Online ultrasonic terminal for measuring pig backfat thickness

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Abstract: The measurement of pig backfat thickness (PBFT) has to stand up to challenges with the reliability, accuracy, and convenience. Acquiring PBFT timely and precisely from a finite distance is extremely necessary to improve the process of pig production and implement effective management. In an attempt to alleviate these problems, an online handheld terminal was designed with a new method based on ultrasonic technology for measuring PBFT during the process of pig breeding, which can overcome the difficulties encountered in other destructive means. The terminal comprised three main components: a main microcontroller unit (MCU) to measure PBFT, a RFID module to identify each pig and send data (e.g. identity, measurement time and PBFT) to a server via wireless transmission module, and an ultrasonic transducer to drive and receive signals between them. A measurement error within 0-1 mm was acquired through testing three groups of samples. Results indicated that this handheld terminal had a required accuracy and proved that the ultrasonic wave processing method can be deployed in a mobile terminal for PBFT measurement. It also provided a feasible nondestructive alternative to measure PBFT. Associated with information management software platform, this method may ultimately help pig production farmers measure the PBFT accurately and conveniently, and improve the pig production efficiency.

Keywords: pig backfat thickness, nondestructive measurement, ultrasonic technology, online terminal, pig production
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1 Introduction

Pig industry, as a traditional industry in China, plays a crucial role in economic development[1]. Pork, as an indispensable part of agricultural and sideline products for daily life, occupies a dominant position in meat products in China. Pig backfat thickness (PBFT) is a crucial predictor of carcass lean content and meat quality, and as the economic performance, reveals one of the most important breeding targets in pig improvement[2-9]. The PBFT also reflects the growth rate, pork percentage and it has a paramount impact on the reproductive system and also reflects lean meat percentage, and as an important indicator also used to evaluate pork quality grade[4]. Accordingly, rapidly acquiring the backfat thickness becomes an effective method to get the growth rate of a pig. Dynamically acquiring PBFT in the growth stage will provide benefits on the breeders to control the feeding, and fairly safely contribute to manage the overall process for smart farming. Traditionally, methods of getting the PBFT data by operating with knife, probe and ruler[10] exist some disadvantages in this process because of the pork surface easily contaminated by direct touching. Furthermore, the detection speed and data storage also become more and more important.

Ultrasonic technology has been widely applied in animal science[11-19], and can play a crucial role in addressing the above mentioned issues, and this experiment presents an online terminal technique that is based on ultrasonic technology for measuring the PBFT with a quick, secure and non-destructive method which also provides real time storage and transmission.

2 Materials and methods

2.1 Principle for detecting PBFT

During the process of measurement, using the ultrasonic pulse echo method[20] to measure the backfat thickness and the method of pulse reflection technique for thickness measurement will apply ultrasonic probe laser and pulse wave into the subject, and determine the material thickness according to the reflection wave of observed object in different materials. Superficial tissue of a pig mainly consists of dermal, fat, muscle and protein etc. The acoustic impedance becomes different because of different tissue components. Therefore, the ultrasonic wave propagation in pig tissue encountering the interface of the two kinds of different organizations will produce a changed the optical phenomena such as reflection, refraction. Through the reflection getting distance of ultrasonic propagation, the PBFT can be obtained. Table 1 show the values of sound velocity, density and acoustic impedance[21] regarding the different superficial soft tissues, which can be used as the experimental samples of acoustic characteristic value as the referred standard.

The process of thickness measurement is as follows: firstly an ultrasonic transducer emits ultrasound, and it will generate

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ultrasonic echo when ultrasound meets obstacles in the process of transmission. Then ultrasonic transducer receives the echo signal and computes the time between launching ultrasonic waves and receiving echo signal. Consequently, the distance between transducer and obstacle can be calculated through Equation (1). Diagram of the pulse reflection is shown in Figure 1.

Table 1 Values of sound velocity and acoustic impedance in superficial tissue

Tissue	Density ρ /g·cm^{-3}	Sound velocity /cm·s^{-1}	Acoustic impedance /Pa·s·m^{-1}
Fat	0.592	1450	1.38×10^6
Muscle	1.08	1580	1.70×10^6
Soft tissue	1.06	1540	1.60×10^6

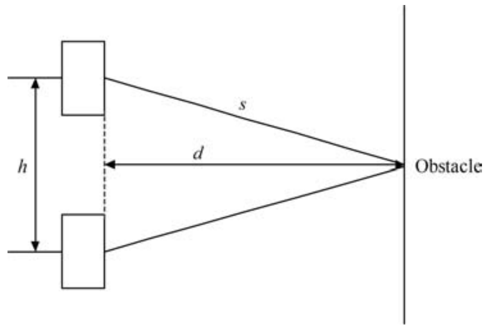


Figure 1 Diagram of the pulse reflection

Calculation equation is:

$$d = vt/2 \quad (1)$$

where, d is the distance between transducer and obstacle, m; t represents the time between launching ultrasonic wave and receiving echo signal, s; v represents ultrasonic propagation velocity in the current medium, m/s.

This method has the advantages of simple operation, high sensitivity, and accurate positioning, and can generate an intensely high resolution for the minimal discontinuous interface and accurately measure the discontinuous depth at the bottom of the interface.

2.2 System structure

The main modules of measurement system for PBFT include data collection module, RFID module, data processing module and wireless transmission module. The system framework is shown in Figure 2.

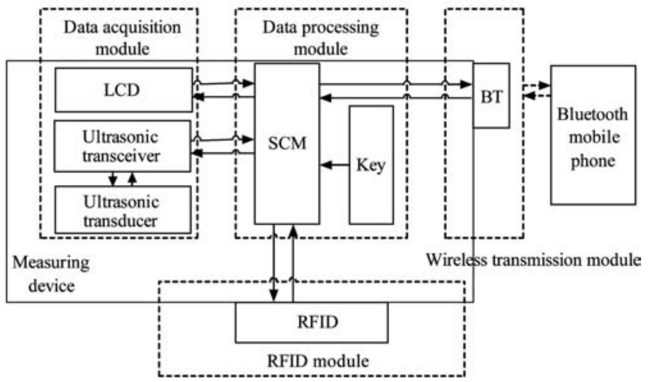


Figure 2 Diagram of the system framework

The data acquisition module used to collect data for calculating through ultrasonic technology designed to detect data. With this method, no need to destructively obtain pigs' vivo information. And ultrasonic wave has the features of high longitudinal resolution and strong anti-interference ability, and it is easy to realize miniaturization and integration. Subsequently, the measured information is sent to the data processing module for analysis, calculation and storage. When the measured data in the data processing module got the relevant processing, and can directly send the information to a smart phone via wireless transmission module. Moreover, before measurement action, firstly identify each pig by means of RFID which obtains individual information concerning each pig in order to trace the related record. Bluetooth technology is experimented for data transmission in this experiment, and widely used transfer function in mobile phone at present time.

(1) Data acquisition module

The module is divided into three parts: transmission, receiving and ultrasonic transducer. Ultrasonic transducer is used to implement the conversion of sound energy and mechanical energy. Transmission and receiving modules are used for signal transmission, filtering, amplifying and shaping.

(2) Data processing module

The data processing module is used to analyze, calculate and store the signal measured by the data acquisition module, and controls the whole hardware system, mainly including microprocessor, keyboard, display, buzzer, external memory and quite a few external interfaces like Bluetooth and so on.

(3) The RFID module

RFID module is used to record authentication, tracking and growth information of different pigs.

(4) Wireless transmission module

Wireless transmission module used to realize the interaction between the measurement device and the intelligent mobile phone for sending the data to the mobile phone.

2.3 Main control chip

The STM32F103R6[22] enhanced by a single MCU chip for measuring the PBFT in this present research, its main functions are as follows: (1) Controlling ultrasonic transmitter circuit for transmitting and receiving ultrasonic signals; (2) Calculating the ultrasonic propagation time in superficial fat; (3) Calculating the thickness according to the ultrasonic spreading time in superficial fat; (4) Displaying the PBFT by the display module; (5) Controlling the RFID to read identification information from a pig's ear tag; (6) Sending all the information to a data server through the wireless module.

Enhanced chip STM32F103R6 using high-performance 32-bit ARM Cortex-M3 core based on the reduced instruction set computer (RISC) architecture; its operating frequency is 72 MHz and working voltage is 2-3.6 V. Built-in 64 k bytes flash and 20 k bytes static random access memory (SRAM). Even possess rich enhanced input/output (I/O) port and two advanced peripheral bus (APB). What's more, it has two analog-to-digital(A/D) converters, three general 16-bit timers and a pulse width modulation (PWM) timer; owns standard and advanced interaction interface: two inter-integrated circuit (I^2C), three serial peripheral interfaces (SPI), five universal synchronous/asynchronous receiver/transmitter (USART), one universal serial bus (USB) port and one controller area network (CAN) bus. These features make performance line microcontroller family suitable for a wide range of applications. It has been developed to provide a low-cost platform that meets the needs of MCU implementation, with a reduced pin count and low-owner consumption, while delivering outstanding computational performance and advanced system response to interrupts.

2.4 Ultrasonic transmission circuit

The ultrasonic transmission circuit consists of two parts:

ultrasonic transducer and ultrasonic excitation circuit. The higher center frequency of the transducer can obtain better response. But the measuring distance is shorter, and at the same time the price is higher and needs higher excitation voltage, usually almost dozens or even hundreds of volts. Considering the PBFT is usually between 5-40 mm and the cost of hardware, a one-piece probe transceiver with center frequency of 1.5 MHz was selected in this paper. The ultrasonic excitation circuit works when instantaneously loading a certain form of voltage signal at both ends of the transducer and the transducer will convert the electrical signals into acoustic signals and emit.

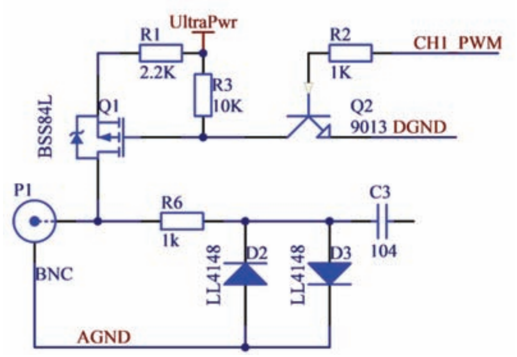


Figure 3 The ultrasonic transmission circuit

The ultrasonic transmission circuit is as shown in Figure 3. The working principle of ultrasonic transmission circuit: when the system starts working, the MCU gives high voltage level through the pin of CH1_PMW opening the Q2 and then opening the Q1. At this time, the transducer driving power (UltraPwr) with capacity of 30v consuming time almost 200 ns. It will produce an excitation signal with high-pressure negative pulse and the ultrasonic transducer will generate mechanical movement to transmit ultrasonic because the ultrasonic transducer is a sensing component, the system does not require a special signal generating circuit because it itself could transmit ultrasonic with the self-oscillating. Through this method, it reduces the signal interference of the transmission circuit to the receiving circuit even reduces the power consumption of the system and saves the cost of hardware.

2.5 Ultrasonic echo-receiving circuit

Echo receiving circuit used to detect the reflected signal when the launched ultrasonic meets different mediums, is divided into signal collecting and signal modulation circuit. There is a certain attenuation degree when the ultrasonic propagating in the medium and the attenuation degree will be proportional with the propagation distance. Thus the received acoustic signals become faint. At the same time, the received signals by the ultrasonic transducer play a role of pulse signal in nature before transferring for further processing, therefore the interference and noise will be removed firstly after removing foreign substances then transferred to a single chip microcomputer and microcontroller. Extracting the effective signals and magnifying them to increase the signal-to-noise ratio. Finally, effective signals are analyzed by the single chip microcomputer (SCM). Ultrasonic echo receiving circuit is as shown in Figure 4.

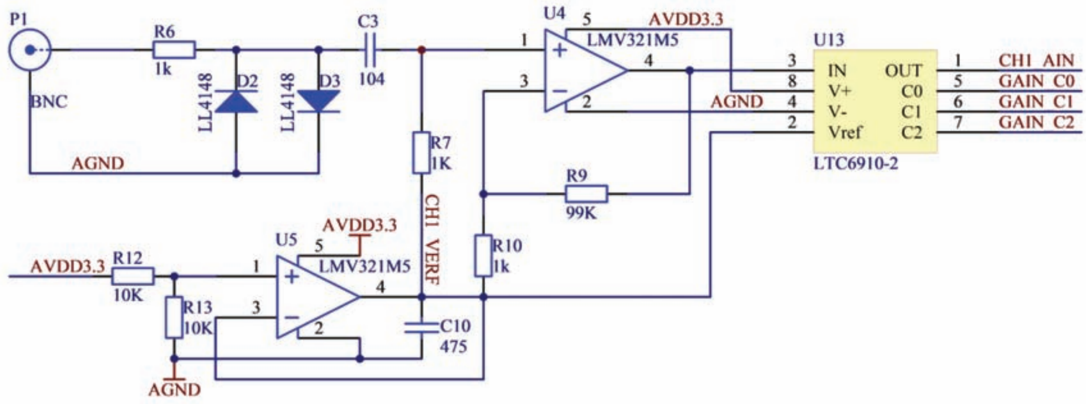


Figure 4 Ultrasonic echo-receiving circuit

There may be a multitude of interference signals exist in the received signals detected by the ultrasonic transducer, like the cross interference between sensors, power line interference, etc. Because of the interference signal concentrated in low frequency, the band-pass filter circuit used to filter out the effective signals becomes feasible. As shown in Figure 4, C3 and R7 form a high pass filter, frequency of 0.16 MHz used to filter the waves below 0.16 MHz. The ADC of the microchip as a single supply cannot detect the negative voltage; the AC signals should be converted to 0-3.3 V and the bias voltage with 1.65 V.

The device adopts the LMV321M5 operational amplifier with dual operational amplifier to amplify the signals. The operational amplifier has a high power bandwidth and small-signal bandwidth, the noise performance becomes better than an army of standard operational amplifiers with lower noise. In Figure 4, the amplification factor is: (R9 + R10)/R10 = 100.

2.6 Transmission module

In the system, the transmission module used the Bluetooth technology based around the BT-HC07 which produced by Guangzhou Huicheng Information Technology Co., Ltd. It uses the type of flash named CSR BC4+8M FLASH and has the pins of PIO0-PIO11, AIO0, AIO1, USB, PCM, UART and SPI. There is an 8M FLASH in it. With such a powerful function, users can customize the software. As a slaver, it is suitable for a variety of Bluetooth devices built-in RF antenna, so it is easy to debug. The Bluetooth module is compliant with Bluetooth Specification of 2.0 + EDR, which is the first one that supports for enhanced transfer rate specification of Bluetooth solutions[23]. The Bluetooth module circuit is as shown in Figure 5.

2.7 RFID module

RFID directly selected in this paper has been well integrated with MF522-AN, which adopted the Philips original chip-MFRC522 designed to the card reader circuit. MF522-AN module has low power dissipation, low cost, and small volume, is a highly integrated reader/writer IC for contactless communication. The module uses a supply voltage of 3.3 V, and interacts with the system CPU via the I^2C interface. It has efficient and reliable stability and can read card at a certain distance. Selected contactless smart card named S50 card as an electronic tag that produced by NXP MFl IC S50 Company.

The circuit of RFID module is as shown in Figure 6. This module communicates with the controller using I^2C interface. Pin 4 and Pin 5 are respectively linked with the Pin SCL and Pin SDA of the SCM to read and write, and controlling CMOS to start/stop the whole module to work through Pin RFID_EN.

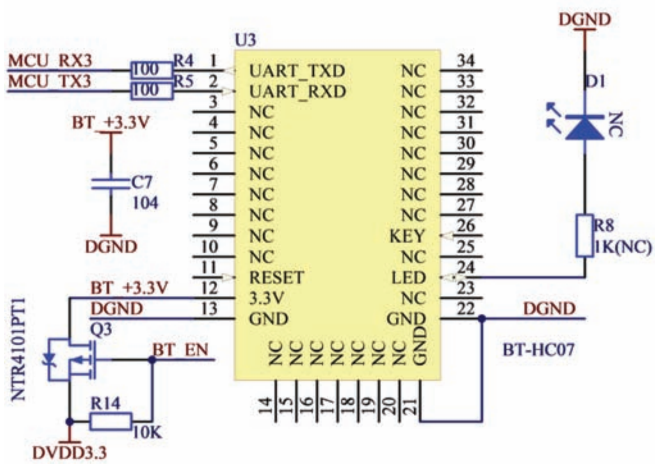


Figure 5 Circuit of Bluetooth wireless transmissions

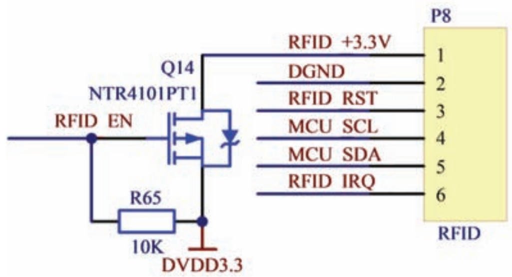


Figure 6 Circuit of RFID module

2.8 Pig backfat thickness measurement

When pressing the 'measurement' button on the keyboard, the SCM will start measuring the backfat thickness, and the transducer will produce oscillation signals and translate them into ultrasonic signal to launch out. And then the data acquisition module begins to work as soon as transducer receives the echo signals pushed into the CPU to calculate. The flow chart of the PBFT measurement is shown in Figure 7.

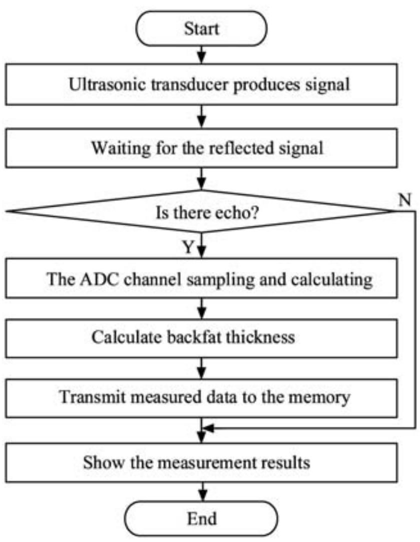


Figure 7 Flowchart of backfat thickness measurement

According to the working principle of ultrasonic pulse reflection, the calculation equation of backfat thickness is as follows:

$$S = 1500\Delta t \times 10^{-3}/2 \quad (2)$$

where, S represents PBFT and its unit is millimeter, mm; Δt is the total passing time and its unit is microsecond, μs.

The size of backfat thickness is changing with Δt which represents the passing time. The propagation rate of ultrasonic in the fat and soft tissue is 1450 m/s and 1540 m/s respectively. In order to find a suitable velocity parameter, by operating an ultrasonic reference block (thickness 40 mm) which the organization structure is the same with a pig's fat layer, and consequently, the velocity parameter with 1500 m/s is selected.

2.9 Data storage format

The PBFT collected by the SCM needs to be stored as a history data and can be formatted as: tag number, operation time (year, month and date) and thickness. The data storage format is as shown in Figure 8. The operation time takes three bytes, and both tag number and thickness one byte. Only five bytes is used for the storage and 1Mb I²C-compatible 2-wire Serial EEPROM-AT24CM01 can be optional in this paper.

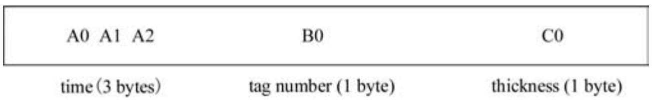


Figure 8 Data storage format

2.10 Samples selection and test

Two types of samples are used to check the prototype device. One is fresh superficial tissue from the pig back got within one hour after slaughtering, and the number of samples is 10, that are from a different pig positon. And cut the tissue into square, which takes a pig's skin as the bottom with the area of 20 cm by 20 cm and avoid being pressed. Use a pen to make marks on the skin of each tissue sample to ensure protection. Another sample is transparent plastic test specimen (thickness 25 mm) which used to adjust ultrasonic measuring instrument, and its tissue structure is same as the fat. Figure 9 is the picture of the terminal for PBFT. Each sample was measured 10 times and averaged.

Figure 9 Photo of the ultrasonic measurement terminal

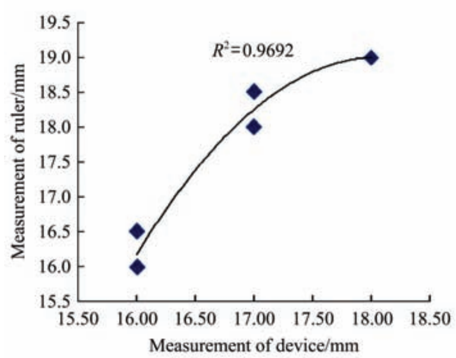
3 Results and discussion

Results of an experimental application of this terminal analysis procedure are given to illustrate the proposed technique. Typical measurement results are shown in Table 2.

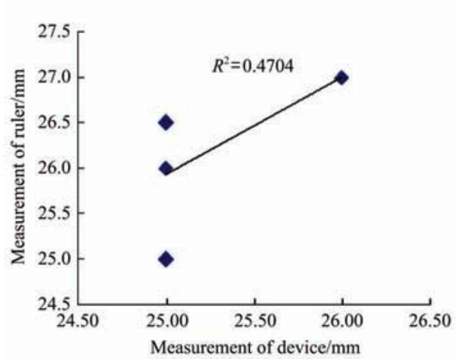
Table 2 Measurement results with prototype device/ruler (mm)

No.	Sample 1	Sample 2	Sample 3
1	18.00/19.00	26.00/27.00	28.00/29.00
2	18.00/19.00	26.00/27.00	28.00/29.00
3	18.00/19.00	26.00/27.00	28.00/29.00
4	17.00/18.50	25.00/26.50	27.00/28.00
5	17.00/18.50	25.00/26.50	27.00/28.00
6	17.00/18.00	25.00/26.50	27.00/28.00
7	17.00/18.00	25.00/26.00	27.00/28.00
8	16.00/16.50	25.00/26.00	26.00/27.00
9	16.00/16.00	25.00/25.00	26.00/26.00
10	16.00/16.00	25.00/25.00	26.00/26.00
Average	17.00/17.85	25.30/26.25	27.00/27.80

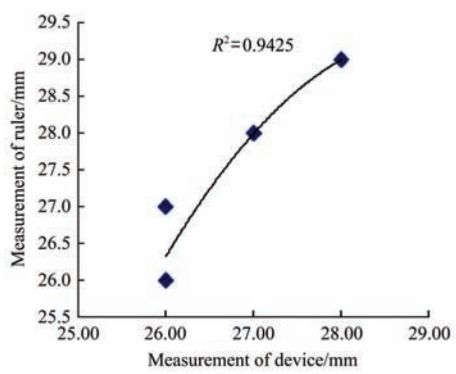
The corresponding result correlation analysis is shown in Figure 10.



a. Sample 1



b. Sample 2



c. Sample 3

Figure 10 Diagram of result correlation analysis

From the measurement results of samples 1-3 in Table 2 and Figures 10a-10c, we can observe that the measurement results are almost consistent when using both the device and the ruler from the three different samples. Although there is no error when testing the known standard specimen using both the device and the ruler, there exists a measurement error within 0-1 mm, compared with Renco Lean Meter, measurement error with ±1 mm (produced by RENCO ELECTRONICS, INC.), the terminal presented can be implemented more easily, with similar efficiency and accuracy results. Possibly existed error produced by human mistakes during the measurement process or maybe the parameter of ultrasonic transmission rate chosen was inadequate or maybe the test objects possess some issue. Overall, as it could be seen the experimental data, the measurement results demonstrated a certain reliability, not stable, but feasible to improve a high practical value when using the device.

4 Conclusions

Based on the ultrasonic measuring technology, an online, interactive, and portable terminal for measuring pig backfat thickness was developed by combining MCU module, RFID module and an ultrasonic transducer. It can be applied to the process of pig production and improve the efficiency when using contactless or nondestructive method. The measurement error was within 0-1 mm. The test results indicated that this handheld device had the characteristics of high precision, low power consumption, easy to carry, easy to operate and low cost comparing with the similar devices. Associated with information management software platform, this method may ultimately help pig production farmers measure the PBFT accurately and conveniently, and improve the pig production efficiency.

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