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Research on Identifying Life States by Analyzing Physiological Raw of Rabbits under Typical Post-Disaster Rescues

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Abstract—Contactless identifying different life states can result in improved rescue strategies in post-disaster rescues (such as earthquake and mine accident). If the buried targets are identified extremely endangered with very poor life states, the rescuing principles should be time first. Conversely, if the life states of the buried targets are relatively good, more reliable and safer methods should be given priority although they may cost a little more time. Unfortunately, there are few corresponding reports in life states identification, and current researches mainly focus on detecting or locating under penetration condition. This paper conducts a research on the change laws of physiological parameters of six New Zealand white rabbits, 3 females and 3 males. Experimental condition is under water and food deprivation to simulate one of the typical trapped situations of buried targets in post-disaster rescuing missions. Respiration is synchronously detected by an ultra-wideband (UWB) system in non-contact and an RM6240E system in contact. Heart rate, weight, and anal temperature are measured in contact measurement meanwhile. Over the time under water and food deprivation condition, there are typical and regular varieties in the respiration waveforms and heart rate values, which provide the possibility to identify different life states. Particularly, the respiration waveform changes in UWB radar signals are envisioned to be applied in practical post-disaster rescue where only UWB radar can penetrate ruins through penetrating measurement method.

1. INTRODUCTION

Ultra-wideband (UWB) radar life-detection technology is getting rapid development and has attracted great interest in civilian and military applications mainly due to its typical advantages in penetrating obstacles and protecting visual privacy [1–4]. Its applications such as gesture recognitions [5], targets identification [6], and human locating [7] are of research hotspots because they have huge market potential in areas like intelligent homeware and internet of thing. Particularly, UWB radar is necessary in post-disaster rescue scenarios such as earthquakes where trapped targets are buried under ruins and unable to move. It can penetrate the ruins and obtain the information of target locations and life states, which make it irreplaceable compared with optical and infrared technologies. Narayanan [8] proposed a viable method which combined noise radar technology and modern signal processing approaches to locate obscured stationary and moving targets. Donelli Massimo designed light-weight [9] and experimental bistatic X-band continuous-wave [10] radar systems for detecting the life signals of victims trapped under building ruins during an earthquake or other disasters. Bao et al. [11] designed a cascaded spatial-temporal three-stage detector to accurately detect short-range targets and remove a few false alarms. In [12] and [13], two novel methods using support vector machine and convolution neural networks

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respectively are proposed to distinguish stationary human and common animals under through-wall condition. Common animals include some family pets such as dogs, cats, and rabbits.

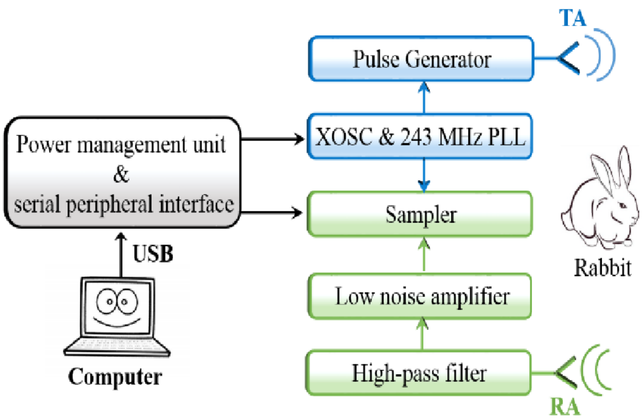
These works can help to detect correct human targets and obtain the approximate locations of buried survivors in post-disaster rescue scenarios. However, little was known about the buried survivors' vital state under trapped conditions due to the limitations of techniques and methodologies. It is significant to refine the rescue missions and facilitate the successful rescue of the survivors. Identifying the vital states using UWB radar based contactless measurements can provide information about the survivors' physical condition. It is regarded as guidance and thereby helps provide an improved rescue strategy. For example, if the buried targets are identified extremely endangered with very poor life states, then the rescuing principles should be time first although there may be some security risks. Conversely, if the life states of the buried targets are relatively good, then some reliable and safe methods should be given priority although they may cost a little more time. Unfortunately, there is few corresponding reports on this area.

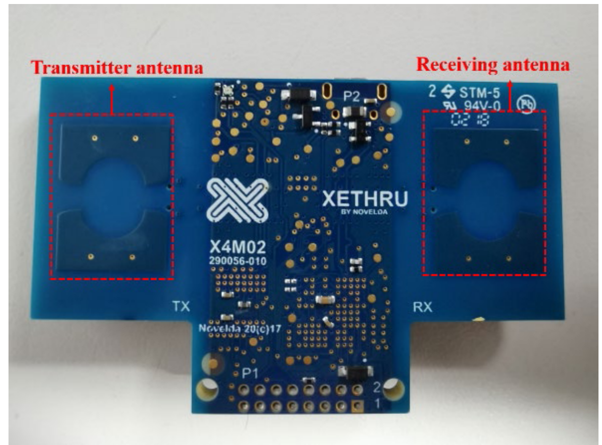
This paper aims to research on the change law of physiological parameters when a target is buried under ruins and unable to move. The targets may be under compound conditions like the combination of water and food deprivation, confined space, squeezed in ruins, etc. It is necessary to first focus on some single condition and then combine all the conditions together in a research procedure, because this can help to understand the impact of various conditions and further reveal the essence. The condition of water and food deprivation is chosen in this research. Rabbits are close to human in many aspects, and they have been applied in many researches like study of cardiac function and infectious diseases studies of orthopedic surgery, cardiovascular surgery, and neoplastic diseases [14]. The key gene expression and function of rabbits are equivalent and close to human. Moreover, histopathological and/or immunohistochemical features of the tissues of disease are similar to humans [14]. Thus, New Zealand white rabbits are chosen to construct an animal model on the research of the change law of physiological parameters under condition of water and food deprivation. We believe that similar vital-sign changes can occur in human targets if under the same condition. More importantly, the methods in this research, which aims to identifying different life states based on the waveform and value changes of UWB radar signals, can provide reference and inspiration on life-state corresponding researches and can be easily applied when there is some corresponding data of human targets that may be obtained in actual post-disaster rescues missions.

2. DATA ACQUISITION

2.1. Non-Contact Detection by UWB Radar System

The block diagram and real picture of the utilized UWB radar system is illustrated in Fig. 1. It is a typical system on chip (SoC) named X4M02, which includes two patch antennas to transmit and receive pulses. The external oscillator (XOSC) clock and phase locked loop is used to produce a stable and high-frequency clock signal. The clock signal can help pulse generator synthesize accurately controlled pulses to excite the transmitter antenna (TA), and control the working frequency of the sample unit at the same time. Then, through the receiving antenna (RA), the return pulse is processed by a fully differential receiving front which consists of a high-pass filter (HPF), a low noise amplifier (LNA), and a sampler. A power management unit (PMU) is used to supply power, while a serial peripheral interface (SPI) is used for communication. They are both excited and controlled by the host computer through universal serial bus (USB). The center frequency of the UWB system is 7.29 GHz with a bandwidth of 1.4 GHz. In addition, the average output power of the center frequency in dBm/MHz is lower than −44 dBm, which complies with Federal Communications Commission (FCC) and European Telecommunications Standards Institute (ETSI) in terms of average transmitted power. It is set to detect a range of 0–5 m here, with range resolution approximately 0.026 m. The radar can create a frame after each detection, and the scanning speed of the frame along measuring time is approximately 17 Hz, namely 17 baseband frames per second.





(a) (b)

Figure 1. (a) Block diagram of the utilized ultra-wideband (UWB) radar system. (b) Real picture of the utilized UWB radar system. Abbreviations: TA, transmitter antenna; RA, receiving antenna; USB, universal serial bus; PLL, phase locked loop.

2.2. Other Measuring Devices by Contact Detection

An RM6240E physiological parameter acquisition system is utilized to measure the respiration by contact through a high-sensitivity pressure sensor. The contact respiration acts as a gold standard to examine the UWB radar respiration. A GOLDWAY UT4000B electrocardiogram (ECG) monitor is used to measure the heart rate. An Omron thermometer MC-347 is employed to measure the anal temperature, whose accuracy is 0.1 degree centigrade. SETPRO counting scales are utilized to measure the weight, whose accuracy is 0.0001 kilogram (kg).

3. RADAR SIGNAL PROCESSING

The raw radar data is interfered by environmental noises; thus, the respiration signals of the targets cannot be directly measured. It is necessary to implement signal processing for extracting clear and true respiration signals. As shown in Fig. 2, three signal processing steps including direct current (DC) removal, 2-Hz low-pass (LP) filtering, and adaptive filtering are utilized.

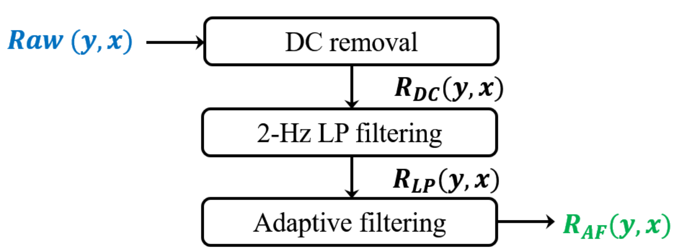


Figure 2. Flow chart of the radar signal processing steps. Abbreviations: DC, direct current; LP, low-pass.

First, DC removal is performed to raw radar data $Raw(mn)$ for eliminating the DC component and baseline drift. It is illustrated by

$$R_{DC}\left(y,x\right)=Raw\left(y,x\right)-\frac{1}{100}\sum_{n}^{n+99}Raw\left(y,x\right), \tag{1}$$

where $R_{DC}(y, x)$ is the radar signal after DC removal. Then, LP filtering of 2 Hz cut-off frequency is utilized for filtering out the environmental noises of high frequency. It is described by

$$R_{LP}(y, x) = R_{DC}(y, x) * h(t), \tag{2}$$

where $R_{LP}(y, x)$ represents the radar signal after LP filtering, and $h(t)$ represents the impulse function of the finite impulse response filter [15].

Finally, adaptive filtering based on the least mean square algorithm is utilized for eliminating the respiration-like noises [16]. The signal after LP filtering $R_{LP}(k)$ mainly contains the target's respirational signal $H(k)$ and respiration-like noises $C(k)$. Generally, the radar data collected in the first few seconds at the beginning contains almost only noises, which is denoted by $\eta(k)$ in the paper. Then, the respiration-like noises can be eliminated by

$$z(k) = \sum_{i=0}^{L-1} w_i(k)\eta(k-i), \tag{3}$$

$$e(k) = R_{LP}(k) - z(k), \tag{4}$$

$$w_i(k+1) = w_i(k) + 2\mu e(k)\eta(k-i), \quad i = 0, 1, ..., L-1 \tag{5}$$

where L denotes the order of the adaptive filter, μ the step-size parameter, and $w_i(k)$ the tap weight vector. The initial value of $w_i(k)$ is set to zero. $z(k)$ is the output of adaptive filter, which is regarded as the respiration-like noises. Thus, the error signal $e(k)$ is almost the same as the clear target's respirational signal $H(k)$.

4. EXPERIMENTAL RESULTS

A total of six New Zealand white rabbits aged approximately five months are provided by the Experimental Animal Centre of Fourth Military Medical University. They are numbered in the experiment. The legend numbers from 1 to 3 represent three female rabbits, and the legend numbers from 4 to 6 represent three male rabbits. They are under the simulated water and food deprivation condition. All the measurements, including respiration of UWB radar and RM6240E in contact way, heart rate of the UT4000B, anal temperature, and weight are conducted every 12 hours, namely twice per day. Particularly, measurements of heart rate of the UT4000B, respiration of UWB radar and RM6240E in contact way are implemented synchronously, namely starting and ending at the same time. The experimental scenarios are shown in Fig. 3.

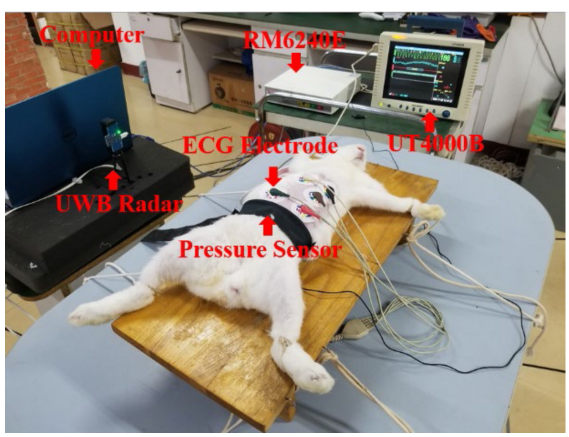


Figure 3. Experimental scenario.

4.1. Respiration Results of the UWB Radar and RM6240E in Contact

A normal respiration waveform of the UWB radar after adaptive filtering and a synchronously measured respiration waveform by RM6240E in contact are illustrated in Fig. 4. The calculated respiration frequency of the UWB radar and the RM6240E in contact are basically equal. This further verifies the accuracy of the UWB radar signal since the signals of RM6240E in contact are regarded as gold standard in clinical practice. The changes in respiration frequency over time of the six New Zealand white rabbits are shown in Fig. 5. The average survival time of male rabbits is smaller than that of female rabbits. The shortest survival time is a male rabbit numbered 6, only 4.5 days. The longest survival time is a female rabbit numbered 2, being 15.5 days.

Particularly, some special respiratory waveform changes can be found over the survival time, especially in the later periods of the experimental process. Fig. 6 shows an example of changes in respiratory waveforms of the UWB radar data and corresponding signal of RM6240E in contact. In Fig. 6, the respiration waveforms within the noted red circle lines vary much faster than other normal waveforms outside the red circle lines. These phenomena can be found both in data of UWB radar and RM6240E in contact. Moreover, these phenomena only appear in the later stage of the process of water and food deprivation condition, namely near the death. And the waveforms in the early stage

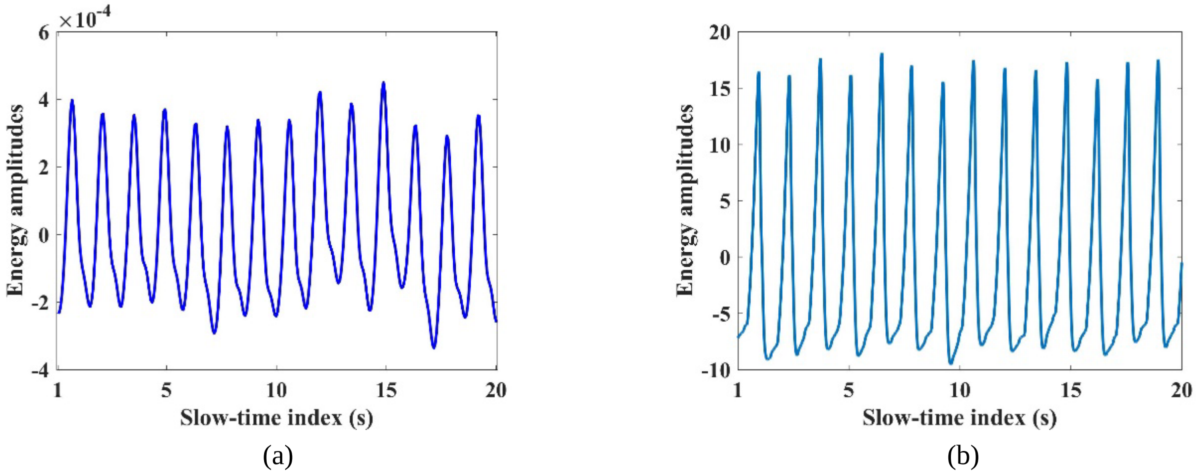


Figure 4. (a) Respiration waveform of UWB radar after 2 Hz low-pass-filters processing. (b) Respiration waveform of the RM6240E in contact.

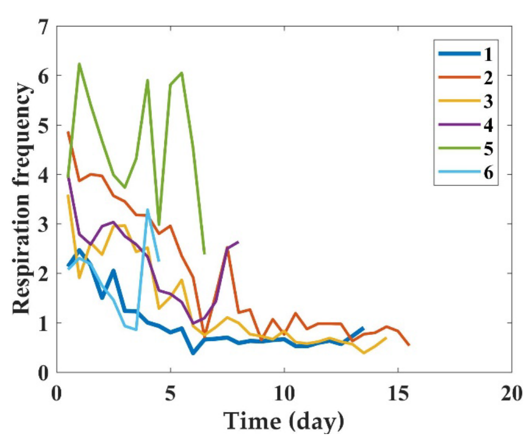
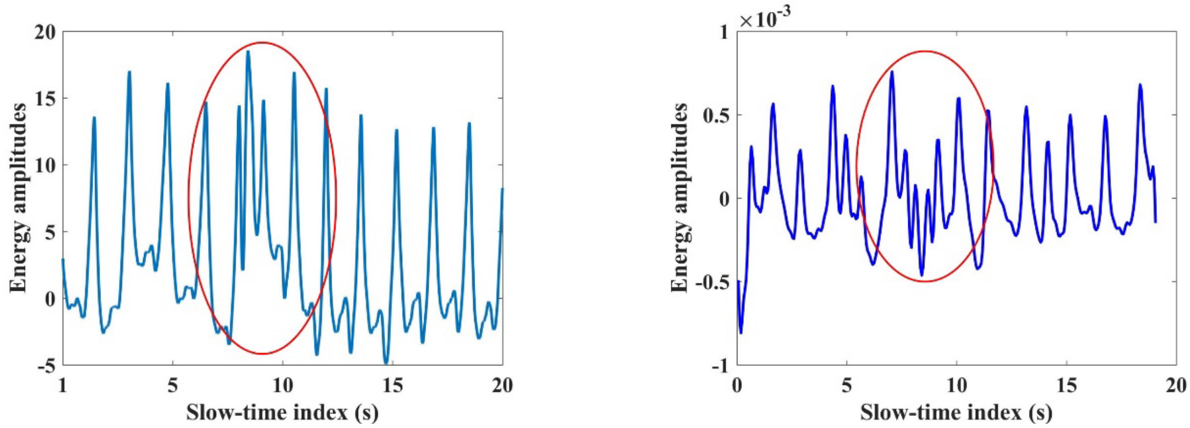


Figure 5. Changes in respiration frequency over time of the six New Zealand White rabbits. The legend numbers from 1 to 3 represent three female rabbits, and the legend numbers from 4 to 6 represent three male rabbits.



(a) (b)

Figure 6. (a) An example of typical changes in respiratory waveforms. (a) UWB radar. (b) RM6240E in contact.

are normal as shown in Fig. 4. It reveals the possibility to identify the life states of the targets using contactless methods by extracting similar waveform varieties from the respiration signals of UWB radar. If these waveform varieties are detected and extracted from the UWB radar signals, it may be concluded that the detected targets are in extremely dangerous state. Further, some significant and professional suggestions can be suggested to corresponding rescuing principle and methods.

4.2. Changes of Heart Rate Over Time

The change of heart rate over time measured by the GOLDWAY UT4000B electrocardiogram (ECG) monitor is illustrated in Fig. 7. It can be seen that the heart rates of the six rabbits change greatly over time. It is noteworthy that a rapid and significant decrease in heart rate occurs in each heart-rate changing curve in the later stage, namely on the verge of death. This may also be a useful sign to identify different life states.

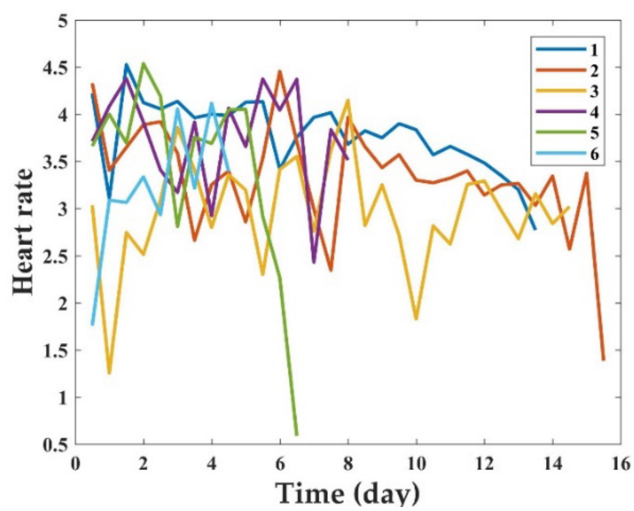


Figure 7. Changes in respiration frequency over time of the six New Zealand White rabbits. The legend numbers from 1 to 3 represent three female rabbits, and the legend numbers from 4 to 6 represent three male rabbits.

4.3. Changes of Anal Temperature and Weight over Time

The changes of anal temperature over time measured by the Omron thermometer MC-347 are shown in Fig. 8. The temperatures basically maintain stable at the early stage. However, in the later stage especially on the verge of death, there are rapid decreases, and the temperatures drop rapidly below 36 degrees centigrade.

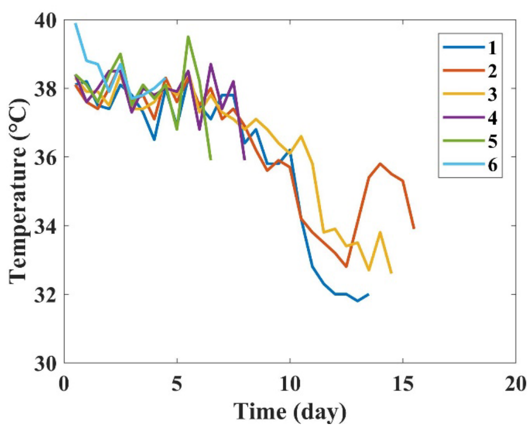


Figure 8. Changes in anal temperature over time of the six New Zealand White rabbits.

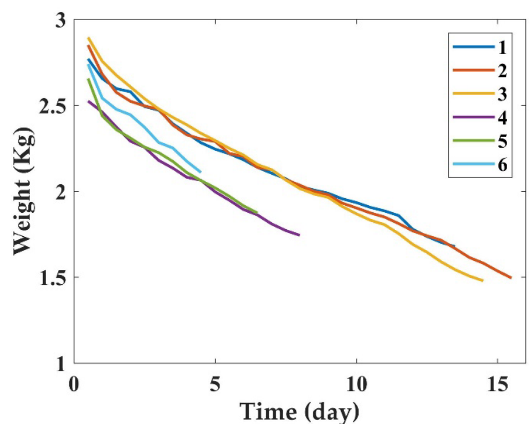


Figure 9. Changes in weight over time of the six New Zealand White rabbits.

The changes of weights over time measured by the SETPRO counting scales are illustrated in Fig. 9. The weight changes are linear and regular, decreasing about 0.05 kg per 12 hours.

5. CONCLUSION

This paper conducts researches on the change laws of physiological parameters of rabbits under water and food deprivation. A total of six New Zealad white rabbits containing 3 females and 3 males are collected. The aim is to preliminarily explore some methods to identifying different life states based on the special varieties of physiological parameters, and further to provide significant and professional suggestion for post-disaster rescuing missions. Respiration signals are measured through non-contact method by an UWB radar system and contact method by an RM6240E system synchronously. Meanwhile, heart rate, weight, and anal temperature are also detected. Some special varieties in the respiration waveforms are found both in the signals of UWB radar and RM6240E in contact in the later stage of water and food deprivation condition, namely on the verge of death. In addition, the heart rate and anal temperature had a rapid and significant decrease when the rabbits are in extremely dangerous life states. These phenomena provide the possibilities to identify different life states. Especially, the respiration waveforms varieties in UWB radar signals are envisioned to be applied in actual post-disaster rescuing missions since only UWB radar data can be collected in penetration condition. Importantly, this paper provides a scientific research method and idea for follow-up studies about identifying different life states, namely extracting special varieties of physiological parameters in different stages.

Authors' Contributions

For the present manuscript, Z.L., Y.M., G.L., and J.W. contributed to the design of the experiments. Z.L., Y.M., Y.Z., and F.L. contributed to the extraction of the features. Y.M., Z.L., and F.Q. contributed to the data collection. X.Y., J.W., and Y.Z. contributed with programming, simulations, and writing. All authors read and approved the final manuscript.

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Ethics Approval and Consent to Participate

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Laboratory Animal Welfare and Ethics Committee of Air Force Medical University (protocol code IACUC-20201201 and date of approval December 1, 2021).

Availability of Data and Materials

The datasets generated during the current study are not publicly available but are available from the corresponding author on reasonable request.

Competing Interest

The authors declare no conflict of interest.

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