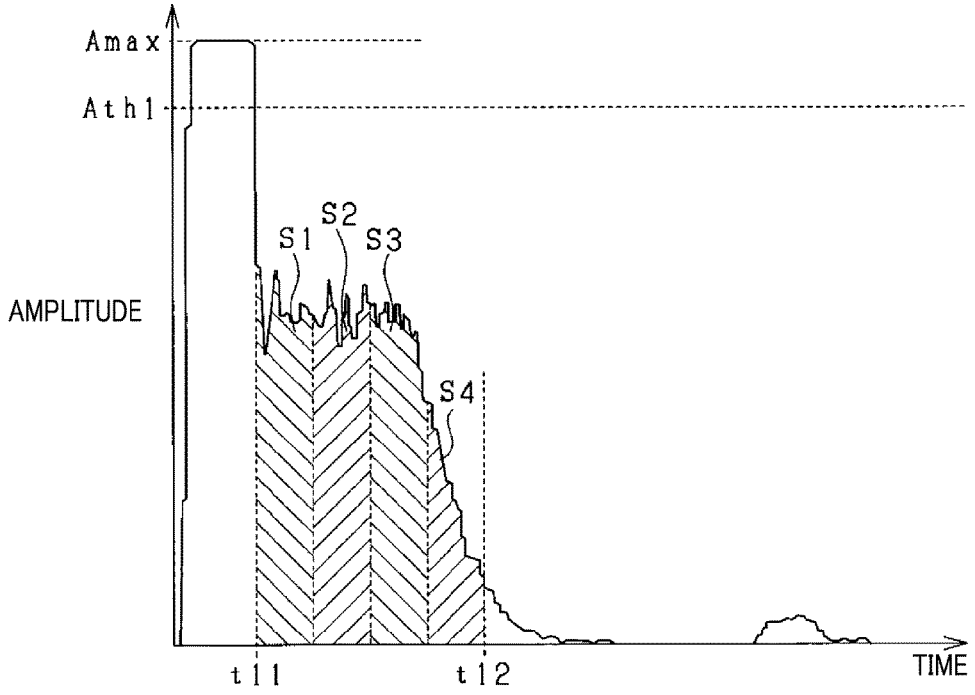

Amax
Ath1
AMPLITUDE
S1
S2
S3
S4
t11
t12
TIME

FIG.12


Amax
Ath1
AMPLITUDE
S1
S2
S3
S4
t11
t12
TIME

ULTRASONIC SENSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This international application is based upon and claims priority of the prior Japanese Patent Application No. 2016-113866, filed in Japan Patent Office on Jun. 7, 2016, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to an ultrasonic sensor that transmits ultrasonic waves as probe waves, and acquires reflected waves that are reflected from objects in the surroundings, with the reflected waves including detection waves.

BACKGROUND ART

[0003] In the prior art, ultrasonic sensors have been implemented which transmit ultrasonic waves as probe waves, receive reflected waves that are reflected from an object, and detect the distance of the object. With such an ultrasonic sensor, when foreign matter such as water or the like adheres to a transmitter/receiver which performs transmission of the probe waves and reception of the detection waves, there is a danger that errors will arise in the calculated distances of objects, or an object may be judged to exist where it does not, or it may be judged that there is no object when an object actually does exist. Hence, it is necessary to be able to judge whether or not there is foreign matter adhering to the transmitter/receiver.

[0004] An ultrasonic sensor which judges when there is foreign matter adhering to the transmitter/receiver is disclosed in PTL 1. With the ultrasonic sensor disclosed in PTL 1, judgement as to whether or not there is foreign material adhering to the transmitter/receiver is made by using a time point at which an amplitude falls below a set threshold value.

CITATION LIST

Patent Literature

[0005] [PTL 1] Japan Patent Publication No. 2015-40837

SUMMARY OF THE INVENTION

[0006] In a case where foreign matter such as water or mud adheres to the surface of the ultrasonic sensor, a change will occur in frequency due to the effects of the mass, etc., of the foreign matter. In general with an ultrasonic sensor, the amplitude is acquired after passing a received signal through a bandpass filter for removal of noise, and hence, if there is a change in the reverberation frequency, the amplitude will not decrease gradually but will vary in a stepwise manner. Thus, with the ultrasonic sensor of PTL1, it is not possible to accurately obtain time point at which the amplitude falls below the threshold value, and hence, it is difficult to accurately judge whether or not there is adherence of foreign matter.

[0007] The present disclosure is intended to overcome the above problem, having a main objective of providing an ultrasonic sensor which can accurately judge when there is foreign matter adhering to the surface of a transmitter/receiver.

[0008] The present disclosure relates to an ultrasonic sensor that transmits probe waves which are ultrasonic waves and acquires detection waves including reflected waves that are reflected from surrounding objects, and includes a transmitter/receiver that transmits the probe waves and acquires the detection waves, a detection wave processing section that executes processing for passing a predetermined band of frequencies which include the frequency of the probe waves, an amplitude measurement section which measures the amplitude of the detection waves, and a judgement section that judges the adherence of foreign matter on the transmitter/receiver, based on a relationship between a time axis and values of the amplitude of the detection waves during a reverberation interval which follows the termination of transmitting the probe waves.

[0009] In a case where there is no foreign matter adhering to the transmitter/receiver, then the frequency of a reverberation, which is produced following termination of transmitting the probe waves, will be close to the frequency of the probe waves. In that case, even when processing for passing a prescribed band of frequencies is executed by the detection wave processing section on the detection waves, in acquiring the amplitude of the reverberation, the detection waves will not be readily attenuated. On the other hand, if there is foreign matter adhering to the transmitter/receiver, then the frequency of the reverberation that is produced following termination of transmitting the probe waves will differ from the frequency of the probe waves. In that case, when processing for passing a prescribed band of frequencies is executed by the detection wave processing section, in acquiring the amplitude in the reverberation interval, detection waves that are outside the prescribed band of frequencies will become attenuated and the accompanying amplitude will become small. Hence, if foreign matter is adhering to the transmitter/receiver, then the amplitude will become smaller than when there is no foreign matter adhering, and this condition of the amplitude being small will continue during the reverberation interval. With the above configuration, a decision as to whether foreign matter is adhering to the transmitter/receiver is made based on a relationship between time and amplitude in the reverberation interval following termination of transmitting the probe waves, and hence, even if processing is executed on the detection waves for passing a prescribed band of frequencies, the adherence of foreign matter can be accurately detected.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The above and other objectives, features and advantages of the present disclosure will be made clearer from the following detailed description, referring to the appended drawings.

[0011] FIG. **1** is a configuration diagram of an ultrasonic sensor;

[0012] FIG. **2** shows waveforms for a case in which foreign matter does not adhere to a transmitter/receiver, with (a) being the waveform of frequency and (b) being the waveform of amplitude;

[0013] FIG. **3** shows waveforms for a case in which foreign matter adheres to the transmitter/receiver, with (a) being the waveform of frequency and (b) being the waveform of amplitude;

[0014] FIG. **4** is a flow chart of processing executed by the ultrasonic sensor;

[0015] FIG. **5** is a diagram for describing processing relating to a second embodiment, for the case in which foreign matter does not adhere to the transmitter/receiver;

[0016] FIG. **6** is a diagram for describing processing relating to the second embodiment, for the case in which foreign matter adheres to the transmitter/receiver;

[0017] FIG. **7** is a diagram for describing processing relating to a third embodiment, for the case in which foreign matter does not adhere to the transmitter/receiver;

[0018] FIG. **8** is a diagram for describing processing relating to the third embodiment, for the case in which foreign matter adheres to the transmitter/receiver;

[0019] FIG. **9** is a diagram for describing processing relating to a fourth embodiment, for the case in which foreign matter does not adhere to the transmitter/receiver;

[0020] FIG. **10** is a diagram for describing processing relating to the fourth embodiment, for the case in which foreign matter adheres to the transmitter/receiver;

[0021] FIG. **11** is a diagram for describing processing relating to a fifth embodiment, for the case in which foreign matter does not adhere to the transmitter/receiver; and

[0022] FIG. **12** is a diagram for describing processing relating to the fifth embodiment, for the case in which foreign matter adheres to the transmitter/receiver.

DESCRIPTION OF THE EMBODIMENTS

Description of Embodiments

[0023] The present embodiment of an ultrasonic sensor is installed on a mobile body such as a vehicle or the like. An object detection system, which includes the ultrasonic sensor that transmits probe waves in each of prescribed control periods, receives reflected waves that are reflected from an object in the surroundings of the mobile body, and measures the time duration between transmission and reception, for thereby obtaining the distance between the mobile body and the object.

[0024] FIG. **1** is a configuration diagram of an ultrasonic sensor **10** of the present embodiment. The ultrasonic sensor **10** is connected for communication with an ECU **20** which controls respective functions of the vehicle, with the ultrasonic sensor **10** being controlled based on commands from the ECU **20**, and transmitting detection results to the ECU **20**.

[0025] A control section **11** communicates with the ECU **20**, and executes control for transmitting probe waves which are ultrasonic waves, based on commands from the ECU **20**, while also transmitting to the ECU **20** the detection results of detection waves that include reflected waves. At that time, the ECU **20** notifies the control section **11** of the frequency of the probe waves, and the control section **11** drives a transmitter/receiver **12** such as to transmit ultrasonic waves having that frequency.

[0026] The transmitter/receiver **12** is of known type, being equipped with a piezoelectric element and a drive circuit which supplies drive power to the piezoelectric element, with the drive power being supplied by the transmitter/receiver **12** to the piezoelectric element by means of control signals from the control section **11**, for transmitting probe waves that are ultrasonic waves.

[0027] The transmitter/receiver **12** in addition receives, as detection waves, reflected waves that are reflected from objects in the surroundings, and also receives other ultrasonic waves as detection waves. The detection waves received by the transmitter/receiver **12** are inputted to the detection wave processing section **13** as voltages.

[0028] A detection wave processing section **13** performs filter processing of the detection waves. Specifically, filter processing of the detection waves is executed using a bandpass filter having a passband that can pass a band of frequencies which include the frequency of the probe waves, attenuating the amplitude of detection waves that are at frequencies other than those of the band of frequencies passed by the bandpass filter. The reason for this is that, when probe waves are reflected from an object and the reflected waves are acquired as detection waves, the frequency of the reflected waves will be close to the frequency of the probe waves, while detection waves having a different frequency have a high possibility of being noise. The detection wave processing section **13** inputs the voltage value to an amplitude measurement section **14**, after filter processing.

[0029] The amplitude measurement section **14** measures the amplitude of the acquired detection waves. Specifically, to acquire the amplitude, a value of voltage that is obtained based on the detection waves is converted to the amplitude. In detecting the amplitude, an upper limit value is determined for the voltage that can be acquired, and if the acquired voltage has a value exceeding the upper limit, the amplitude is made the upper limit value Amax.

[0030] The amplitude that is measured by the amplitude measurement section **14** will be explained referring to FIGS. **2** and **3**, based also on the frequency of the detection waves. The frequencies shown in FIGS. **2**(*a*) and **3**(*a*) are obtained, for example, by taking the points at which the voltage changes from positive to negative as zero crossing points, and calculating the inverse of the period between the zero crossing points as a frequency. The frequency count values in the diagrams show the measured numbers of reference waves between the zero crossing points of the detection waves. That is to say, if the value of the frequency count becomes large, this signifies that the time between the zero crossing points becomes longer and that the frequency becomes lower.

[0031] Since the amplitude of the ultrasonic waves is obtained as an alternation between positive and negative values, the positive peaks for each frequency define the amplitude at that frequency. FIGS. **2**(*b*) and **3**(*b*) show connected amplitudes that are maximum positive values for the respective frequencies, that is to say, these diagrams show the result of envelope detection.

[0032] As described above, the detection wave processing section **13** performs processing for attenuating waves having frequencies other than those of the prescribed frequency band of the bandpass filter. Hence, if foreign matter adheres to the surface of the transmitter/receiver **12** and causes the frequency in the reverberation interval to change, then as shown in FIG. **3**(*a*), the amplitude will be attenuated by the bandpass filter, and the amplitude will be reduced by comparison with the case in which there is no adherence of foreign matter, as shown in FIG. **3**(*b*). If judgement is made based only on whether or not the amplitude is small, then it is not possible to determine whether the amplitude has become small due to adhering foreign matter, or has become small due to the fact that the reverberation interval has ended. However, if the amplitude remains above a pre-

scribed value during a prescribed range of time, then it is judged that there is adhering foreign matter. It should be noted that the foreign matter may include snow, water, mud, etc., while the expression "adhering" can signify a condition in which water is flowing on the surface of the transmitter/receiver **12**.

[0033] As shown in FIGS. **2**(*b*), **3**(*b*), a first threshold value Ath**1** and a second threshold value Ath**2**, which is smaller than the first threshold value Ath**1**, are set. The specific values of the first threshold value Ath**1** and the second threshold value Ath**2** are determined through experiment, and are set by a threshold value setting section **15** and inputted to a timer section **16**.

[0034] The timer section **16** measures, as a first interval ΔT**1**, an interval for which the amplitude is higher than the first threshold value Ath**1**, and measures, as a second interval ΔT**2**, an interval for which the amplitude is higher than the second threshold value Ath**2**. The amplitude may momentarily fall below the first threshold value Ath**1**, due to errors in detecting the amplitude, etc., even when there is no foreign matter adhering to the transmitter/receiver **12**. Furthermore, the amplitude may in some cases momentarily fall below the second threshold value Ath**2**, when there is foreign matter adhering to the transmitter/receiver **12**, even during the reverberation interval. Hence, for the first interval ΔT**1** and the second interval ΔT**2**, it would be equally possible to terminate the time measurement on condition that the amplitude has been below the first threshold value Ath**1** or the second threshold value Ath**2** continuously during a prescribed sampling period.

[0035] A judgement section **17** calculates the time that elapses from the point at which the amplitude falls below the first threshold value Ath**1** until it falls below the second threshold value Ath**2**. Specifically, the judgement section **17** acquires the first interval ΔT**1** and the second interval ΔT**2** from the timer section **16**, and subtracts the first interval ΔT**1** from the second interval ΔT**2**. A decision is then made as to whether or not the calculated interval is a value that is greater than a prescribed value. If the calculated value is greater than the prescribed value, then it can be said that the amplitude in the reverberation interval has remained above the prescribed value during a time interval that is within the prescribed range. Hence, the judgement result is transmitted to the control section **11**.

[0036] When the control section **11** acquires a judgement result from the judgement section **17** indicating that there is adherence of foreign matter, processing is then executed for notifying this to a driver of the vehicle. Specifically, the judgement result is transmitted to the ECU **20**, and the driver of the vehicle is notified by use of a display apparatus, etc., installed in the vehicle. It should be noted that the processing which is executed when it is judged that there is foreign matter adhering to the transmitter/receiver **12** is not limited to this example, and it would be equally possible to execute various other forms of processing.

[0037] The processing sequence executed by the ultrasonic sensor **10** will be described referring to the flow chart of FIG. **4**. The processing of the flow chart of FIG. **4** is executed repetitively at each of prescribed sampling periods.

[0038] Firstly, in step S**101**, the detection waves are acquired, and then in step S**102**, the amplitude is measured. In step S**103**, a decision is made as to whether or not the time measurement of the first interval ΔT**1** is in progress. It is possible to judge in this way whether or not the value of the first interval ΔT**1** is zero. Step S**103** can be performed by judging whether the value of the first interval ΔT**1** is not zero, or by judging a flag which indicates that the time measurement of the first interval ΔT**1** is in progress. As described above, since the time measurement of the first interval ΔT**1** and that of the second interval ΔT**2** are started concurrently, if the time measurement of first interval ΔT**1** is in progress, then the time measurement of the second interval ΔT**2** is also in progress.

[0039] If there is a positive judgement decision in step S**103**, that is to say, the time measurement of the first interval ΔT**1** is not in progress, then the processing proceeds to step S**104**, in which a decision is made as to whether or not the time measurement of the second interval ΔT**2** is in progress. In the same way as for step S**103**, step S**104** can be performed by judging whether the value of the second interval ΔT**2** is not zero, or by judging a flag which indicates that the time measurement of the second interval ΔT**2** is in progress.

[0040] If there is a negative decision in step S**104**, that is to say, the time measurement of the second interval ΔT**2** is not in progress, processing then proceeds to step S**105**, in which a decision is made as to whether the amplitude measured in step S**102** is higher than the first threshold value Ath**1**. As described above, processing proceeds to step S**105** if a negative decision is reached in both step S**103** and step S**104**, so that reaching a positive decision in step S**105** is limited to the case in which the amplitude exceeds the first threshold value Ath**1** for the first time after transmitting of the probe waves has started. A negative decision in step S**105** is reached in an interval which extends from the start of transmitting the probe waves until the amplitude reaches the first threshold value Ath**1**, or in an interval which follows the time at which the amplitude falls below the second threshold value Ath**2**, that is to say, an interval which follows the end of the of the reverberation interval.

[0041] If there is a positive decision in step S**105**, that is to say, if it is judged that the amplitude exceeds the first threshold value Ath**1**, then the time measurement of the first interval ΔT**1** and the second interval ΔT**2** is started, and the processing sequence is then ended. Step S**106** in the processing sequence is executed at time point t**1** shown in FIGS. **2** and **3**. On the other hand, in a case in which there is a positive decision made in step S**105**, that is to say, it is judged that the amplitude is not greater than the first threshold value Ath**1**, then the processing sequence is ended directly.

[0042] If there is a positive decision in step S**103**, that is to say, in a case in which the time measurement of the first interval ΔT**1** is in progress, then processing proceeds to step S**107**, in which a decision is made as to whether or not the amplitude exceeds the first threshold value Ath**1**. If there is a positive decision in step S**107**, that is to say, the amplitude that has been measured in step S**102** is greater than first threshold value Ath**1**, then processing proceeds to step S**108**, in which the first interval ΔT**1** and second interval ΔT**2** are incremented. That is to say, the time measurement of the first interval ΔT**1** and second interval ΔT**2** is continued. Step S**108** of the processing sequence is executed in an interval that extends from after time point t**1** until time point t**2**, shown in FIGS. **2** and **3**. The processing sequence is then ended.

[0043] If there is a negative decision in step S**107**, that is to say, if the amplitude that was measured in step S**102** is

less than the first threshold value Ath**1**, then processing proceeds to step S**109**. In step S**109** the value of the first interval ΔT**1** is stored in temporary memory, and in the succeeding step S**110**, incrementing of the second interval ΔT**2** is performed. The time measurement of the second interval ΔT**2** is continued, while ending the time measurement of the first interval ΔT**1**. Step S**110** of the processing sequence is executed in the next sampling period after time point t**2**, shown in FIGS. **2** and **3**. The processing sequence is then ended.

[0044] If there is a positive decision in step S**104**, that is to say, if the time measurement of the first interval ΔT**1** has ended and the time measurement of the second threshold value Ath**2** is in progress, then processing proceeds to step S**111**, in which a decision is made as to whether or not the amplitude is greater than the second threshold value Ath**2**. If there is a positive decision in step S**111**, that is to say, if the amplitude measured in step S**102** is greater than the second threshold value Ath**2**, then processing proceeds to step S**112**, in which incrementing of the second interval ΔT**2** is performed. That is to say, the time measurement of the second interval ΔT**2** is continued. Step S**112** of the processing sequence is executed in an interval that extends from after the next sampling period following time point t**2**, shown in FIGS. **2** and **3**, up to time point t**3**. The processing sequence is then ended.

[0045] If there is a negative decision in step S**111**, that is to say, if the amplitude measured in step S**102** is less than the second threshold value Ath**2**, then processing proceeds to step S**113**. In step S**113**, the value of first interval ΔT**1** that has been temporarily stored in memory is subtracted from the value of the second interval ΔT**2** whose time measurement has been completed, and a decision is made as to whether the resultant value is greater than a prescribed value. That is to say, a decision is made as to whether or not the length of the interval for which the amplitude is less than the first threshold value Ath**1** and above the second threshold value Ath**2** is greater than a prescribed value. Step S**113** of the processing sequence is executed in the next sampling period following time point t**3**, shown in FIGS. **2** and **3**.

[0046] If there is a positive decision in step S**113**, that is to say, if the length of the interval for which the amplitude is less than the first threshold value Ath**1** and above the second threshold value Ath**2** is greater than the prescribed value, then processing proceeds to step S**114**, and a judgement is made as to whether or not there is foreign matter adhering to the surface of the transmitter/receiver **12**. The processing sequence is then ended. However, if there is a negative decision in step S**113**, then the processing sequence is ended directly.

[0047] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides the following effects.

[0048] If there is foreign matter adhering to the transmitter/receiver **12**, then the frequency of a reverberation that is produced following the transmitting of the probe waves becomes different from the frequency of the probe waves. If filter processing is performed by the detection wave processing section **13** at that time, then since detection waves that are at frequencies outside the passband of the filter will become attenuated, the amplitude will be reduced. For that reason it can be considered that if the amplitude is greater than the first threshold value Ath**1**, then the frequency during the reverberation interval is close to the frequency when transmitting the probe waves, while if the amplitude is smaller than the second threshold value Ath**2** then it can be considered that the reverberation interval has ended. On the other hand, if an interval continues during which the amplitude is less than the first threshold value Ath**1** and is greater than the second threshold value Ath**2**, then it can be assumed that the interval is the reverberation interval and that the frequency in that interval deviates from that of the probe waves. With the present embodiment, the time interval which elapses from the point at which the amplitude falls below the first threshold value Ath**1** until it falls below the second threshold value Ath**2** is acquired, and by judging whether or not that interval is longer than a prescribed interval, a decision can be made as to whether or not the frequency during the reverberation interval deviates from the frequency of the probe waves. Hence, an accurate judgement can be made as to whether or not there is foreign matter adhering to the transmitter/receiver **12**.

Second Embodiment

[0049] The present embodiment differs from the first embodiment with respect to a part of the processing executed by the judgement section **17**. Specifically, the judgement section **17** acquires a number of times that local maximums of the amplitude are attained in a prescribed interval following the time at which the amplitude falls below the first threshold value Ath**1**. This number of occurrences of local maximums is taken to be the number of times that the amplitude changes from an increasing to a decreasing condition. It should be noted that if the amplitude, after having once increased then remains constant, and thereafter decreases, then this can be taken as being a single occurrence of a local maximum value.

[0050] The judgement section **17** compares the counted number of local maximums of the amplitude with a predetermined value. If the number of local maximums is greater than the predetermined value, then it is judged that there is adherence of foreign matter.

[0051] The processing applied to the amplitude with the present embodiment will be described referring to FIGS. **5** and **6**. In FIGS. **5** and **6**, the positions where there are local maximums are surrounded by dashed lines.

[0052] As shown in FIG. **5**, if there is no foreign matter adhering to the transmitter/receiver **12**, then the time at which the amplitude falls below the first threshold value Ath**1** is time point t**11** at which the reverberation interval ends. After falling below the first threshold value Ath**1** at time point t**11**, the amplitude thereafter continues to decrease, and a condition is reached at which it is hardly possible to detect the amplitude. For that reason, in a prescribed interval beginning from time point t**11** and elapsing at time point t**12**, the acquired number of local maximums of the amplitude becomes small.

[0053] On the other hand, as shown in FIG. **6**, if there is foreign matter adhering to the transmitter/receiver **12**, then time point t**11** at which the amplitude falls below the first threshold value Ath**1** is the time at which transmitting the probe waves is ended. Since the interval of attenuation following time point at which the amplitude falls below the first threshold value Ath**1** is a continuation of the reverberation interval, the amplitude repetitively increases and decreases in the vicinity of a certain value. For that reason, the acquired number of local maximums attained by the

amplitude becomes large during a prescribed interval which extends from time point t**11** and elapses when a certain time point t**12** is reached.

[0054] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides the following effects, in addition to effects similar to those provided by the ultrasonic sensor **10** of the first embodiment.

[0055] If there is no foreign matter adhering to the transmitter/receiver **12**, then when the amplitude falls below the first threshold value Ath**1**, this signifies that the reverberation interval has ended, so that the amplitude will continue to gradually decrease after having fallen below the first threshold value Ath**1**, until the value can hardly be detected. For that reason, the acquired number of local maximums of the amplitude will become small. On the other hand, if there is foreign matter adhering to the transmitter/receiver **12**, then when the amplitude falls below the first threshold value Ath**1**, this signifies that the transmission of probe waves has ended, and during the reverberation interval thereafter the amplitude will repetitively increase and decrease, and hence, the number of local maximums of the amplitude will increase. Hence, by counting the number of local maximums during a prescribed interval extending from time point at which the amplitude falls below the first threshold value Ath**1**, a judgement can be made as to whether or not there is foreign matter adhering to the transmitter/receiver **12**.

Third Embodiment

[0056] The present embodiment differs from the first embodiment with respect to a part of the processing executed by the judgement section **17**. Specifically, the judgement section **17** provides a prescribed period in the reverberation interval, and obtains the number of times that local maximum value of amplitude are attained during that prescribed period. The prescribed period is set such as to include at least part of the reverberation interval, and with the present embodiment, the prescribed period commences when the transmitting of the probe waves is ended. The processing for obtaining the number of times that local maximum value of amplitude are attained are the same as for the second embodiment, so that specific description is omitted.

[0057] The processing of the amplitude with the present embodiment will next be described, referring to FIGS. **7** and **8**. In FIGS. **7** and **8**, time point t**21** is the start of an interval in which the number of local maximums is counted and which ends at time point t**22**. In FIGS. **7** and **8**, as for the second embodiment, the locations of the local maximums are enclosed by dashed lines.

[0058] If there is no foreign matter adhering to the transmitter/receiver **12**, as shown in FIG. **7**, the amplitude will generally be maintained close to an upper limit value Amax during the reverberation interval, and will become attenuated when the reverberation interval terminates. For that reason, the number of local maximums that are obtained in the interval from t**21** to t**22** will become small.

[0059] On the other hand, if there is foreign matter adhering to the transmitter/receiver **12**, as shown in FIG. **7**, then the amplitude will repetitively increase and decrease in the vicinity of a certain value during the reverberation interval. For that reason, the number of local maximums obtained during the interval from t**21** to t**22** becomes large.

[0060] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides the following effects, in addition to effects similar to those provided by the ultrasonic sensor **10** of the first embodiment.

[0061] In the processing executed for obtaining the amplitude of the detection waves, an upper limit value Amax is provided for the value that can be obtained, and if the actual amplitude is greater than the upper limit value Amax, processing is executed for setting the amplitude of the detection waves as the upper limit value Amax. If there is no foreign matter adhering to the transmitter/receiver **12**, then since the attenuation of the amplitude of the detection waves during the reverberation interval is small, the amplitude becomes the upper limit value Amax. Hence, the number of local maximums of the amplitude becomes small. On the other hand, if there is foreign matter adhering to the transmitter/receiver **12**, then the attenuation of the amplitude of the detection waves during the reverberation interval will be relatively great, so that the amplitude becomes smaller than Amax. Hence, if there is foreign matter adhering to the transmitter/receiver **12**, the number of local maximums of the amplitude will become greater than for the case in which no foreign matter adheres, so that a judgement can be made as to whether or not there is adherence of foreign matter, from the number of these local maximums.

Fourth Embodiment

[0062] The present embodiment differs from the first embodiment with respect to a part of the processing executed by the judgement section **17**. The processing executed by the judgement section **17** of the present embodiment will be described referring to FIGS. **9** and **10**.

[0063] The judgement section **17** obtains an area S that is enclosed by the envelope which extends from the point at which the amplitude falls below the first threshold value Ath**1** up to the point at which it falls below the second threshold value Ath**2**. Specifically, the amplitudes at each of respective sampling periods are accumulated, and the cumulative value is set as the area S.

[0064] The judgement section **17** judges whether or not the calculated area S is greater than a prescribed value. If the area S is greater than the prescribed value, then it is judged that there is matter such as water adhering to the transmitter/receiver **12**, and that judgement result is notified to the control section **11**.

[0065] It should be noted that when the area S is obtained surrounded by an envelope as with the present embodiment, it would be equally possible to set a prescribed interval following the point at which the amplitude falls below the first threshold value Ath**1**, as with the second embodiment, and to obtain the area S for that interval.

[0066] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides the following effects, in addition to effects similar to those provided by the ultrasonic sensor **10** of the first embodiment.

[0067] If there is foreign matter is adhering to the transmitter/receiver **12**, then the frequency during the reverberation interval becomes changed, and the duration of the interval from the point at which the amplitude falls below the first threshold value Ath**1** up to the point at which it falls below the second threshold value Ath**2** becomes increased. As a result, the area S enclosed by the envelope of amplitudes will become larger. With the present embodiment, since a decision is made as to whether or not the area S enclosed by that envelope is greater than a prescribed value, a judgement can be made as to whether or not the frequency

during the reverberation interval deviates from the frequency of the probe waves. Hence, it becomes possible to accurately judge whether or not there is foreign matter is adhering to the transmitter/receiver **12**.

Fifth Embodiment

[0068] The present embodiment differs from the above embodiments with respect to a part of the processing executed by the judgement section **17**. The processing executed by the judgement section **17** of the present embodiment will be described referring to FIGS. **11** and **12**.

[0069] The judgement section **17** provides a plurality of prescribed intervals which follow the point at which the amplitude falls below the first threshold value Ath**1**. With the present embodiment, there are 4 prescribed intervals provided, having respectively identical lengths of period. Areas S**1** to S**4** are calculated for the respective periods. The processing for calculating these areas S**1** to S**4** is the same as that for the area S of the fourth embodiment.

[0070] The judgement section **17** next calculates the amounts of change in the areas S**1**~S**4**. In doing this, the average of the amounts of change between the areas S**1**~S**4** may be used, or the difference could be obtained between the area S**1** having the largest value and the area S**4** having the smallest value, or the differences between the areas that are mutually preceding and succeeding could be obtained, and the largest one of these differences used. Furthermore, it would be equally possible to obtain an approximate function based on the values of the areas S**1**~S**4** and to perform judgement based on the approximate function. For each of these cases, if there is adherence of foreign matter, the amount of change in area will be greater than when foreign matter is not adhering. Hence, a decision can be made as to whether there is adherence of foreign matter, by comparing the value of the amount of change in area with a prescribed value, and determining that there is adherence of foreign matter if the value of the amount of change in area is greater than the prescribed value.

[0071] It should be noted that in the processing for setting the plurality of periods with the present embodiment, the prescribed intervals can extend from time point at which the probe waves are terminated, as with the third embodiment. In that case, if there is no adherence of foreign matter, the amplitude will greatly decrease when the reverberation interval ends, so that if the change in area is small, it can be judged that there is adherence of foreign matter.

[0072] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides the following effects, in addition to effects similar to those provided by the ultrasonic sensor **10** of the first embodiment.

[0073] If there is foreign matter is adhering to the transmitter/receiver **12**, then the amplitude during the reverberation interval becomes attenuated. Hence, by obtaining a plurality of areas S**1**~S**4** that are enclosed by amplitude envelopes, and judging whether or not these areas are becoming attenuated, a decision can be made as to whether there is foreign matter adhering to the transmitter/receiver **12**.

Sixth Embodiment

[0074] The present embodiment differs from the above embodiments with respect to a part of the processing executed by the judgement section **17**. With the present embodiment, the judgement section **17** compares a part of the detection waves with a reference waveform, which has been predetermined. The reference waveform is a waveform that has been measured beforehand in a case in which there is no foreign matter adhering to the transmitter/receiver **12**. If the correlation between the waveform of the detection waves and the reference waveform is obtained and the correlation value is greater than a prescribed value, then since it can be said that the shape of the waveform of the detection waves is close to that of the reference waveform, it is judged that there is no foreign matter adhering to the transmitter/receiver **12**. On the other hand, if the correlation value is smaller than the prescribed value, then since it can be said that the shape of the waveform of the detection waves deviates from that of the reference waveform, it is judged that there is foreign matter adhering to the transmitter/receiver **12**.

[0075] It should be noted that although a waveform which is measured beforehand in a condition in which there is no foreign matter adhering to the transmitter/receiver **12** is used here as the reference waveform, it would be equally possible to use, as the reference waveform, a waveform for the case in which there is foreign matter adhering to the transmitter/receiver **12**. Furthermore, it would be equally possible to provide beforehand a waveform for the case in which there is foreign matter adhering to the transmitter/receiver **12** and a waveform for the case in which there is no adherence of foreign matter, respectively, and to judge which of these waveforms is closest in shape to the waveform of the detection waves.

[0076] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides effects that are similar to those provided by the ultrasonic sensor **10** of the first embodiment.

Seventh Embodiment

[0077] The overall configuration of the present embodiment is similar to that of the first embodiment, with a part of the processing being different. With the present embodiment, the detection wave processing section **13** is provided with two bandpass filters having respectively different widths of passband. The center frequency of each of these bandpass filters is the frequency of the detection waves. It should be noted that in the following description, the bandpass filter having the narrower one of the passbands is referred to as the first bandpass filter, and the bandpass filter having the wider passband is referred to as the second bandpass filter.

[0078] The detection wave processing section **13** executes, in parallel, processing for passing the acquired detection waves through the first bandpass filter and through the second bandpass filter. Next, the processing of the flow chart shown in FIG. **4** is applied to the detection waves that have passed through the first bandpass filter and have passed through the second bandpass filter, respectively, with the interval during which the amplitude is smaller than the first threshold value Ath**1** and is greater than the second threshold value Ath**2** being respectively obtained for these, that is to say, the value resulting from subtracting the first interval $\Delta T1$ from the second interval $\Delta T2$ is obtained. The respective calculated values are then compared, and a decision is made as to whether or not there is foreign matter adhering to the transmitter/receiver **12**.

[0079] If there is no foreign matter adhering to the transmitter/receiver **12**, then since the frequency of the detection waves during the reverberation interval will be close to the frequency of the probe waves, the amplitudes of the respective detection waves which pass through the bandpass filters will not become readily attenuated, irrespective of which of the filters is passed through. Hence, the value obtained by subtracting the first interval ΔT**1** from the second interval ΔT**2** will be substantially the same for the detection waves that are passed by the first bandpass filter and the detection waves that are passed by the second bandpass filter.

[0080] If there is foreign matter adhering to the transmitter/receiver **12**, then since the frequency of the detection waves during the reverberation interval will be different from the frequency of the probe waves, the detection waves that pass through the first bandpass filter will have a relatively high degree of attenuation in amplitude, while the degree of amplitude attenuation of the detection waves that pass through the second bandpass filter will be relatively small. Hence, the value obtained by subtracting the first interval ΔT**1** from the second interval ΔT**2** will be greater for the detection waves that are passed by the second bandpass filter.

[0081] It should be noted that it would be equally possible to apply processing for effecting passing of detection waves through two bandpass filters, as performed with the present embodiment, to the second and third embodiments. That is to say, instead of comparing the number of local maximums of the amplitude with a predetermined value, it would be equally possible to compare the respective numbers of local maximums of the amplitude of detection waves that have passed through bandpass filters having different passbands, and judgement could be performed by using the difference between them.

[0082] Furthermore, it would be equally possible to apply processing for effecting passing of detection waves through two bandpass filters, as performed with the present embodiment, to the fourth embodiment. If there is no foreign matter adhering to the transmitter/receiver **12**, then the frequency during the reverberation interval will be close to the frequency of the probe waves, and hence, even when the detection waves have been passed through bandpass filters having passbands that are different from one another, the variation of amplitude with time will be closely similar between the detection waves, and the correlation value will be relatively large. On the other hand, if there is foreign matter adhering to the transmitter/receiver **12**, then the variation of amplitude with time will be different between them, so that the correlation value will be relatively small. Hence, a judgement can be made as to whether or not there is adherence of foreign matter.

[0083] Due to the above configuration, the ultrasonic sensor **10** of the present embodiment provides effects that are similar to those provided by the ultrasonic sensor **10** of the first embodiment, and also provides the following effects.

[0084] When the detection waves are passed through a bandpass filter having a wide passband, then irrespective of whether or not the frequency deviates from the center frequency, the amplitude will not be significantly attenuated. On the other hand, if the detection waves are processed by means of a bandpass filter having a narrow passband, then if the frequency deviates from the center frequency, the amplitude will be relatively greatly attenuated. Hence, it is possible to judge whether or not there is foreign matter is adhering to the transmitter/receiver **12** by comparing detection waves that have passed through bandpass filters having respectively different passbands.

Modified Examples

[0085] With the above embodiments, in addition to using the relationship between amplitude and time, it would be possible to also use frequency in judging whether or not there is foreign matter adhering to the transmitter/receiver **12**. Specifically with each of the above embodiments, the judgement conditions are set as a first condition, and a second condition which is whether or not a frequency deviates from the frequency of the probe waves, with the first condition and the second condition being used in judging whether or not foreign matter is adhering to the transmitter/receiver **12**. It should be noted that it would be equally possible for the second condition to include a requirement relating to time, for each of the above embodiments.

[0086] With the first embodiment, the time measurement of the first interval ΔT**1** and the second interval ΔT**2** is started on condition that the amplitude falls below the first threshold value Ath**1**. However, it would be equally possible to commence the time measurement of the first interval ΔT**1** and the second interval ΔT**2** at time point of commencement of transmitting the probe waves.

[0087] With the first embodiment, time measurement of the first interval ΔT**1** and the second interval ΔT**2** is performed, and the difference between the measured values is obtained. However, it would be equally possible to set, as a required condition for starting the time measurement, that the amplitude is less than the first threshold value Ath**1** and is greater than the second threshold value Ath**2**, and to set, as a required condition for ending the time measurement, that the amplitude is less than the second threshold value Ath**2**. In that case, the judgement as to whether or not there is adhering foreign matter can be performed by comparing the measured value of time with a prescribed value.

[0088] With the above embodiments, bandpass filters are used; however, it would be equally possible to use band-stop filters instead. Furthermore, since the frequency becomes lower if there is foreign matter adhering to the transmitter/receiver **12**, it would be equally possible to use detection waves that have been passed through a high-pass filter, in the processing for judging whether or not there is adhering foreign matter. This is similarly true for the fifth embodiment, where it would be equally possible to use high-pass filters or band-stop filters having respectively different passbands.

[0089] With the second embodiment, the number of local maximums of the amplitude is obtained during a predetermined interval which commences when the amplitude becomes less than the first threshold value Ath**1**. However, it would be equally possible to obtain the number of local maximums during an interval in which the amplitude is less than the first threshold value Ath**1** and is greater than the second threshold value Ath**2**. As shown by the first embodiment, that interval, in which the amplitude is less than the first threshold value Ath**1** and is greater than the second threshold value Ath**2**, is longer when there is foreign matter adhering to the transmitter/receiver **12** than when there is no adhering foreign matter. Furthermore, since, if there is no adhering foreign matter, the amplitude will generally

decrease monotonically from the point at which it becomes less than the first threshold value Ath**1** until it becomes less than the second threshold value Ath**2**, so that the possibility of producing maximum values is low. Hence, judgement can accurately be made as to whether or not foreign matter is adhering to the transmitter/receiver **12**, by obtaining the number of local maximums of the amplitude during the interval in which the amplitude is less than the first threshold value Ath**1** and is greater than the second threshold value Ath**2**.

[0090] With the second embodiment, instead of obtaining the number of local maximums, it would be equally possible to perform the judgement as to adhering foreign matter on the transmitter/receiver **12** by using the highest-magnitude one of the local maximums, or by using the average magnitude of the local maximums, etc. If there is no foreign matter adhering to the transmitter/receiver **12**, then since in that case the point at which the amplitude becomes less than the first threshold value Ath**1** is the termination of the reverberation interval, the amplitude will continue to become attenuated thereafter, until a condition is reached where it can hardly be detected. For that reason, the maximum amplitude will be small. On the other hand, if there is foreign matter adhering to the transmitter/receiver **12**, then the point at which the amplitude becomes less than the first threshold value Ath**1** is the termination of transmitting the probe waves, and the amplitude will repetitively increase and decrease during the reverberation interval thereafter, so that there will be relatively large maximum values of the amplitude. Hence, a decision can be made as to whether foreign matter is adhering to the transmitter/receiver **12**, from the maximum value of the amplitude during a predetermined interval that follows the point at which the amplitude becomes less than the first threshold value Ath**1**.

[0091] With the third embodiment, instead of using the number of local maximums, it would be equally possible to judge whether foreign matter is adhering to the transmitter/receiver **12** by using the highest one of the local maximums of the amplitude, or by using the average of the local maximums, etc. Since the attenuation of the amplitude during the reverberation interval will be relatively small if no foreign matter is adhering to the transmitter/receiver **12**, there will be a relatively large maximum value of the amplitude during that interval, while if there is foreign matter adhering to the transmitter/receiver **12** then there will be a relatively high degree of attenuation of the amplitude during the reverberation interval, so that the maximum value of the amplitude will be relatively small. Hence, a decision can be made as to whether foreign matter is adhering to the transmitter/receiver **12**, from the maximum value of the amplitude during a predetermined interval that follows the termination of transmitting the probe waves.

[0092] With the fifth embodiment, processing is performed using bandpass filters, in parallel, having respectively different passbands. However, it would be equally possible to perform processing for passing the detection waves through bandpass filters which have respectively different transmission intervals, for example a preceding and a succeeding transmission interval.

[0093] With the fifth embodiment, two bandpass filters having respectively different passbands are used; however, it would be equally possible to use three or more bandpass filters. Moreover, it would be equally possible to compare detection waves that have been passed by filters having respectively different functions. For example, the detection waves passed by a bandpass filter could be compared with the detection waves passed by a high-pass filter, or compared with the detection waves passed by a band-stop filter.

[0094] The ultrasonic sensor **10** of the embodiments is installed on a mobile body such as a vehicle; however, the ultrasonic sensor **10** is not limited to such installation, and could be installed on a stationary object such as a road structure or the like.

[0095] The present disclosure has been described based on embodiments, however, it should be understood that the disclosure is not limited to the embodiments or their configurations. The present disclosure incorporates various modifications and equivalences within its scope. Furthermore, other combinations and forms, including single elements or more, are contained in the scope and concepts of the present disclosure.

1. An ultrasonic sensor that transmits probe waves which are ultrasonic waves, and acquires detection waves that include reflected waves which have been reflected from surrounding objects, comprising:

a transmitter/receiver that transmits the probe waves and acquires the detection waves;

a detection wave processing section that executes processing for passing a predetermined frequency band which includes the frequency of the probe waves;

an amplitude measurement section that measures the amplitude of the detection waves; and

a judgement section that judges whether there is adherence of foreign matter on the transmitter/receiver, based on a relationship between a time axis and values of the amplitude of the detection waves during a reverberation interval following the termination of transmitting the probe waves.

2. The ultrasonic sensor according to claim **1**, wherein

the judgement section acquires, as the relationship between the time axis and the amplitude, an interval extending from the point at which the amplitude falls below a first threshold value until the amplitude falls below a second threshold value, and executes the judgement based on the acquired interval.

3. The ultrasonic sensor according to claim **1**, wherein

the judgement section provides, as the time axis, a prescribed interval that follows the point at which the amplitude falls below a threshold value, and the judgement section acquires a count of a number of local maximums of the amplitude in the prescribed interval, and executes the judgement based on that count.

4. The ultrasonic sensor according to claim **1**, wherein

the judgement section provides, as the time axis, a prescribed interval that follows the point at which the amplitude falls below a threshold value, and the judgement section executes the judgement based on the maximum value of the amplitude in the prescribed interval.

5. The ultrasonic sensor according to claim **1**, wherein

the judgement section provides, as the time axis, a prescribed interval that follows termination of transmitting the probe waves, and the judgement section acquires a count of a number of local maximums of the amplitude in the prescribed interval, and executes the judgement based on that count.

6. The ultrasonic sensor according to claim 1, wherein the judgement section provides, as the time axis, a prescribed interval that follows the termination of transmitting the probe waves, and the judgement section executes the judgement based on the maximum value of the amplitude in the prescribed interval.

7. The ultrasonic sensor according to claim 1, wherein the judgement section acquires, as the relationship between the time axis and the amplitude, an area enclosed by an envelope of values of the amplitude, and executes the judgement based on that area.

8. The ultrasonic sensor according to claim 7, wherein the judgement section acquires the area after the amplitude has fallen below a threshold value, and executes the judgement based on that area.

9. The ultrasonic sensor according to claim 7, wherein the judgement section acquires respective areas for each of prescribed intervals, following termination of transmitting the probe waves, and executes the judgement based on changes in the areas.

10. The ultrasonic sensor according to claim 1, wherein the judgement section sets an upper limit value to the values that can be acquired for the amplitude, and when the amplitude of the detection waves is greater than the upper limit value, makes the amplitude of the detection waves the upper limit value.

11. The ultrasonic sensor according to claim 1, wherein the judgement section executes the judgement by comparing a relationship between the time axis and the amplitude that is based on the acquired detection waves with a predetermined relationship between the time axis and the amplitude.

12. The ultrasonic sensor according to claim 1, wherein the detection wave processing section is equipped with a plurality of filters which pass respectively different frequency bands, and

the judgement section compares the relationships between the time axis and the amplitude for the respective outputs passed by the different filters, and executes the judgement by means of the comparison result.

13. The ultrasonic sensor according to claim 1, wherein the judgement section acquires the correlation value between a waveform expressing the time-axis variation of the amplitude and a waveform serving as a reference, and executes the judgement by means of the correlation value.

14. The ultrasonic sensor according to claim 1, wherein the detection wave processing section is equipped with a plurality of filters which pass respectively different frequency bands, and

the judgement section acquires a correlation value between respective waveforms that express the time-axis variation of the amplitudes passed by the different filters, and executes the judgement by means of the correlation value.

15. The ultrasonic sensor according to claim 1, wherein the ultrasonic sensor further acquires the frequency of the probe waves,

the judgement section compares the acquired frequency with a frequency that serves as a reference frequency of the probe waves, and

the ultrasonic sensor executes the judgement by using a first condition that is based on time and amplitude, and a second condition that is based on frequency.

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