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A Novel Teaching Case Design for Complex Engineering Problems in Embedded Training Courses

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Abstract. Training students' ability to solve complex engineering problems is the core of graduation requirements in engineering certification. In view of the outdated teaching cases and serious lack of innovation in embedded training courses, this paper takes the design of livestock temperature monitoring system as an example to solve the pain point problem in the real society. Through project background investigation, definition of design objectives, hardware design, software design and system performance evaluation, etc, the support of the courses for graduation requirements can be enhanced, and students can be cultivated to comprehensive and applied talents with embedded engineering awareness, practical ability and teamwork ability.

Keywords: embedded training course; complex engineering; teaching case; low power consumption; data acquisition and transmission.

1. Introduction

Among the 12 standards of engineering certification education, 8 standards are related to cultivating the ability to solve complex engineering problems, so cultivating students' ability to solve complex engineering problems is the core of graduation requirements [1]. Embedded training course is a comprehensive application training course of hardware in colleges and universities. It is one of the most effective teaching methods to improve students' ability to solve complex engineering problems. However, how to improve students' awareness of embedded engineering and practical ability to meet the requirements of university innovation and entrepreneurship competitions and embedded industry is a new challenge in actual teaching [2, 3]. The primary key problem in teaching at this stage is that the teaching cases are outdated, not close to the actual needs of students, and can not effectively mobilize students' enthusiasm for learning. Also there are few innovative teaching case projects, and the science and technology content of case projects is not high [4]. Therefore, it is of great significance to design teaching cases for complex engineering problems in embedded training courses.

Then the monitoring system of livestock temperature is taken as an example to design a teaching case. First of all, the background of livestock temperature detection was clarified through literature query. Livestock meat (pigs, cattle, horses and sheep) is a strategic material for controlling market prices in China. However, how to accurately, timely and quickly monitor the growth of livestock and release the information of livestock is the basic work for effectively ensuring the healthy growth of livestock and promoting the safety of modern agriculture. Wherein temperature is an important physiological indicator of livestock, and abnormal temperature is one of the important symptoms of livestock physiological function being disturbed. In addition, in many diseases, especially infectious diseases, the rise of temperature often occurs earlier than other symptoms. Therefore, the measurement of temperature is one of the indispensable bases for ensuring livestock marketing rate and diagnosing livestock diseases [5]. Secondly, the traditional methods of livestock temperature measurement mainly include: ① Non-contact temperature measurement, mainly including hand-held infrared temperature measurement and fixed infrared temperature measurement. Hand-held thermometer is manually used to measure the temperature of livestock. The disadvantages of this method are that the measurement is not accurate enough, the labor intensity is high, and the automation level is low. The fixed thermometer is usually fixed on the automatic feeder to measure the temperature of livestock when they are eating. The disadvantage is that due to

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the complexity of various environmental factors in the feedlot, the measurement data is not accurate enough and it is easy to make wrong judgments. ②Contact temperature measurement. One of them is to use the commonly used method of measuring the temperature of livestock in clinical practice, and use the livestock thermometer to measure the rectal temperature of livestock to determine the temperature of livestock. The data obtained is reliable, but due to the complexity of the actual operation, this method is far from suitable for modern large-scale livestock farms. The other is to equip each livestock with an independent temperature measuring device to measure the temperature of livestock. The disadvantage is that the cost is large, and because of the wide range of growth activities of livestock, it is inconvenient to maintain the product and easy to damage the product [6]. Finally, in view of the shortcomings of the existing technical means, the case design objectives are clarified. Through the joint design of hardware and software, it is proposed to provide a high-precision livestock temperature monitoring system, that can measure stably and transmit data in real time. Considering the limited class hours of practical training courses and the limited financial support of the college, this paper mainly focuses on the topic of temperature measuring ear markers, that is the main and important design part of the system. The rest can be used as other training topics.

To sum up, this paper takes complex engineering problems as the starting point to carry out the reform of embedded training courses. Through designing teaching cases based on actual engineering projects, the support of the courses for graduation requirements can be enhanced, and students can be cultivated to comprehensive and applied talents with embedded engineering awareness, practical ability and teamwork ability.

2. Design Objectives

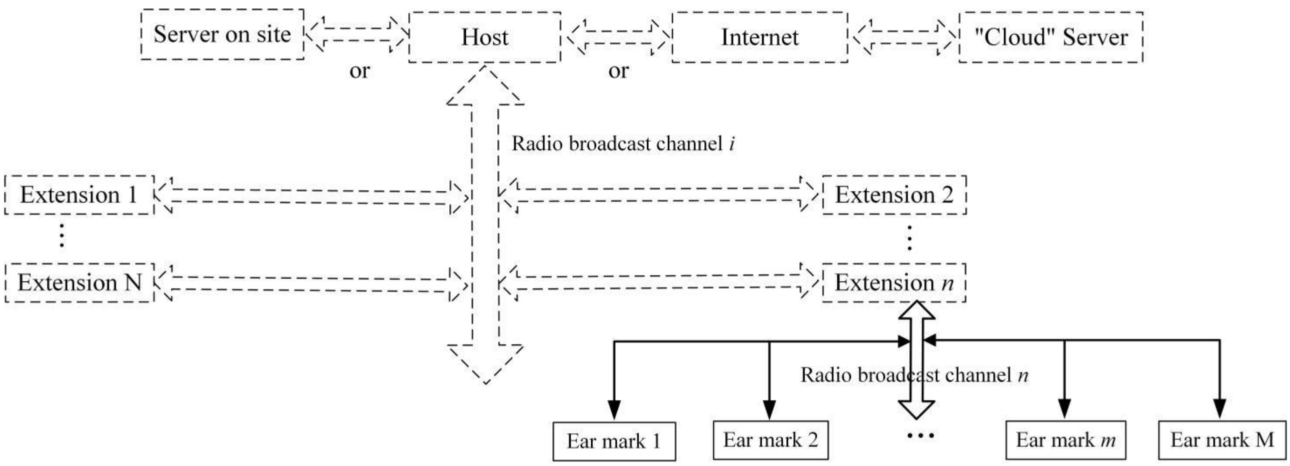

Fig. 1 Overall block diagram of case design

The overall block diagram of case design is shown in Fig. 1. The unrealized part (i.e. the extended part) is marked with dotted lines, which can be used to realize the on-site gathering and remote transmission of temperature measuring ear mark data. The design objectives of the temperature measuring ear mark are as follows:

(1) The ear marks shall detect the temperature data at least 4 times a day; Temperature measurement accuracy: two decimal places; Keep working for at least one year.

(2) The data transmission distance between the ear mark and the extension shall be at least 300 meters; Data packet loss rate: less than 0.1%.

(3) The cost price of each ear mark is about ￥100.

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3. Design Process

3.1 Hardware Design

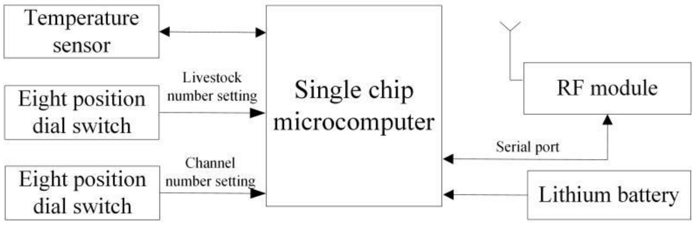

Fig. 2 Hardware design block diagram

The hardware design block diagram of the ear mark is shown in Fig. 2. In order to achieve the design objectives, it is necessary to select various devices.

3.1.1 Selection of SCM (Single Chip Microcomputer)

STC15L2K16S2 [7] is selected after comparison of multiple SCMs. The working voltage of STC15L2K16S2 is 2.4V~3.6V; It belongs to domestic SCM, with stable price; It has strong anti-interference ability and adopts the eighth generation encryption technology; No external crystal oscillator and external reset circuit are required, which provides feasibility for reducing the weight of the ear mark; The 2K byte SRAM can fully meet the requirements of data storage; Three power saving modes can be run to reduce power consumption, namely: low speed mode, idle mode and power down mode. The typical power consumption in idle mode is 1.8mA, and that in power down mode is<0.1uA; It is equipped with a power-down and wake-up special timer. After the SCM is power down, it starts the power-down and wake-up special timer. In this state, the electric current is about 3uA, and the maximum single timing is 15 seconds. This provides feasibility for long-term power supply of lithium batteries with limited weight and capacity.

3.1.2 Selection of temperature sensor

DS18B20 is selected after comparison of various temperature sensors. DS18B20 is a commonly used high-precision single bus digital temperature measurement chip, which has the characteristics of small size, low hardware overhead, strong anti-interference ability and high precision. Its working voltage is 3.0V~5.5V. When the resolution of DS18B20 is 12, its resolvable temperature is 0.0625 ° C. Therefore, the detection accuracy of DS18B20 can meet the detection requirements, and the temperature value can be converted into a digital value within 750ms at most, which is fast. The specific circuit design can refer to [8]. If the fault detection of temperature sensor is added, it can judge whether the temperature sensor works normally and upload fault codes. The working modes can be: normal, short circuit and open circuit [9].

3.1.3 Selection of RF module

E30-433T20D [10] is selected after comparison of various RF modules. The RF module is a wireless serial port module based on SI4438 RF chip, with size of 16mm*26mm and power supply voltage of 2.3~5.2V; It has data encryption and compression functions, that can make data interception meaningless, reduce the probability of interference, and improve reliability and transmission efficiency; It has a software FEC (Forward Error Correction) algorithm, which has high coding efficiency and strong error correction capability. In the case of sudden interference, it can actively correct the interfered data packets, greatly improving the reliability and transmission distance. This provides feasibility for reducing packet loss rate; The working frequency band is 425MHz~450.5MHz, and 255 orthogonal sub channels can be configured, that is, the extension can collect the temperature of 255 livestock at most. This provides feasibility for deployment of large-scale scenarios; The maximum transmission power is 100mW, which can be adjusted according to the actual communication distance to reduce power consumption.

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3.1.4 Selection of lithium battery

SAFT Ls14250 is selected after comparison of various lithium batteries. The size of the lithium battery is 14mm (diameter)*25mm (height); The working temperature is -60 ℃ ~+85 ℃ ; The maximum continuous discharge current is 35mA, and the output voltage is 3.6V. This can meet the working requirements of the ear mark, and does not require additional voltage conversion; Nominal capacity: 1200mAh.

3.2 Software Design

3.2.1 Software design flow chart

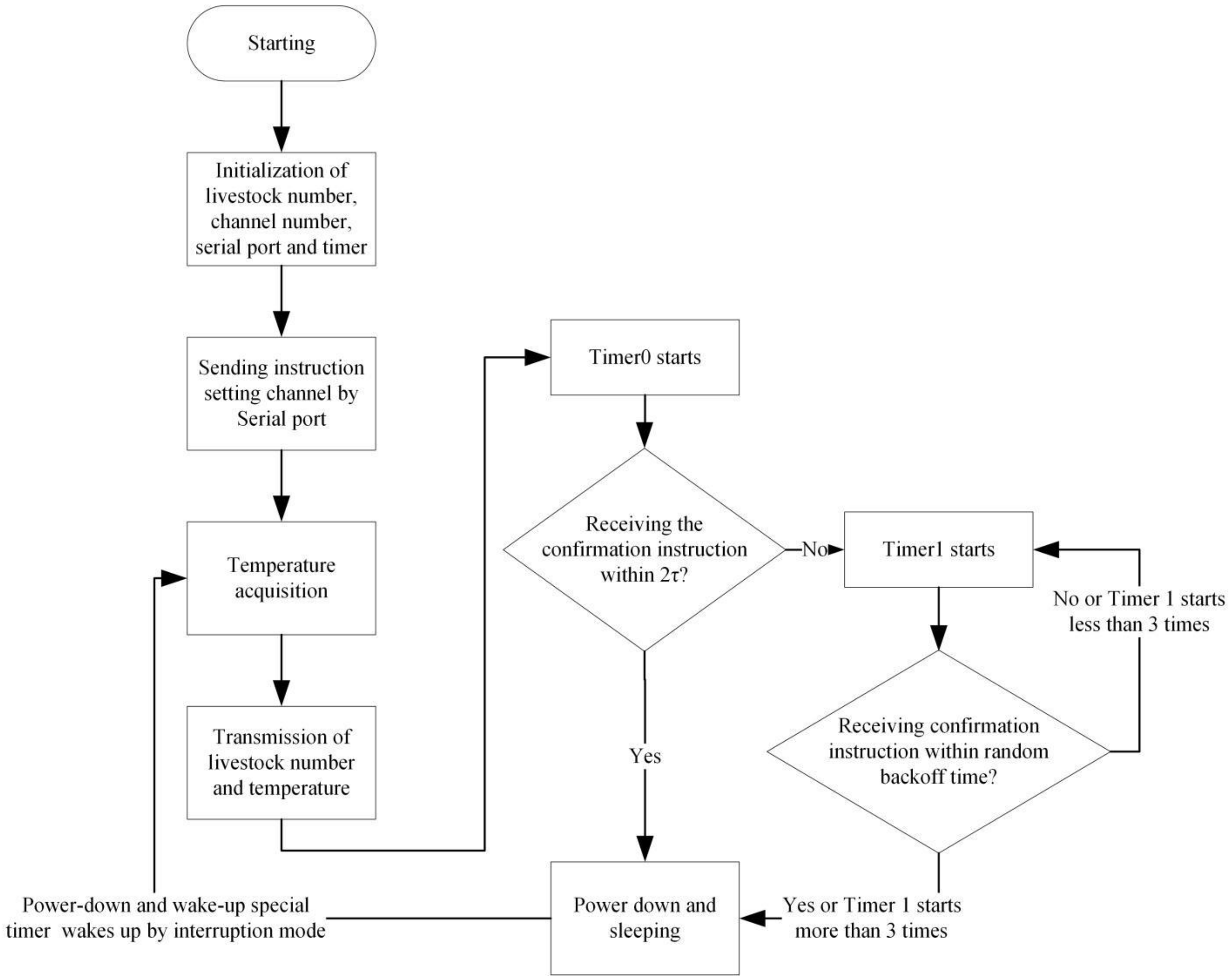

Fig. 3 Software design flow chart

The software design flow chart of the ear mark is shown in Fig. 3. In general, after 6 hours the power-down and wake-up special timer wakes up SCM by interruption mode. Then SCM begins to collect temperature data, and send data by wireless module. When receiving the correctly received confirmation instruction sending by the extension, it will enter the next sleep cycle. The application scenario of temperature measuring ear mark belongs to large-scale measurement and control scenario. The temperature drift of its crystal oscillator will lead to 1% of the temperature drift or the actual application of a ear mark module requires maintenance, which will lead to data conflict in the wireless broadcast channel. Since the power on time of each ear mark is concentrated in a certain period of time, and there is a power on interval of about 1s, serious data conflict will not occur. Therefore, a low-power backoff algorithm is designed based on the random backoff idea and retransmission confirmation mechanism of wireless LAN and wireless sensor networks. Where, 2τ is the round-trip time, that is, the time from sending the temperature data to receiving the correctly received confirmation instruction sending by the extension. In addition, if the correctly received

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confirmation instruction is not received in 2τ, the data conflict is considered to occur, and the backoff value (Unit time length is 2τ) is randomly selected from 0 to 3, which means the temperature data can be retransmitted for up to 3 times. This backoff algorithm can effectively solve the data conflict problem while reducing power consumption.

3.2.2 Data transmission and receiving format

Table 1. Data transmission format

Frame header	Data type	Livestock number (Address)	Data
0x55 0xAA	0x01	0x01	0x38 0x52

The data transmission format of the ear mark is shown in Table 1. MAC (Multiple Access Channel) frame format in wireless LAN is is referenced, which has good scalability in practice. This data format only has the livestock number field, but do not has destination address, because each extension and its temperature measuring ear mark are in a dedicated broadcast channel, and only the extension is always in the receiving state. The frame header field is used to prepare the extension for reception. The data type field is used for the extension to quickly identify that the following data is temperature related. The livestock number field is used to let the extension store the temperature data to the corresponding storage space. Generally, the livestock numbers of all 0 and all 1 are not used. The data field stores the temperature value with two decimal places.

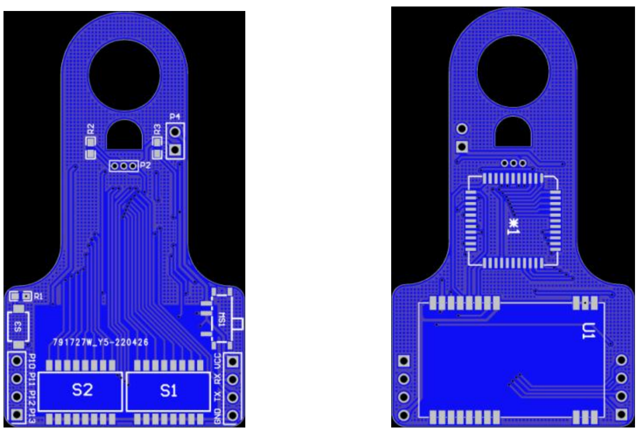
Table 2. Data receiving format

Frame header	Data type	Address
0x66 0xBB	0x02	0xFF

The data receiving format of the ear mark is shown in Table 2. The frame header field is used to prepare the ear mark for reception, that has just uploaded data. The data type field is used to enable the ear mark to quickly identify that the frame type is a confirmation frame, that is, the extension has correctly received the temperature data. The livestock number field is used to make the corresponding ear mark be clear that the data is fed back by the extension. Since this frame is a confirmation frame, the data field does not need to exist.

4. System Performance Evaluation

4.1 PCB Diagram of Temperature Measuring Ear Mark



A. Front B. Back

Fig. 4 PCB diagram of temperature measuring ear mark

The PCB diagram of the temperature measuring ear mark is shown in Fig. 4. The overall size is about 48mm*32mm, and there is no additional redundancy in the device selection, so it can improve the comfort of livestock wearing ear mark.

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4.2 Communication Distance between The Ear Mark and The Extension

When PCB antenna and maximum transmission power are used for the temperature measuring ear mark, and high gain sucker antenna is used for the extension, the zero BER (Bit Error Rate) communication distance can reach 550 meters by actual testing. This can fully realize the design goal of that, data transmission distance of the temperature measuring ear mark is at least 300 meters.

4.3 Cost Evaluation

About ￥4 for one STC15L2K16S2, about ￥4 for one DS18B20, about ￥30 for one E30-433T20D, about ￥2 for one PCB antenna, about ￥6 for two dial switches, about ￥30 for one SAFT Ls14250, and about ￥20 for other expenses (i.e. PCB manufacturing, housing, and several small devices), so the total cost of a ear mark is about 4+4+30+2+6+30+20=￥96. Therefore, in the case of limited funds of the college, cost evaluation can improve the use efficiency of funds, and can provide some effective business data support for the preparation of competition works.

4.4 Power Consumption Evaluation

The power consumption evaluation is calculated according to the lithium battery SAFT Ls14250 power supply for one year.

4.4.1 SCM power consumption

(1) Related to DS18B20

The maximum working current of the SCM is 120mA. The actual test result shows that the maximum time for DS18B20 to collect a temperature data is 1s. The power consumption of n times of collection per day is 120mAs*n.

(2) Related to power-down and wake-up special timer

The actual test result shows that it takes 1ms at most from the normal working state to the power down state of the SCM. The power consumption of a wake-up cycle is 3uA*15s+120mA*1ms=0.165mAs, and the number of wake-up cycles in a day is 24 h*3600s/h/15.001s=5760, so the power consumption of a day without operation is 0.165mAs* 5760=950.4mAs.

(3) Related to RF module

According to the actual test, it takes 150 ms at most for the RF module to transmit data once, and the power consumption of the SCM to transmit n times per day=120 mA*150 ms*n=18 mAs*n

4.4.2 DS18B20 power consumption

The maximum working current of DS18B20 is 1.5mA, and the sleep current is 1uA. The power consumption for one acquisition is 1.5mA*1s=1.5mAs. power consumption of n times of collection per day is 1.5mAs*n

4.4.3 RF module power consumption

The transmitting current of the RF module is 135mA (Due to the limited output current of the lithium battery, the actual value is far less than 135mA), the sleeping current is 8uAs, and the power consumption for sending data once is 135mA*150ms=20.25mAs. The power consumption of n times of collection per day is 20.25mAs*n

In conclusion, the total working power consumption of the ear mark in one year is (120mAs+18mAs+1.5mAs+20.25mAs)*365*n =58308.75mAs*n. The total non-working power consumption of the ear mark in one year is (1uAs*24*3600+950.4mAs+8uA*24*3600)* 365=630720mAs. To be conservative, based on 50% of the lithium battery capacity, n=(1200mAh* 3600s/h/2-630720mAs)/58308.75mAs=26. Therefore, the proposed design scheme can meet the design goal of that, the ear mark can measure temperature 4 times per day and can work continuously for one year.

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5. Summary

The course case designed in this paper has solved three key core problems in the design objectives, and carried out the system performance evaluation supported by actual data. This case is innovative and has the characteristics of complex engineering problems, so it belongs to a complex engineering problem case. Through the implementation of this case, students can master the technologies and methods required for the design of application systems such as SCM, RF communication and computer network. Through the experience of projects with engineering background, students can improve their ability to solve complex engineering problems, which can meet the requirements of engineering education certification, and provide strong support for innovation and entrepreneurship competitions in colleges and universities and stable over employment in embedded industries.

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