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Performance Enhancement of Ultrasonic Sensitivity by Improving the Transmitter Circuit

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Abstract

We have developed the spirometer system; many patients having weak respiration have difficulties in using conventional spirometers in hospitals, because their weak breath can be affected by the errors of inertia and instrumental pressure. We have developed a new ultrasound spirometer using an ARM 920T processor. To detect weak respiratory signals, we add a comparator circuit, which can afford more information of respiration characteristics such as respiration volume, directions, and velocities. We have also developed GUI for graphical display of respiration characteristics. Through the pilot test, it has been verified that the developed spirometer is operating reliably.

Key words : ultrasound, spirometer, respiration measurement

I. INTRODUCTION

In the field of respiration measurement, many different approaches have been studied for many years. But the various measurements and methods used in those researches didn't give satisfactory results. Fig. 1 shows the methods for a checkup of lung functions. The problem with each method is described as follows.

First, one of the volume change measurements, plethysmography, is divided into thoracic plethysmography and total body plethysmography, which causes large errors and noises when checking lung functions.

Second, in the spirometry measurement, the type of turbine uses an accelerated motion, the type of thermal-convection using the thermister elements can measure in only one direction, and the type of differential pressure causes high-frequency noises in the equipment itself.

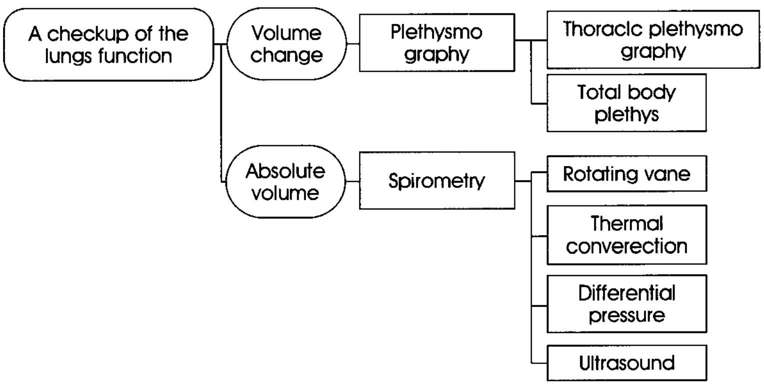

Fig. 1. The methods for a checkup of lung function.

Third, one of the absolute volume measurements, the method of dilution, makes large errors in measuring.

At present, most of the spirometers used for the checkup of lung function in a hospital utilize the nitrogen-washout method [1-3].

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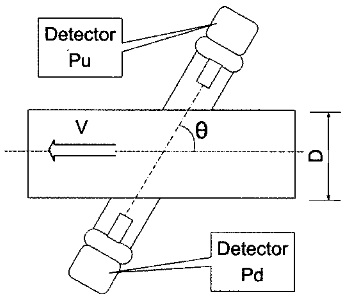


Fig. 2. Measurement principle.

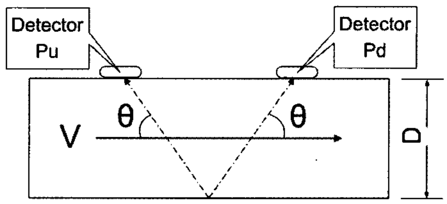


Fig. 3. A cross-section of the housing.

This method requires a large bottle of nitrogen, and the movement of equipment is very inconvenient and is not quick. Also, those who have difficulty breathing, the patients who have weak respiratory function, have experienced lots of difficulties in using a common spirometer in hospitals, since this method requires the patients to make a big respiration. One of the recently released papers, the author examined the sensitivity enhancement of the ultrasonic sensor during transmission and receipt of the signal.

However, this paper improved not only to enhance the sensitivity of the ultrasonic sensor, but to display respiratory characteristics. In particular, the use of an additional transmitter circuit enables observers to display respiratory characteristics, including the respiratory volume, directions, and velocities in more detail than before, when only the volume was included.

II. THE METHODS

A. The Principle

The main principle in the ultrasound measurement for respiration is to utilize the differences in the transmission time. That is to say, it is to measure the speed of the aerial current as a difference of the ultrasound transmission time.

Fig. 2 shows how to measure the speed of the aerial current. The two working detectors transmission and reception, Pu and Pd, face each other in the measurement tube. First, the detector Pu sends Pd the ultrasound pulse. Then td, the transmission time of the flow forward (Pu ⇒ Pd) is obtained. Second, the detector Pd sends Pu the ultrasound pulse. Then tu, the transmission time of the flow backward (Pd ⇒ Pu) is obtained.

td and tu can be shown in the following equations (1) ~ (2).

$$td = \frac{L}{C + V\cos\theta} \tag{1}$$

$$tu = \frac{L}{C - V\cos\theta} \tag{2}$$

Where L : the length of the ultrasound transmission path (L = D/sin Θ).
D : the diameter of the tube.
Θ : the angle between the path of the ultrasound and the axis of the tube.
C : the aerial velocity of sound.
V : the average velocity of the current in ultrasound transmission path.

The frequencies fd and fu, which are inverse numbers of td and tu in the measurement circuit, should be considered. Those frequencies are shown in the following equations (3) ~ (4).

$$fd = 1 / td \tag{3}$$

$$fu = 1 / tu \tag{4}$$

The frequency Δf from the above equations (1) ~ (4) is as follows:

$$\Delta f = fd - fu = \frac{1}{td} - \frac{1}{tu} = \frac{2\cos\theta}{L} \cdot V \tag{5}$$

Very importantly, the right side term of the equation (5) doesn't have C, the aerial velocity of sound. Consequently, V, the average velocity is as follows:

$$V = \frac{L}{2\cos\theta}\left(\frac{1}{td} - \frac{1}{tu}\right) \tag{6}$$

The aerial velocity of sound C of the transmission time td and tu in equations (1) and (2) changes according to the aerial composition and temperature. However, as shown in equation (5), in the difference method of the transmission time, the aerial velocity of sound C disappears, and the average

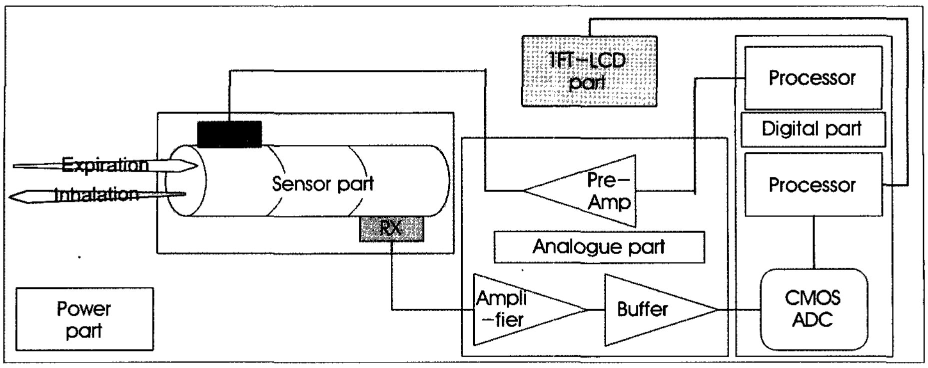


Fig. 4. Block diagram of the ultrasound spirometer.

velocity V only depends on the constants L, Θ. Thus, it is possible for the average velocity of the current to be measured regardless of the change in the temperature of the air [4][5][6].

B. The Application

Fig. 3 shows the ultrasound sensors, in a cross-sectional view of the housing to which the detectors Pu and Pd are attached. The housing shows that the detector Pu transmits an ultrasound pulse signal and counts until Pd receives it. When Pd stops counting, the time is forward, td. Next, the detector Pd transmits a ultrasound pulse signal and counts until Pu receives it. When Pu stops counting, the time is backward, tu.

The forward and backward directions are shown as Table 1.

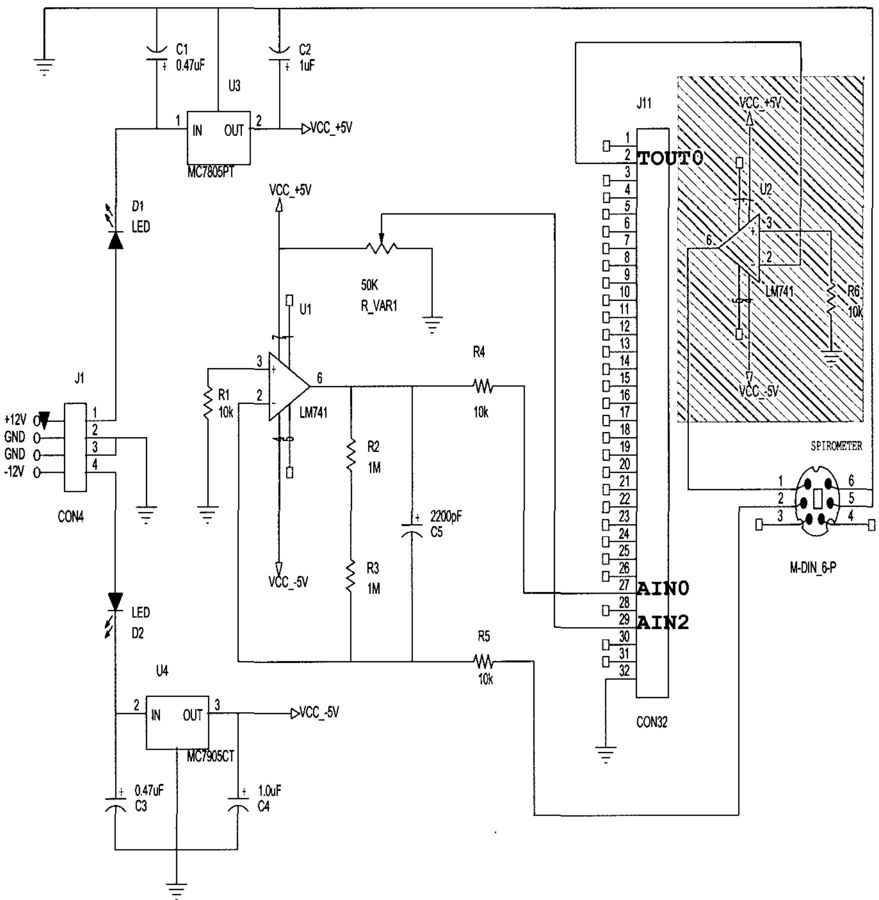


Fig. 5. Additional part of the transmitter circuit.

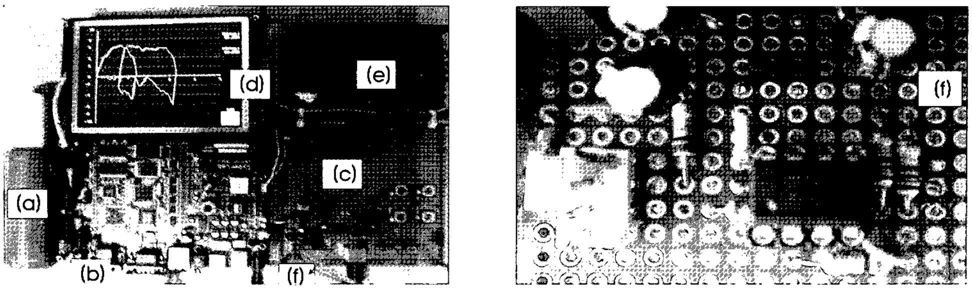


Fig. 6. Modeling process of teeth in CATIA v5. (a) import of scan, (b) removing noise and sampling scan, (c) fill-hole process, (d) final teeth model

Table 1. Detection procedure forward and backward [7][8].

Direction	Detect procedure
(a) Forward direction	Processor ⇨ Transmitter circuit ⇨ Detector Pu ⇨ Respiration air ⇨ Detector Pd ⇨ Receiver circuit ⇨ Processor
(b) Backward direction	Processor ⇨ Transmitter circuit ⇨ Detector Pd ⇨ Respiration air ⇨ Detector Pu ⇨ Receiver circuit ⇨ Processor

Fig. 4 shows the overall block diagram of the entire system. It is divided into the sensor, the analog, the digital signal processor, the display, and the power supply. First, the sensor consists of the housing of the ultrasound sensor and an output cable. The ultrasound sensor detects weak respiration. Next, the analog part supplies the ultrasound pulses to the sensor, and amplifies received signals from weak respiration to improvement sensitivity. Then the amplified signals are sent to the digital signal processor. The digital signal processor is controlled by the ARM 920T processor, which also controls the whole system. The amplified signals sent from the analog section are processed by the CMOS-ADC, and analog signals are converted to digital signals. It saves the digital signals in the memory, and sends them to the display. The display receives the digital signals and displays them on the TFT-LCD in real time. The power supply supplies all the parts with 3.3 V, 5 V, and 12 V for the operation of the entire system.

C. Improvement and Implementation

The following Fig. 5 shows the addition of the transmitter circuit in the analog part. The added circuit increased the sensitivity of the transmitter circuit by amplifying weak ultrasound pulses, enabled detection of the volume, directions, and velocities in the receiver circuit, and stabilized the transmitter circuit.

Fig. 6. shows the ultrasound spirometer which is based on the ARM 920T Processor. This prototype system uses the principle, method, and application of the ultrasound measurement mentioned the above.

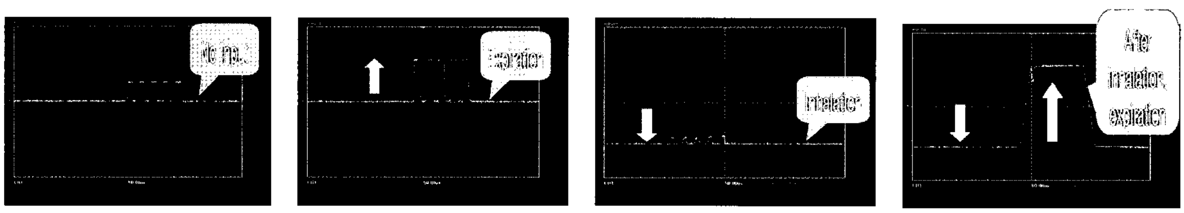
D. The Experiments

The following Fig. 7. show the experiments with the added circuit in the ultrasound spirometer system of Fig. 6.

Fig. 7(a) shows when there is no signal, and Fig. 7(b) shows the expiration signals. Fig. 7(c) shows the inhalation signals, and Fig. 7(d) shows the inhalation and expiration signals. They are displayed on the oscilloscope.

The following Fig. 8. shows a volumeter can keep precise volume for experiments of table 1.

The table shows the compared values of the expiration and inhalation voltages using fig. 8. a volumeter. The values took the mean of 10 time measurements.



(a) No input. (b) Expiration signals. (c) Inhalation signals. (d) After inhalation, expiration signals.

Fig. 7. The signals of the system with the added circuit.

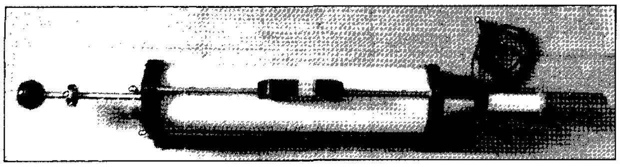


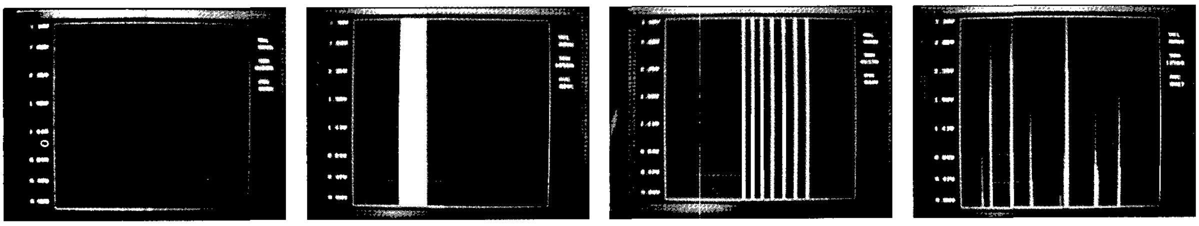
Fig. 8. A volumeter.

Table 2. The comparison of the expiration and inhalation voltages when volume is 1.0 Liter.

Sec	0	1	2	4	8
Expiration	0V	9V	5V	2V	1V
Inhalation	0V	−9V	−4V	−1.5V	−0.8V

The following Fig. 9. show the experiments without the added circuit of Fig. 6.

PFX, from the Medical Graphics Corporation) from a hospital. Fig. 11(b), Fig. 11(c) and fig. 11(d) show the results of the spirogram experimented on the TFT-LCD implemented in the system. The results also show when a man respires at the entrance of the system's housing. They show not only the volume and directions of respirations but also the velocities. The horizontal lines indicate the sizes and volumes and the vertical lines indicate the velocity of the flow. Also, the up-side of the horizontal lines in the respiratory curves indicate the expiration, and the down-side of the horizontal lines in the respiratory curves indicate the inhalation. The starting point of the expiration is rendered only from a point where the horizontal lines and the vertical lines meet, for the convenience of observers and users. The analog volumes of these respiratory curves were converted into decimal numbers (unit: ml) and were displayed on the upper right side of the



(a) No input. (b) Strong, long, continuous signals. (c) Strong, short intermittent signals. (d) Weak or strong, short and intermittent signals.

Fig. 9. The display of the expiration intensity experiment.

Fig. 9. can show only the volume of the expiration and the intensity(strong and weak, continuous or intermittent) of the input signals, and can't show the directions or the velocities. Fig. 9(a) shows when there is no signal, and Fig. 9(b) shows the strong, continuous expiration signals. Fig. 9(c) shows the strong, short, intermittent signals, and Fig. 9(d) shows the weak or strong, short, intermittent expiration signals. They are displayed on the TFT-LCD [9].

Fig. 10. shows the continuous graph of the respiratory volume and directions. Also, this respiration shows whether it is expiration or the inhalation, but doesn't show velocity. For the users' convenience, the expiration shape and the inhalation shape are colored in green and pink.

III. RESULTS AND DISCUSSION

Fig. 9. and Fig. 10. can't show all the things being directions, velocities, and volume of the respiration. However, Fig. 11(a) can show those results of the spirogram. The respiratory curve is the measured result of the respiratory characteristics of a man using the spirometer (model: ULTIMA

TFT-LCD for exact discernment of the volumes.

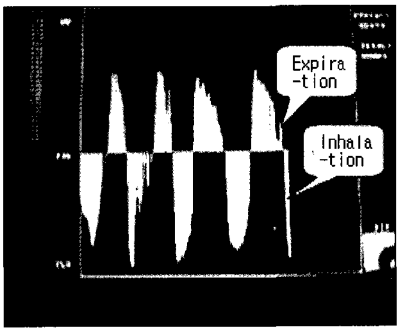
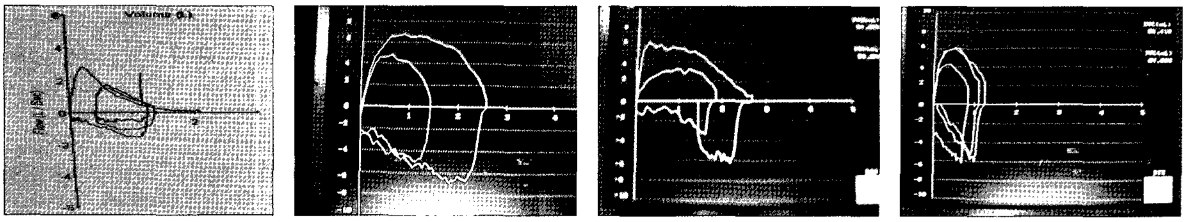


Fig. 10. The continuous display of the expiration and inhalation experiment.

IV. CONCLUSION

Many patients with weak respiratory ability have difficulties in using conventional spirometers in hospitals, because their weak breath can be affected by the errors of inertia and instrumental pressure. We developed a new ultrasound type spirometer using ARM 920T processor. To detect weak respiratory signals, we add a comparator



(a) Spirogram in hospital. (b) Spirogram in an experiment. (c) Spirogram in an experiment. (d) Spirogram in an experiment.

Fig. 11. Spirogram (a) is shown in hospital and spirograms (b), (c), (d) show the respiratory volume, directions, and velocities.

circuit, which can afford more information of respiration characteristics such as volume of respirations, directions, and velocities. We also developed GUI for graphical display of respiration characteristics. Through the pilot test, it is verified that operation of the developed spirometer is reliable.

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