Non-contact respiratory monitoring radar system based on micro-Doppler effect

Taichang Guo, Fan Yang*
School of Physics and Electronic Information, Inner Mongolia Normal University, Hohhot, China

ABSTRACT

Breathing often reflects people's physical condition, such as sleep apnea is closely related to cardiovascular and cerebrovascular diseases, sleep quality is also closely related to breathing. A non-contact respiratory monitoring device is designed to monitor people 's breathing for a long time, so that people can understand their own breathing conditions and prevent some potential diseases. System hardware mainly includes LimeSDR, 2.4G directional antenna, power amplifier, low noise amplifier and host computer. The software is GNURadio for data visualization and data extraction. A flow chart is built on GNURadio to process the signals transmitted and received by LimeSDR, and the human respiratory data is obtained according to the micro-Doppler effect. The effective detection distance of the device is about 1 meter, and the accuracy rate is 93.75%. Compared with the traditional contact breathing monitoring, the device avoids the discomfort when people are attached to the sensor. This device is mainly used for sleep monitoring, which is small in size and easy to operate, making it more suitable for individuals and families, and has great market prospects.

Keywords: Non-contact, respiratory monitoring, micro-Doppler effect, sleep monitoring

1. INTRODUCTION

When the human body has problems, it will send out the corresponding signal. When people sleep with abnormal breathing, the body may have a potential disease. However, people in sleep cannot find that they have abnormal breathing activities, and miss the best time to prevent diseases[1]. With the growing awareness of health, more and more people hope to find and prevent some potential diseases early[2]. It is estimated that there are more than 40 million patients with apnea syndrome in China. The main hazards are insufficient sleep depth, prone to mental depression and other phenomena, resulting in elevated blood pressure, which can seriously affect life expectancy[3-6]. At the same time, non-contact respiratory monitoring can also be used in the prevention and control of new coronavirus disease. China mentioned in the "New Coronavirus Pneumonia Diagnosis and Treatment Program" that when the respiratory rate is greater than 30 times per minute, it is a differential indicator for severe patients with new coronavirus pneumonia[7]. Non-contact respiratory monitoring can reduce the probability of infection and protect medical personnel more effectively.

At present, the human respiratory information is mainly obtained by respiratory mask and chest pressure sensor, which has the characteristics of high reliability[8]. Compared with the contact breathing monitoring equipment, the non-contact monitoring gets rid of the constraints of electrodes and sensors on the detection object, and can provide a relaxed and comfortable detection environment for the detection target, thus improving the accuracy of respiratory monitoring[9, 10]. Infrared non-contact monitoring technology can detect physiological signals through temperature changes caused by human physiological activities, but it cannot directly penetrate the clothes for detection. Moreover, the infrared device has high cost, large volume and difficult operation[11, 12].

Therefore, this paper proposes a non-contact respiratory monitoring system based on micro-Doppler effect. When the human body breathes, the abdomen is accompanied by fluctuations, resulting in the frequency inconsistency between the transmitted signal and the received signal. According to the Doppler effect, the frequency difference between the two is the Doppler frequency shift. The frequency shift data is obtained by GNURadio, and the data is put into MATLAB. The number of human respiration can be analyzed by peak detection, and the respiratory frequency can be measured. This device is easy to operate, only need to open GNURadio on PC, run the flow chart already built can start monitoring. At night, if the user monitors the breathing condition after sleep, the device can automatically save the whole night's breathing data, which can be used for users to wake up the next day to see whether they have apnea at night, and then know whether

* 676752175@qq.com

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there is a potential disease.

2. SYSTEM DESIGN

2.1 System design

Hardware includes LimeSDR, 2.4G directional antenna, power amplifier, low noise amplifier and host computer. The software is GNURadio for data visualization and data extraction. The transmitter and receiver of LimeSDR are connected to power amplifier and low noise amplifier, respectively. The USB port of LimeSDR is connected to the host computer, and then the two directional antennas are connected to power amplifier and low noise amplifier. The overall design diagram of the system is shown in Figure 1. After completing the connection of the hardware part, it is also necessary to build a flow chart on GNURadio and use modules with different functions to realize the Doppler radar function, as shown in Figure 2. When used, you simply adjust the antenna distance and angle, and run the flow chart in GNURadio to start monitoring breathing. Human respiration data can be obtained by analyzing the frequency difference between the received and transmitted signals. Finally, the extracted data can be processed in MATLAB.

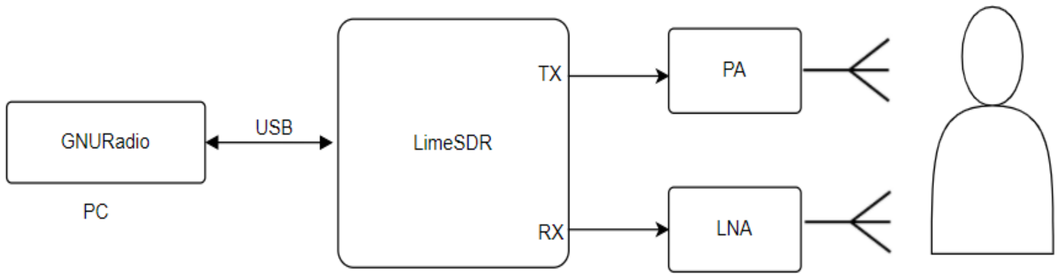

Figure 1. Overall design diagram of the system.

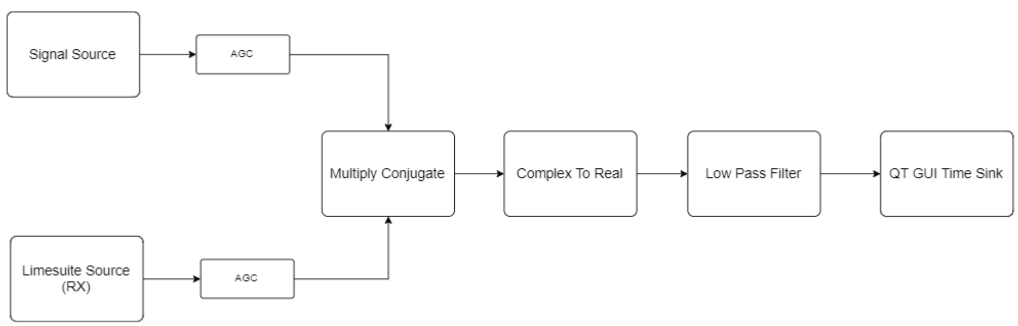

Figure 2. Radar design diagram.

2.2 Hardware design

Hardware includes LimeSDR, 2.4G directional antenna, power amplifier, low noise amplifier, PC. LimeSDR is a low-cost software defined radio platform that supports applications and supports the frequency range from 100KHz to 3.8GHz. The LimeSDR is controlled by GNURadio to transmit and receive signals, and the carrier signal is set to 2.4 GHz. Directional antennas are used to make the signal propagation more accurate and farther, so as to make the effective distance of respiratory monitoring farther and the respiratory data more accurate. Since the micro-Doppler frequency shift caused by abdominal fluctuation during human respiration is extremely weak, the data accuracy will be greatly reduced without power amplification, so the power amplifier is connected at the transmitter. In order to reduce the noise interference to the signal, the low noise amplifier is connected at the receiver. When used, the antenna should be aligned to the abdomen of the human body to sense the fluctuation of the abdomen during breathing. Hardware device, as shown in Figure 3.

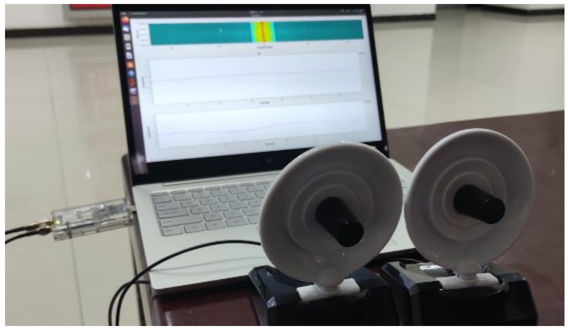

Figure 3. Hardware device.

2.3 software design

Because of the simple operation, the software uses GNURadio. Using GNURadio does not need to understand the underlying logic code, only need to clear the function of each module and the function realized after the module connection. GNURadio can also visualize and save the desired data. Connecting the required modules and setting appropriate parameters can realize Doppler radar function and observe respiratory curve. The GNURadio flow chart is shown in Figure 4.

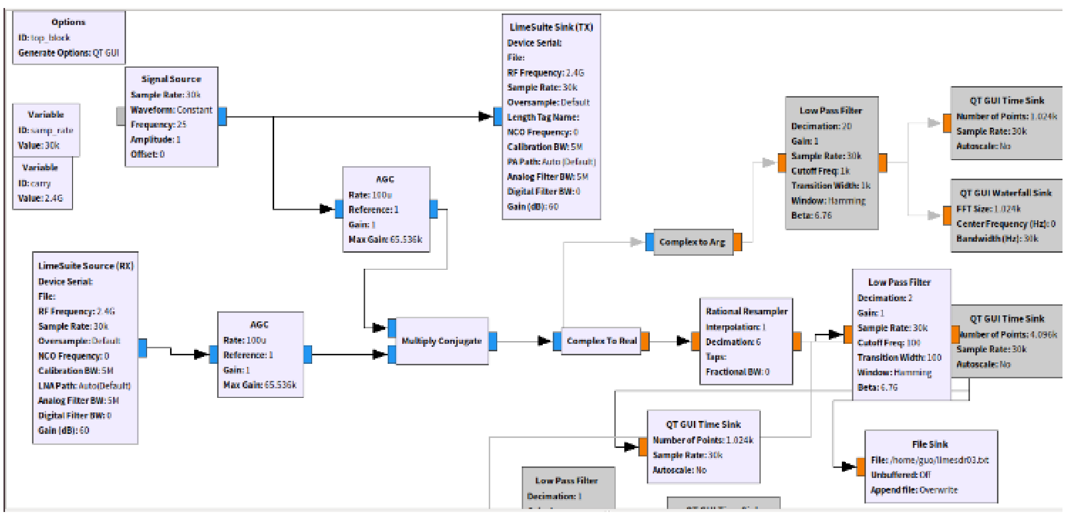

Figure 4. GNURadio flow chart.

Signal Source is a signal source module, sending 25Hz sine wave signal. LimeSuite Sink (TX) controls LimeSDR to emit 2.4G carrier signals. AGC is an automatic gain to match the amplitude of the carrier signal. Limesuite Sink (RX) as the receiver receives the reflected signal. The received signal and the transmitted signal are connected to the Multiply Conjugate module to obtain the Doppler frequency shift signal. Then the burrs in the signal are eliminated by a low-pass filter. Finally, the respiratory signal can be seen in QT GUI Time Sink. Only real-time breathing curves can be observed in GNURadio without viewing the full breathing curve. Therefore, using File Sink module to save the signal and put it into MATLAB for processing can see the complete respiratory curve. By analyzing the peak, excluding noise and other parts of the body disturbance, get more accurate number of breathing.

3. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

The experimenter lay in bed to simulate the state of sleep. Place the device on the table beside the bed, the antenna is about 1 meter away from the human body, and adjust the antenna angle to the abdomen of the human body. When the body breathes, the abdomen fluctuates. Due to the micro-Doppler effect, the fluctuation of the abdomen causes the Doppler frequency shift between the transmitting signal frequency and the receiving signal frequency. Human respiratory data can be obtained by analyzing Doppler shift. After running the program, we monitored the experimenter for one minute. The experimenter tested the respiratory curve measured by the equipment under three conditions: normal breathing, stopping breathing and body disturbance. Cut some breathing curves, as shown in Figure 5.

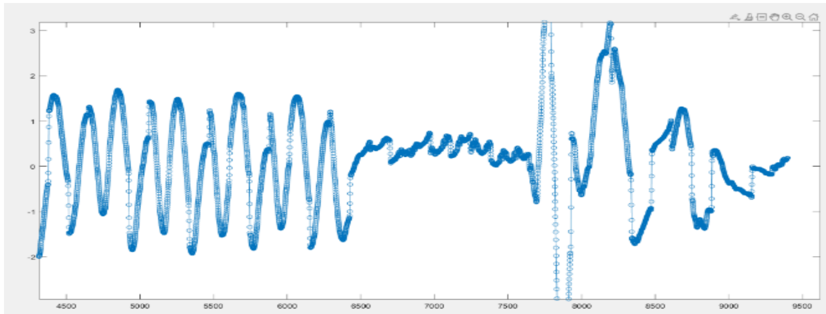

Figure 5. Partial respiratory curve.

From Figure 5, we can see three situations during the test: the left part of the figure is normal breathing, the frequency of the curve is uniform, and the amplitude is between 1 and 2.5. The middle part is when the breathing is stopped, the curve frequency is fast, but the amplitude is small, which is due to the influence of other objects' motion or signal noise. The right part is that the curve amplitude is larger when the experimenter moves. Therefore, we can calculate the number of human respiration by peak detection, as shown in Figure 6. Add threshold judgment. When the amplitude is less than 1, it can be judged as noise interference. When the amplitude is greater than 2.5, the body movement can be judged. Between amplitude 1 and 2.5, it represents normal breathing. Finally, the data were put into MATLAB, and the number of human respiration was measured to be 15, and the accuracy rate of the equipment reached 93.75%.

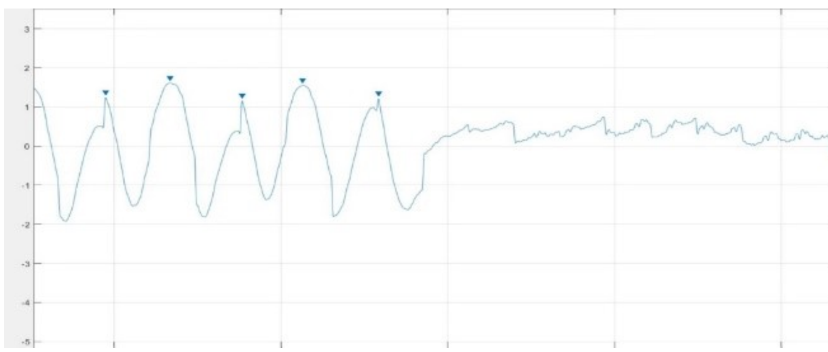

Figure 6. Peak detection.

4. CONCLUSION

In this paper, the respiratory curve is analyzed when the antenna is 1 m away from the human body and is aligned to the human abdomen. People use this device to monitor sleep breathing. Just open GNURadio before sleep, run the flow chart, has begun to monitor breathing. At the same time, breathing data will be completely saved for the next day to see if you have an apnea or shortness of breath at night to discover and prevent potential diseases. However, when the distance increases to 1.5 m, the signal strength decreases significantly, which makes it impossible to accurately monitor respiration. Therefore, this device is largely limited by the distance. The accuracy is high when people are within 1m away from the antenna. At the same time, the equipment is affected by body movement. Therefore, the equipment cannot monitor breathing during human movement, which is more suitable for monitoring the breathing state in sleep. In this experiment, we only tested the breathing state of the experimenter in the lying state, and the accuracy of breathing monitoring under different sleeping postures remains to be studied.

The greatest advantage of the equipment is non-contact monitoring. It can accurately measure people's respiratory status without affecting people's sleep, and determine whether apnea has occurred, which is of great significance for people to find and prevent potential diseases. The constraint of contact breathing monitoring electrode and sensor on detection object is solved. At the same time, the equipment is small in size, simple in operation and low in cost, which can effectively solve the basic requirements of user monitoring sleep respiration and is more suitable for individuals and families. It has great development potential and market prospect in the field of sleep monitoring.

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