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Sensitivity Enhancement of Spirometer Employing Ultrasonic Method

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Abstract: Respiration measurement method using an ultrasound sensor is influenced very little by an error of inertia and pressure. This device measures the amount and flow of respiration using a delivery speed difference of the ultrasound waves that are a return format by the pneumatic stream that is a flogging of ultrasound waves during transmission and receipt as having used a characteristic of ultrasound waves. This paper examines improving the sensor's sensitivity during transmission and receipt of the signal. Because the measurement must be performed on patients, clinicians need to be sure that it is accurately measuring even very weak breathing.

Key words: Ultrasound, Respiration, Spirometer

INTRODUCTION

Respiration detection and measurement devices have been adopted in studies for several years; however, the performance necessary for their commercialization has not been fully achieved.

Respiration detection devices use various methods. One method measures the flow and amount of respiration with the turning ratio of a turbine; this is the turbine sensing method. Its shortcoming is that a measurement error is caused by the turbine's inertia at the start and end points of the measurement.

Measurement with a pressure sensor device is another method. This measures the amount and flow of respiration by measuring the rate of a resistor's interference to breathing.

This method, however, is inconvenient because it must be calibrated depending on conditions in the external environment. Accordingly, this study's purpose is to facilitate mass-production of the supplemented system by researching and developing the basic ultrasound sensor, hardware design for signal process, and processing software algorithm, as well as experimenting and evaluating it in a clinical setting. Following rapid advances of non-invasive patient monitoring techniques in respiratory care, anaesthesia and intensive-care ventilation, the demand for a rapidly responding and accurate flow transducer has arisen. Instantaneous recording of gases flowing in and out of the patient's lungs will not only generate primary information such as volume, respiration rate and breathing-circuit abnormalities, but also additional information such as airway pressure and respiratory gas analysis, so that further physiological parameters can be measured [1][2][3][4].

A spirometer is a medical device that measures the moment velocity of flowing respiratory gas and is used in testing and monitoring patients' pulmonary function; in electrical engineering, the lungs' absolute volumetric change is measured in addition to the flow's amount. The spirometer that is most popularly used now uses linear resistance. The pressure of a fluid, in this case, respiratory gas, is inversely proportional to its velocity (Bernoulli's Principle). When the flow's velocity is low, resistance is used to reduce gas pressure proportionally to measure the amount of flow [5][6].

This study used characteristics of ultrasonic waves. Respiratory volume and flow were measured by utilizing the difference in transmission speed of ultrasonic waves that are reflected by air flow through the media of ultrasonic waves in a transmission/receiving situation. It is still in its initial stage; thus, R&D of the basic ultrasonic sensor, design of hardware for signal processing, and study of software algorithm are required. In

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terms of stability or manifestation, measurement with existing sensors is not sufficient. Their response to breath is not well measured because many difficulties hinder accurately measuring respiratory volume. This study's purpose was to elevate the sensitivity to weak breath by improving the function of the analogue part and to identify the mark of various respiratory strengths by transmitting the output signal to the signal processor.

RESPIRATION MEASUREMENT METHOD

Various techniques for measuring gas flow have been reported or commercially applied, ranging from the machine, pressure drop and ultrasound to more sophisticated approaches such as thermal dilution, vortex shedding and fluidic oscillation. However, the most popular existing clinical flow-meters are based on pressure drop, rotating vane and thermal dissipation.

When we examine the flow-meter requirements of applications mentioned earlier (fast response bidirectional, low resistance to flow and independence of changing gas composition), it becomes obvious that ultrasonic methodology can provide distinct advantages over these existing methods to construct a clinically adequate flow-meter.

Essentially two types of ultrasonic techniques are used to measure flow rate: single transducer Doppler frequency shift measurement and transmit-time measurement, which uses more than one transducer. Both techniques measure the fluid's flow velocity in a conduit of fixed and known dimension. Volume flow rate is then calculated from the velocity and dimension information.

Doppler ultrasonic flow-meters operate on the Doppler shift principle, whereby the transmitted frequency is altered linearly by being reflected by particles and bubbles in the fluid. The net result is a frequency shift between transmitter and receiver that can be directly related to the flow velocity. If the pipe's internal diameter is known, the volumetric flow rate can be calculated. Doppler meters require some minimum amount of solid particles or air in the line to perform the measurement.

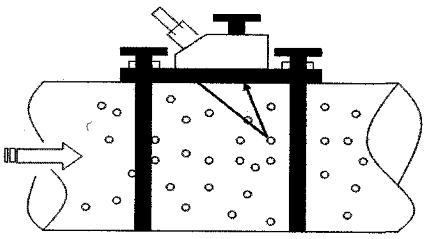


Fig. 1. Doppler ultrasonic flow-meters operate on the Doppler effect.

The transit-time technique uses a pair of transducers with each sensor sending and receiving ultrasonic signals obliquely through the fluid.

When the fluid is flowing, transit-time in the forward direction is shorter than in the reverse direction. Because the difference between these transit-times is proportional to the velocity, the flow rate and direction can be measured properly by detecting this time difference. Measurements are made by sending bursts of signals through a pipe. The flow measurement is based on the principle that sound waves travelling in the same direction as the fluid require less time than when travelling in the opposite direction. At zero velocity , the transit time is zero. If we know the pipe's diameter, wall thickness and material, the angle of refraction can be calculated automatically and we will know how far apart to space our transducers.

The difference in transit times of the ultrasonic signals is an indication of the fluid's flow rate. Since ultrasonic signals can also penetrate solid materials, the transducers can be mounted onto the outside of the pipe [7].

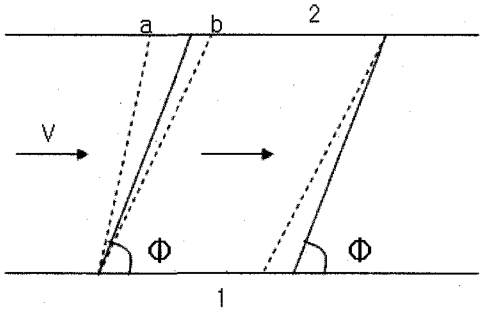


Fig. 2. Transit-time flow-meters measure the difference in travel time between pulses transmitted in a single path along and against the flow. Two transducers are used, one upstream of the other.

AN APPLIED ULTRASONIC FLOW-METERS

Ultrasonic flow-meters transmit ultrasound between a pair of transducers and measure changes in transit time caused by the velocity of the intervening medium.

Changes in the speed of sound C are indistinguishable from changes in flow velocity when we measure transit time in only one direction. By measuring transit time both upstream and downstream and measuring the difference, we can reduce or eliminate dependence on C. For simplicity and to avoid asymmetric paths, a pair of transducers transmit alternately, in each direction. The offered digital spirometer is intended for medical application for measurement of current speed or a pulsing gas flow and calculation of volumes of inhaled and exhaled air.

The principle of digital spirometer operation is the acoustic phase method. Gas flow and velocity measurement are being over-processed according to certain programs to calculate the volume.

The waves' propagation time from the radiating ring to the receiving ring T is approximately determined.

$$T=\frac{L}{Cs\pm V_f}$$

The mark "±" takes into account concurrence of a propagation direction of the sound and flow. The block diagram of the transducer is shown in Fig. 3.

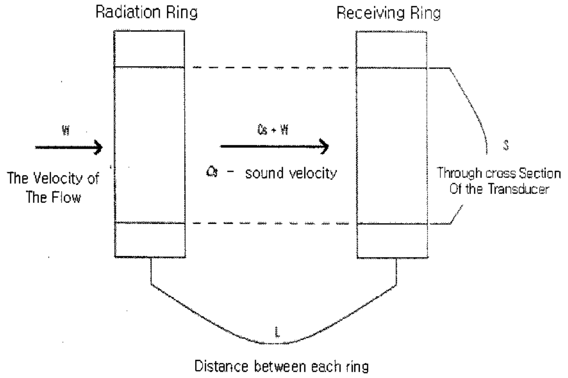


Fig. 3. The Ultrasonic Spirometer with two rings of transmitter and receiver

When concurrence takes place these velocities are being summed, when discrepancy takes place these velocities are being substracted.

Gauging propagation time from the transmitting to the receiving ring can be replaced by gauging of phase shift(Φ) between signals from the radiating and receiving rings.

$$\phi=\frac{2\pi fL}{Cs\pm V_f}$$

Ring piezo-sensors have brightly expressed frequency properties and are convertible, which allow the rings to function alternately as radiators or receivers, changing the direction of the sound propagation [8][9][10].

Fig. 4 is the overall block diagram of system. The processor to be used at the analog part is the PIC (8-bit) processor, also shown in Fig. 4. The signal is to come from the oscillator inputs at the processor and is at 30KHz. We used the pre-amp before the input of this signal to be outputed at the sensor and designed it so that we could react to a weak signal. The signal to be outputed to the sensor was amplified (doubled) to enhance the sensor's reaction to the breath. The amp's instability characteristic needed to be offset; consequently, we used a capacitor to offset the amp's instability. Then the amplified signals are sent to the digital signal processor, which is controlled by the ARM9 processor, which also controls the whole system.

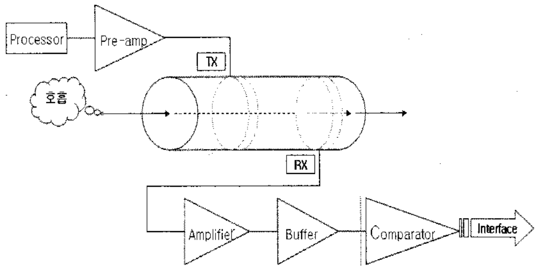


Fig. 4. The block diagram of the ultrasound spirometer

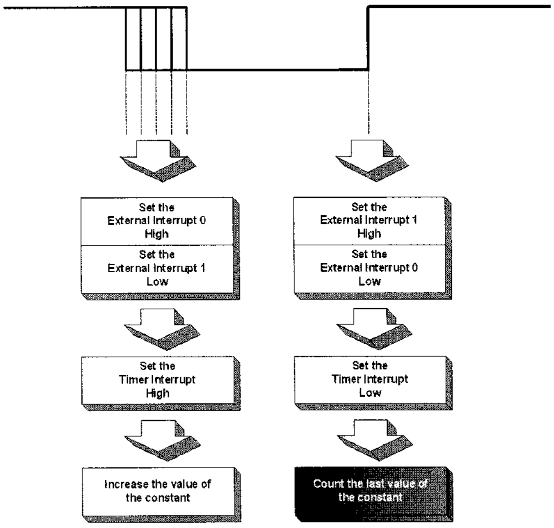


Fig. 5. Method of calculating velocity

The ARM processor performs signal control and filtering of the receiving part and algorithm, and then displays the definitive measurement variable. This sets the External Interrupt pin's input to the comparator's output of the analog and uses a Timer Interrupt. It measures the time while falling off to 0. We can find out the total respiratory quantity by producing variables that considering the amount of time to be measured and supersonic waves. Fig. 5 expressed the calculation method of the comparator's output.

EXPERIMENT AND RESULT

The system consists of power, analog part, digital part and ultrasonic sensor. The sensor has two rings on the inner wall of the cylinder. One is radiating ring; the other is a receiving ring. The sensor was made of aluminium. In the digital part we used an ARM9 (32bit micro-processor) to mark the reaction of the sensitivity to breath on the screen.

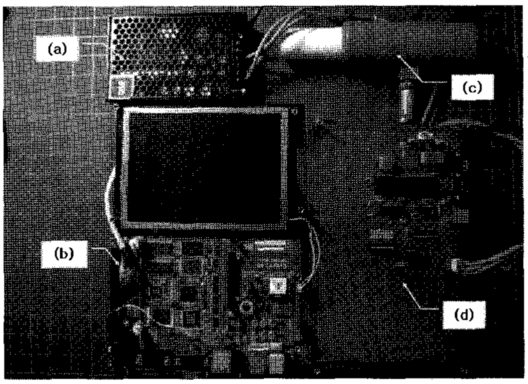
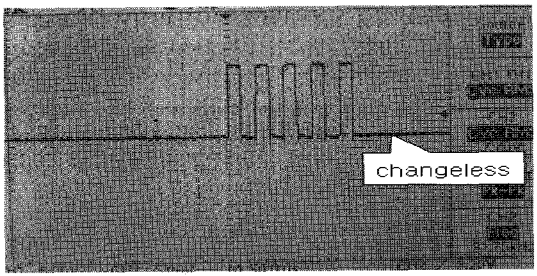


Fig. 6. Configuration of system with (a) power, (b) digital part, (c) sensor part, and (d) analog part

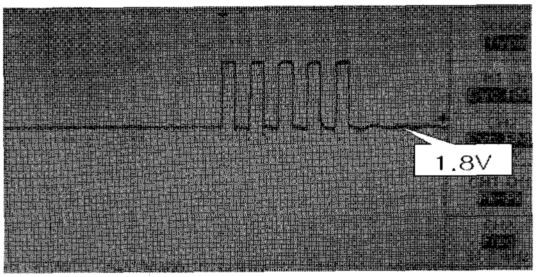
This system is a machine that focuses on the patient. We used the amplifier to measure the possibility of weak breath at the radiation of the sensor. The signal to be received from the sensor goes via the buffer for impedance matching and then is amplified. Then this signal enters the comparator after going through the amplifier to set the level with the signal in the generator. The comparator's output is input to control calculates the difference of phase and converts it to speed.

Illustrated in Fig. 7 is the experiment's result; this is the wave that appears when the 30KHz signal is input to the radiating ring.

In this wave, the ground(0V) becomes the base datum line to express the intensity of the breath. This line is oriented so that it goes up when breath is inhaled and goes down when breath is exhaled. Therefore, the line is proportional to the intensity of the breath. Fig. 7.(a) shows the result when volume is 0.2L(Litter : weak breath), but the datum line did not change. Consequently, we could not measure the minute signal. On one side, shown in Fig. 7(b), we increased the sensitivity at the sensor's radiating ring and organized it so that we could sense a minute signal. As a result, the line went up to 1.8V as in Fig. 7(b). When we compare this with Fig. 7(a), which showed no change in the breath, the sensitivity was better in Fig. 7(b) despite the breath being at the same intensity.



(a) : Existing Experimental Result

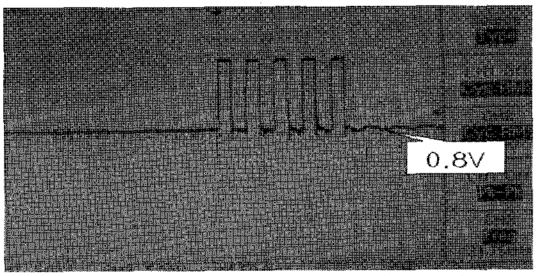


(b) : Current Experimental Result

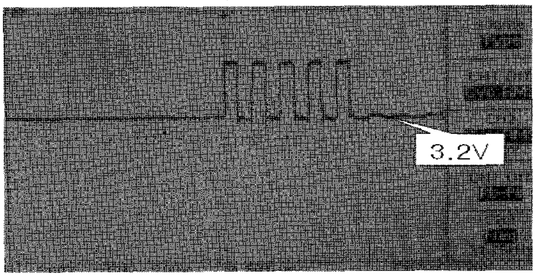
Fig. 7. Weak Exhalation

When Fig. 8(a)s volume poured more strongly into 1L(Litter : strong breath), the datum line went up to the 0.8V. Now the reaction shows weakly even if a healthy man blows strongly. It was therefore impossible to accurately measure patients' respiration. As we raised the radiating ring's sensitivity and poured into volume 1L, the datum line went up to 3.2V as in Fig. 8(b). The sensitivity was improved as the pour became stronger.

The next table expresses a datum line with some volume values.



(a) : Existing Experimental Result



(b) : Current Experimental Result

Fig. 8. Strong Exhalation

Table 1. The Comparison of Existing Experimental Result(a) and Current Experimental Result(b)

	0.2L	0.5L	1L	1.5L
(a)	0V	0.4V	0.8V	1.1V
(b)	1.8V	2.5V	3.2V	5.5V

The reaction of breath strength is difficult to distinguish in existing experimental result. Also, the ground's top and bottom movement caused instability.

To solve this problem we modified the offset from the op-amp, stabilized the ground, increased the radiating ring's amplifier rate and used dual amplification at the receiving ring. We thereby organized the equipment so that we could distinguish the differences in breathing intensity.

Fig. 9. marked at LCD various reaction to the breath. (a) is the screen which turned the power supply on for the first time. (b) shows breathing for two seconds regularly. Screen (c) shows the result of continuous, short breaths. (d) expresses the reaction when we made the breath strong or weak.

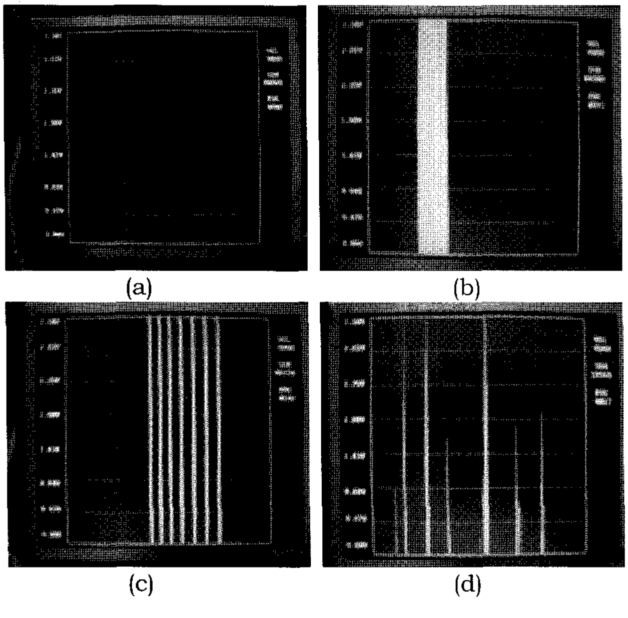


Fig. 9. LCD Display about the Sensitivity of the Breath : (a) no input, (b) strong and long input, (c) Strong, short intermittent input, and (d) random input

CONCLUSION

This study is an initial stage of investigating a spirometer using the characteristic of a cylindrical ultrasonic sensor. Because the measurements made focus on patients, sensitivity to weak breath is required. However, existing experimental results showed that a weak signal could be produced by a powerful exhalation, which is not case with a normal person. This study focused on an analogue, and sensitivity to breath was improved compared to existing experimental methods. Nevertheless, repeated breathing deposits moisture on the cylinder's inner wall because it is made of aluminum, so the response to breath becomes somewhat dull. When measurement is taken after wiping the inner wall with a towel, normal sensitivity was restored, but this requires the inconvenience of cleaning the inner wall at each use for precise measurement. Therefore, it may first be necessary to change the sensor's material.

In the medical area various studies are widely conducted and many applied products are used, including spirometers. Possible in-home care and convenient portable types of products are continuously studied, and such products are promoted with grafting of more application techniques. Ultrasonic sensor techniques for measuring respiratory function have not been practically used domestically or overseas and, if their application succeeds, we will take technical priority over foreign countries. As this technique is one that uses ultrasonic waves, if it is applied to other medical areas, subsidiary techniques may also be induced, and there is a large potential for development as the diagnostic algorithm of respiratory function is still in its initial stage.

In this study, sensitivity to breath was first measured with the possibility of identifying its application by developing interface parts between the signal processing part and the processor. The study needs to be continued before this technique's clinical application to respiratory systems. To obtain the measurements that may practically be used in hospitals, more studies are required on the possible application in an actual respiratory system through improvement in the algorithm of respiratory air flow and through verification by many studies. This thesis can be applied to probe measurement devices related to respiration, including the respiration part of stress electrocardiographs, respiration part of advanced patient monitoring systems, and anesthesia and respiration devices.

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