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Development of Respiratory Signal Detection System Based on Intelligent Terminal Ultrasonic Transceiver

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Abstract: Breathing is one of the important vital signs with periodic characteristics. Its small amplitude of movement and weak reflected energy make non-contact breathing monitoring challenging. This innovative project focuses on developing a respiratory signal detection system based on intelligent terminal ultrasound transceiver. Generate and receive Frequency Modulated Continuous Wave (FMCW) sound signals using smartphones, computers, and even external hardware. Complete the extraction and analysis of respiratory signals to pave the way for further health monitoring.
Keywords: Ultrasound; Respiratory monitoring; FMCW; Differential frequency signal; FFT; FRFT; Peak detection method

1. Background and research

1.1 Research Background

Mobile health sensing is an emerging field that has aroused great interest in industry and research. Using mobile and intelligent devices to monitor routine vital signs such as pulse, blood pressure, respiratory rate, and blood oxygen concentration is a good vision. In medical treatment, doctors and other professionals use specialized equipment to routinely monitor vital signs. However, this is usually very limited in frequency, only once or twice a year. However, in order to lead a healthy lifestyle, managing personal health data at a finer granularity is crucial, especially by tracking vital signs more regularly and frequently, even preferably once a day. Thanks to the rapid development of the Internet of Things and mobile sensing, mobile health sensing provides a universal, user-friendly, sustainable, and affordable opportunity to achieve these goals. If we can monitor vital signs with our daily smartphones, we can track the measurement results of these elusive signs anytime, anywhere, and maintain health records every day.

1.2 Research status

With the emergence and popularization of smart terminals such as smartphones and wearable devices, human-computer interaction such as health monitoring has developed rapidly. Health and safety issues have received increasing attention, and a large number of research institutions and scholars at home and abroad have invested in various types of research. In general, the existing respiratory monitoring technologies are mainly divided into two categories: (1) respiratory monitoring technology based on wearable devices; (2) Respiratory monitoring technology based on non-contact devices.

1.2.1 Respiratory detection technology based on wearable devices

Wearable devices are characterized by the need for users to contact or wear the device. In related work, Chen et al. proposed that users wear earphones connected to mobile devices, and collect the sound of users' breathing through the microphone of the earphones to extract respiratory signals. Mobile terminal devices are also integrated with various sensors, such as gyroscopes, accelerometers, magnetometers, etc. in smartphones, and sensors such as light sensors, altimeters, heart rate sensors, and gyroscopes in smart watches. These sensors can help users perceive their surroundings. Some scholars have turned their eyes to the camera and attempted to analyze respiration and heartbeat using computer vision based methods. When the camera is turned on, the flash is also turned on. The camera records data and analyzes the data for experiments. Nowadays, there are a variety of wearable devices, including common smart watches and smart bracelets, as well as devices that exist in personal items such as glasses, clothing, and even rings, shoes, and socks. MindfulWatch is a smart watch based sensing system that can monitor breathing in real time while users meditate.

Although wearable devices with increasingly powerful functions meet the monitoring of key vital signs as much as possible, the poor experience brought about by the hard conditions they need to wear or contact has brought negative impacts to users. Especially for the elderly, using wearable devices is extremely inconvenient. At the same time, the high price also makes its promotion difficult.

1.2.2 Breath detection technology based on non-contact equipment

Compared to wearable devices, non-contact respiratory monitoring technology has a wider range of applications. Most of them have the characteristics of strong universality, convenient use, and low cost. Currently, there are three main methods for contactless devices. First, based on computer vision. This method generally uses video capture

Set up images with breathing, and then use computer vision processing methods to segment and extract respiratory features from the environment, and recognize respiratory signals through techniques such as deep neural networks. However, the disadvantages of this method are also obvious. Firstly, additional cameras and high technical barriers require a certain cost. Secondly, the use of cameras may lead to issues such as user privacy disclosure. Finally, the use of cameras has its own limitations, and the shooting range and external light intensity can greatly affect the accuracy of respiratory monitoring. Second, based on RF technology. Vital-radio is a wearless device technology that transmits FMCW through an antenna, estimates the differential frequency signal using the transmitted and received signals, and further converts the signal into phase based signal data to extract respiratory and heartbeat signals. However, radio frequency is an electromagnetic wave with a very high frequency, and the reliability of differential frequency signals depends on the accuracy of the transmitted and received signals. In order to obtain ideal results, high-precision equipment is often required, which is extremely unfriendly to low-cost users. Third, based on sound signals. The principle is roughly the same as radio frequency, but the speed of sound is six orders of magnitude less than that of electromagnetic waves, which makes signal processing much simpler at low speeds. Sound signals can be transmitted and received only by using the microphone and speaker of a smartphone or headset.

1.3 Research contents

Our ideal approach is to use only off-the-shelf commercial smartphones, without requiring users to carry any personal or internal devices. We use inaudible sound signals to sense fluctuations in the chest cavity, known as respiratory frequency. The ultimate goal is to design a respiratory signal monitoring system based on mobile phone ultrasound signals for indoor scenes.

Since we have no experience in such research, we have encountered various difficulties during the development process, resulting in multiple simplifications of scenarios and implementation schemes. After that, we will describe the basic principles, implementation plans, and research results one by one.

2. Fundamentals

First, we will describe the frequency of sound signals and our definition of ultrasound. Next, we will introduce the respiratory process and monitoring mechanism. Finally, we will introduce FM continuous wave and its principle.

2.1 Sound signal frequency

We know that sound is produced by vibration. Through a certain medium, it spreads from the sound source to the human ear, causing tympanic membrane vibration, and then transmits it to the brain to form hearing. Science generally believes that the human ear perceives sound in the range of 20 Hz to 20 kHz, so microphones for commercial devices generally cover this range. However, the most sensitive sound frequency range for the human ear is 1000 Hz to 3000 Hz, and the common music playback frequency range is 50 Hz to 11 kHz, which means that the audio range of 20 Hz to 20 kHz is slightly broader for the human ear. The human ear does not perceive low-frequency and high-frequency sound signals well. After previous research and independent testing, we have found that audio signals above 16 kHz are almost difficult to capture, and we may refer to this sound frequency as a critical frequency. The critical frequency varies from person to person, and it decreases with age. Therefore, for systems whose main target group is the elderly, audio above 16 kHz can be completely considered as non audible signals.

2.2 Respiratory process and monitoring mechanism

Gas enters and exits the lungs by the pressure difference between inside and outside the lungs. Air is inhaled into the lungs due to lung expansion, resulting in lower intrapulmonary pressure than atmospheric pressure; "When gas is exhaled out of the body, it is due to the narrowing of the lung, with the intrapulmonary pressure higher than atmospheric pressure. The lung itself cannot actively expand and contract, and its expansion and contraction depend on the movement of the thorax.". Respiratory movement refers to the contraction and relaxation of respiratory muscle groups such as intercostal muscles and septum, resulting in the expansion and contraction of the thorax. It is the driving force for lung ventilation. "The fluctuation frequency of the thorax can be completely equivalent to the respiratory rate, and based on this, we only need to monitor the changes in the thorax.".2.2, a mobile device is fixed at a certain distance from the user's chest. When the user inhales, air enters the chest cavity, causing the chest to bulge, reducing the distance from the device; Conversely, when the user exhales, the thorax contracts, and the distance from the device increases. When the user breathes continuously, the device monitors the periodically varying distance to simulate the user's respiratory signal.

3. Signal transceiver

3.1 Preliminary Exploration of Ultrasonic Signals

3.1.1 LibAS platform

It has been determined that the sound signal we need is between 16 kHz and 20 kHz. At first, we tried to find various ready-made solutions that were convenient for achieving this goal. LibAS was the first software we tried.

LibAS is a cross platform framework that facilitates the rapid development of mobile acoustic sensing applications. It helps developers quickly implement their ideas by using advanced Matlab scripts, and tests them on various OS platforms,

It divides a common acoustic sensing application into two parts:

(1) Basic sensing algorithm

(2) Platform control assembly.

With LibAS, application developers simply select the signals they want to sense, and then build a callback function to handle each received sensing signal. Developers can either use Matlab to build callback functions using LibAS's server client remote mode, or use C language to choose a standalone mode (both support cross platform development).

LibAS can provide cross platform support because the platform control API is connected to developers' awareness algorithms through several common interfaces/wrappers.

3.2 Intelligent machine based transceiver

We have noted Han's proposal for the generation of ultrasound signals in his paper. Given its strong operability, we attempt to explore and reproduce the proposal she provided. The preliminary plan is to use a mobile phone to transmit and receive sound signals generated by Matlab, and then use a computer to analyze and process them offline.

4. Summary and reflections

Breath detection based on intelligent terminal ultrasound transceivers is not a particularly cutting-edge technology, but it is also a significant challenge for me when I am first exposed to research work. The actual effect of transmitting and receiving ultrasound signals is not significant, and the inability to break through many key steps has led us to repeatedly lower standards. For example, changing from real-time detection to offline processing, breathing detection to wall detection, and even finding a new way to send and receive from smart phones to hardware circuits. Overall, the results of the work have not met expectations, but they have also been achieved.

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