International Journal of Smart Home
Vol. 10, No. 7 (2016), pp. 143-154
http://dx.doi.org/10.14257/ijsh.2016.10.7.15

Research on the Real-time Monitoring System of Cow's Rumination

Shuang Zhang, Yu Zhang, Weizheng Shen, Lu Xu, Hao Wu, Zhongbin Su*

College of Electrical and Information
Northeast Agricultural University, Harbin 150030, China
zhangshuang_0909@126.com

Abstract

Cow's rumination is an important process of food digestion for dairy cows which is a valuable indicator during the cow management. By measuring the cow's rumination time, it is capable to predict the cow's estrus, and learn the cow's health situation. This paper uses MSP430F149 processor with a sound sensor to achieve the design of real-time monitoring system for cow's rumination. Since the system require high accuracy of the audio signal of the cow's rumination, the ADC acquisition module and filtering and amplification process was made a special design. For the change of the spectral characteristics of the voice when cows ruminating, this paper designed the endpoint detection algorithm and sound sequence windowed function, and FFT transform is performed on the data in the Hamming window, and then do the frequency domain analysis to the audio of cow's rumination. Comparing the sound spectrum collected from high precision recording instrument and this system, this system has done a good job in frequency and time domain. Applying the high precision recording instrument to the simulation experiment for cow's rumination which conduct 50 sets of different time ranging, using this system to do the real-time monitoring, the mean error was 4.38, the R^2 value is 0.877, the Pearson correlation was 0.936. This system performed accurate in the acquisition of the sound signal, and more accurately in identifying cows ruminating, and it can also provide effective means for the intelligent management of the pasture on cow's health and breeding.

Keywords: *cow's rumination, real-time monitoring, endpoint detection, window function, time and frequency domain*

1. Introduction

With the rapid development of livestock production, cow's rumination is an important part of food digestion for the dairy cows [1]. The cow ruminating behavior can reflect the health status of dairy cows and the recovery status in Postpartum Dairy Cows. It can also optimize the new born cows' health program, and is capable of predicting the estrus of the cows in advance. In addition, it can improve the reproductive rate, increase the production of milk and improve the economic benefit of the pasture [2-5].

At present, most of the China's dairy farms still using the traditional manual observation method to monitor the situation of the cow's rumination, this method is only suitable for small-scale pasture, and the large-scale intensive farming are often unable to put in mounts of human resources [6-9]. So, it is difficult for the managers to achieve the real-time monitoring of the cow's rumination, especially the cows ruminating behavior often occurs at night. Because of this, managers in the farms always miss the cow's estrus and fail to breed the cows on time. This not only influence the potential yield of per cow, but also impact the economic of the farms [10]. Application of modern engineering science and technology in agriculture has greatly promoted the development of

ISSN: 1975-4094 IJSH

agricultural technology. Computer technology takes an important role in the pasture management in recent years [11]. In foreign countries, especially Israeli SCR company and Afi King Ranch, all the cows are weared high-tech collars so that managers can monitor the rumination time of each cow at any time. They have achieved the real-time monitoring of cows' estrus and physical health conditions [12]. But it is expensive and difficult to get after-sale maintenance. In China, so far, there is no practical technology for real-time monitoring of the cow's rumination. So the goal of this study is to develop a real-time monitoring system which can be performed on monitoring each cow's rumination period, changing the situation of artificial observation on cow's rumination in our country. If this system was used in most of the farms in China, not only the managers can do work effectively, but also can help the farms to improve the economic. Providing effective technical means for early prediction of the cows' estrus, the physical health and the development of breeding formula, the system plans to achieve the automatic monitoring management of the cows ruminating.

2. Design of Real-Time Monitoring System of Cow's Rumination

2.1. Overall Design

The real-time monitoring system of cow's rumination mainly uses the MSP430F149 microcontroller with a sound sensor to collect and store data. Firstly, the analog signal board amplifys and filters the signal. Then, the sound signal is collected by the ADC0809 and the processor processes it. Lastly, the data is read by the RF receiving module, and the data is transmitted to the upper computer by wireless transmission module. The upper computer is mainly the information management system of cow's rumination. Through the upper computer, we can know the situation of each cow in the farms. By using the software, it can be realized to analyze the changes of the cow's rumination time. Then we can make the correct judgment and prediction of the cow's health and estrus, and realize the real-time monitoring of the cow's rumination time. Considering the actual application requirements, we set up a time reference point of cow's rumination in each period of the day for the system which can monitor the changes of the cow rumination. When the rumination time is out of the reference, the system would give a warning. Figure 1 is the overall design block diagram of the real-time monitoring system for cow's rumination. The system mainly consists of five parts, the sound sensor, analog signal processing board, digital signal processing board, radio frequency identification module and wireless communication module.

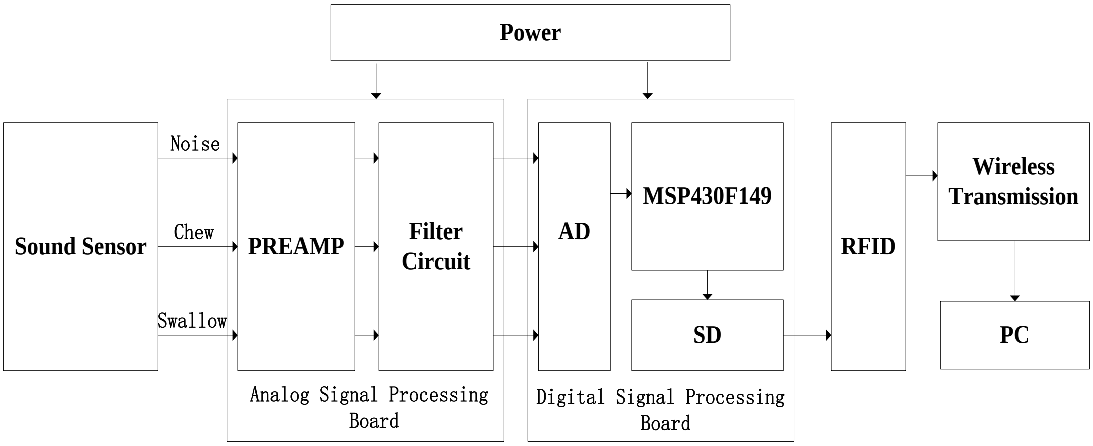

Figure 1. Overall Design Block Diagram of the Real-Time Monitoring System for Cow's Rumination

Firstly, the audio signal is collected by the sound sensor, and the signal is amplified and filtered by the analog signal processing board, then the signal is converted to a digital signal which is processed by the MSP430F149 processor. Then the data is stored in the SD card, and the memory of the card is read by the radio frequency identification module, and then use the wireless transmission module to transmit the information to the PC. And the upper computer would analize the data whether it should give warnings to the managers or not.

2.2. Hardware Design

In the process of the system hardware design, considering the system's speed, memory capacity, sound sampling frequency, anti jamming ability, low cost and low power, the system uses the MSP430F149 microcontroller. The microcomputer uses a 16-bit RISC system, which has the characteristics of strong processing ability, ultra-low power and so on [13]. In addition, as the system has a higher accuracy for the audio signal acquisition, it has a special design for the ADC module and the amplification and filtering process.

ADC analog digital converter is a digital signal which is proportional to the analog signal, and the analog signal is discrete in time and amplitude [14]. According to Nyquist theorem [15]:

$$f_S \geq 2 f_{\max} \tag{1}$$

where f_S refers to maximum sampling rate, $f_{\max}$ refers to the maximum frequency limit, so the sampling frequency of this system is 16KHz. After confirming the sampling rate, we have a detailed comparison between the selected range of the parallel AD converter and the successive approximation AD converter in order to make the ADC module as accurate as possible. The parallel AD converter is composed of a resistance divider, a voltage comparator, a register and an encoder, and the sampling rate is higher. However, with the increase of resolution, the number of originals will be increased as the geometric progression, so it is more difficult to integrate the parallel ADC with higher resolution. Successive approximation type AD converter adds and subtracts scalar value voltage to achieve that the voltage value approaches the converted voltage, which uses its own D/A converters and registers. The accuracy is higher than the parallel AD converter. Thinking about the conversion accuracy, conversion speed, performance and other issues, the system selects the successive approximation AD converter, the ADC0809 module. It consists of 8 analog switches, address latch and decoder, comparator, D/A converter, SAR, control circuit and three state output latch buffer. ADC0809 circuit diagram is shown in Figure 2.

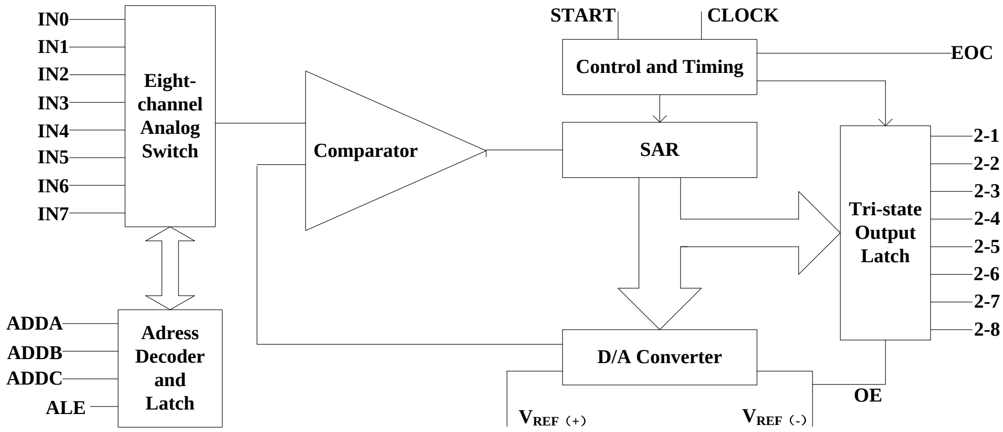

Figure 2. ADC0809 Circuit Diagram

The figure above is the circuit of the ADC0809 module. Because the sound of the rumination is very weak, we design the amplifying and filtering circuit for the system as shown in Figure 3.

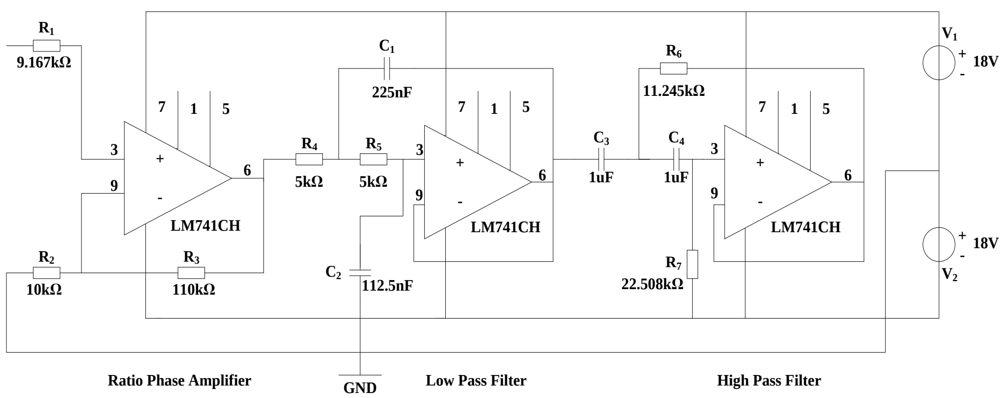

Figure 3. Amplifying and Filtering Circuit

The circuit is applied to the integrated operational amplifier and the high and low pass filter circuit, the analog signal is amplified by 12 times, and the amplifier is amplified with the same phase proportional amplifier. Filter circuit is a bandpass filter, which is composed of second-order voltage-controlled low-pass filter and second-order voltage-controlled high-pass filter. The circuit has simple structure, good performance and good effect.

2.3. Software Design

The external structure of the real-time monitoring system is composed of various parts of the hardware. If you want to realize the function of the system, it also needs the support of the software. The main control chip of the system is MSP430F149, the development environment is Embedded Workbench IAR. This kind of software has C/C++ compiler and debugger, real-time operating system and middleware, hardware emulator and state machine modeling tool [16]. After the system is initialized, the analog signal is amplified and filtered. After the AD module collects the signal, the main processor processes it and the valid signal is stored in the SD card and displayed in the LCD. At the same time, the card reader reads the information and transmits the information to the PC. According to the setting of the rumination standard, the system can determine whether cow rumination is normal or not. If there is an exception, the real-time warning is carried out. It is convenient for the managers to monitor the health and estrus of the cows. System software design flow chart is shown in Figure 4.

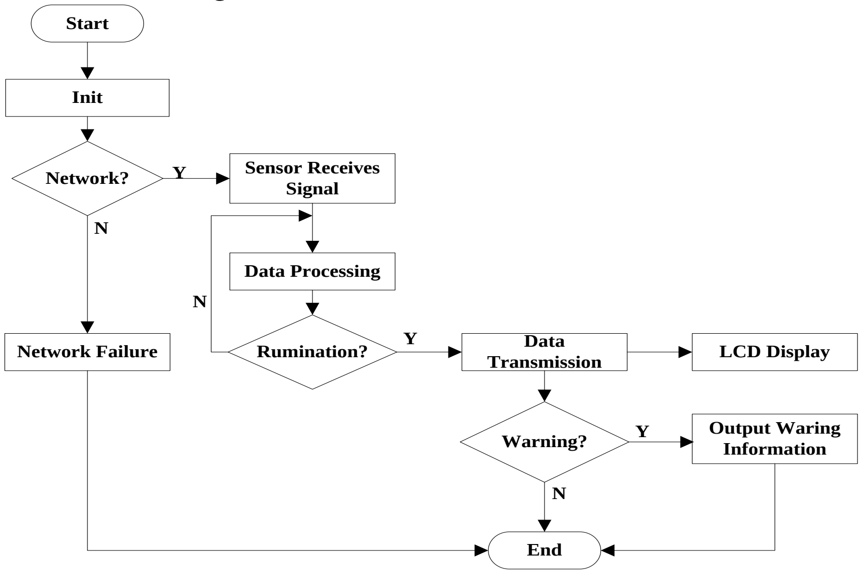

Figure 4. Flow Diagram Design of the System

2.3. Algorithm Design for the Recognition of Rumination

Cows will emit different frequencies while they are eating, ruminating and swallowing. However, all the three behaviors have a certain regularity. The energy of the swallowing sound is higher than that of the chewing sound and the zero rate between the three behaviors is also different [17-18]. Because the sound signal has a relatively large random, noise processing is also very important. In order to reduce the influence of the noise, we should do the endpoint detection of noise firstly. Its short-term energy is:

$$E_T = \sum_{n=0}^{N-1} X^2(n) \tag{2}$$

where N refers to cow ruminating voice signal frame length, where E_T refers to voice signal energy value of one frame, where $X^2(n)$ refers to windowed speech sequence pretreated. It takes 20ms for one frame and the average energy of the frame is:

$$T = \frac{1}{L}\sum_{i=0}^{L-1} E_T(i) \tag{3}$$

Dynamic threshold values for each frame of the noise are:

$$G_i = (E_{\max} - Q) \bullet a_i, i = 1,2,3,4 \tag{4}$$

where a_i refers to frame threshold discriminant coefficient, a_1 is 4, a_2 is 8, a_3 is 4, a_4 is 3. The first two are used to determine the beginning of the cow's rumination sound sequence, and the other two are used to determine the end. Sound signal is a typical non-stationary signal, which changes with time. But in the time interval of a frame, the characteristic of the spectrum can be approximated as the same. So the processing of each short-time sound signal is equivalent to the processing of the fixed characteristic sound signal. The sampling sequence of the cow's rumination sound is $x(c)$. It is equivalent to multiply by $w(n-c)$, where $w(n-c)$ refers to a moving window. The time series obtained after processing are:

$$Q_n = \sum_{-\infty}^{+\infty} T\left[x(c)\right] w(n-c) \tag{5}$$

where Q_n refers to time series, $x(c)$ refers to the speech sequence input. The time series with Hamming window function is:

$$w_n = \begin{cases} 0, other \\ 0.5 - 0.46\cos\left(2\pi \dfrac{n}{N-1}\right), 0 \le n < N \end{cases} \tag{6}$$

Assuming that a window of the signal represents a periodic signal, then FFT transform is performed on the data in the Hamming window. After that, we can get frequency domain signal. In this way, we can analize the changes of the sound spectrum characteristics of the cow rumination and recognize whether the cow is ruminating or not.

3. Simulation Analysis of the System

To ensure the reliability of the algorithm, we use signal source to generate the sine signal. Its frequency is 50Hz, the amplitude is 3V, the signal phase is -30 degree, the sampling number is 256. Figure 5 shows that FFT transform is performed on the data in the Hamming window.

As shown in Figure 5, we find that the frequency we have got is 50Hz, the same as we have given. So, the algorithm is reliable in performance. We can use this algorithm to detect the behavior of cow's rumination.

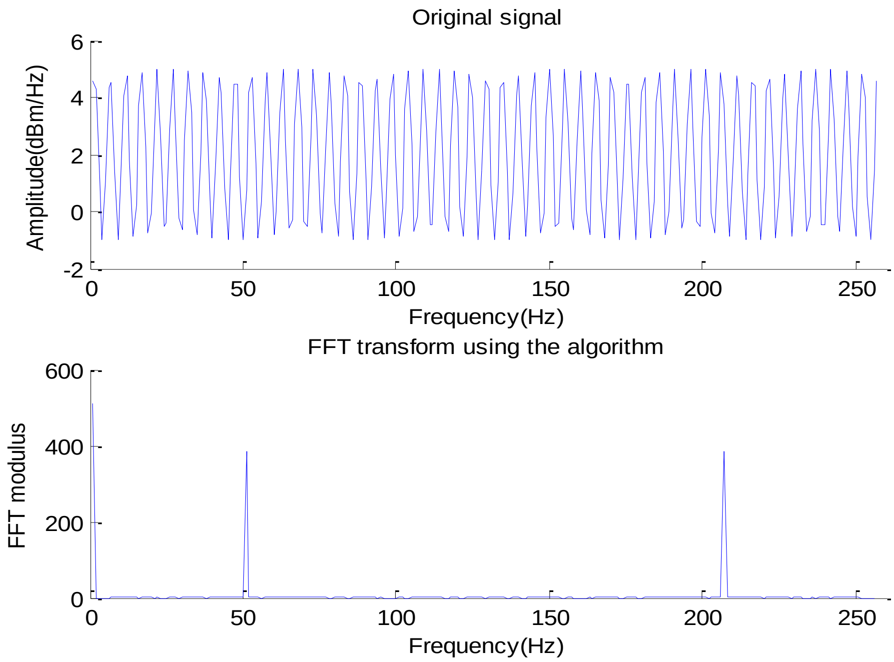

Figure 5. FFT Transform for 50Hz Signal

As we all know, cow rumination behavior often occurs in the night. So,we use high precision recording instrument to collect the sound signal of the cow's chewing, ruminating, and swallowing during 00:00 to 5:00am. In order to verify the accuracy of the system, we use this system to do the same experiment. After that, we selected 3 segments of the sound spectrum which can represent the cow's chewing and swallowing. Then we compared the spectrum of the two instruments. The sound spectrum is shown in Figure 6.

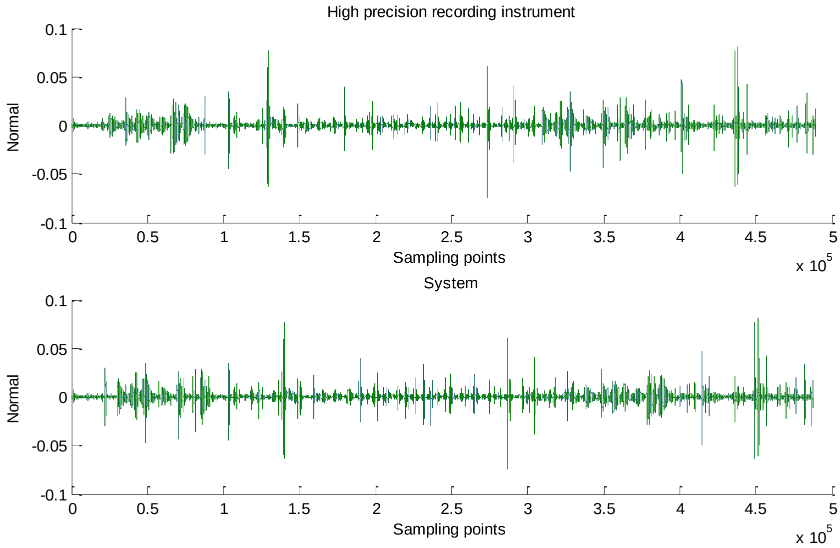

Figure 6. Comparison Chart of Sound Spectrum Feature between two Instruments

The horizontal axis represents the number of sampling points, the vertical axis represents the sound signal reference value. The higher part of the energy values is the cow's swallowing behavior, and the rest three segments are the cow's chewing behavior. Through the comparison of the two figure, there was no obvious change in the sound spectrum of chewing and swallowing. Although there is a small delay problem in the time, the sound signals that the system collected are similar to the signals collected by the high precision recording instrument. The high precision instrument detected three times of swallowing, so did the system. So the algorithm is more reliable and we can use it to identify the rumination. The spectrum analysis of the FFT transform is shown in Figure 7.

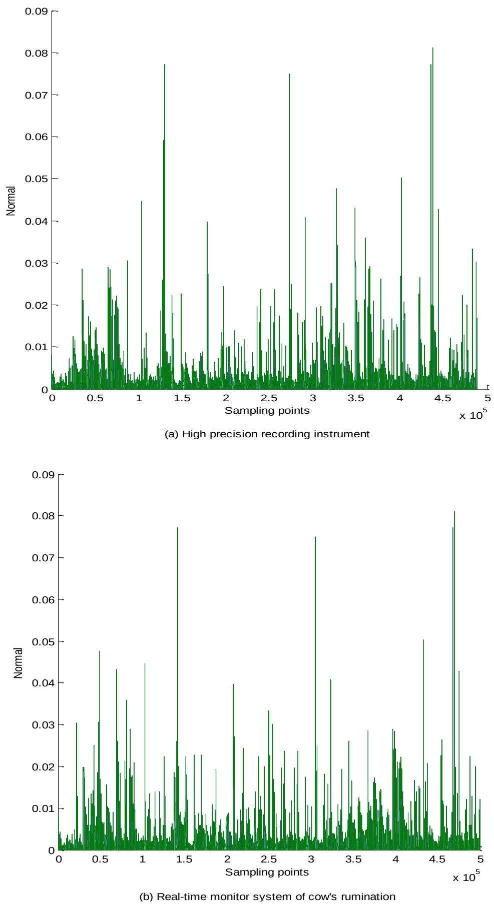

Figure 7. Spectrum Analysis of the FFT Transform

As shown in Figure 7, there are three peaks in both pictures. The three peaks represent the behavior of swallowing and the rest represent the behavior of chewing. This system has also detected the three peaks. According to the analysis of rumination, its vomiting is similar to the swallowing and the behavior of rumination is much regular. By this way, we can take a preliminary identification of rumination. Figure 8 shows that the spectrum analysis of sound signal in high precision recording instrument and system.

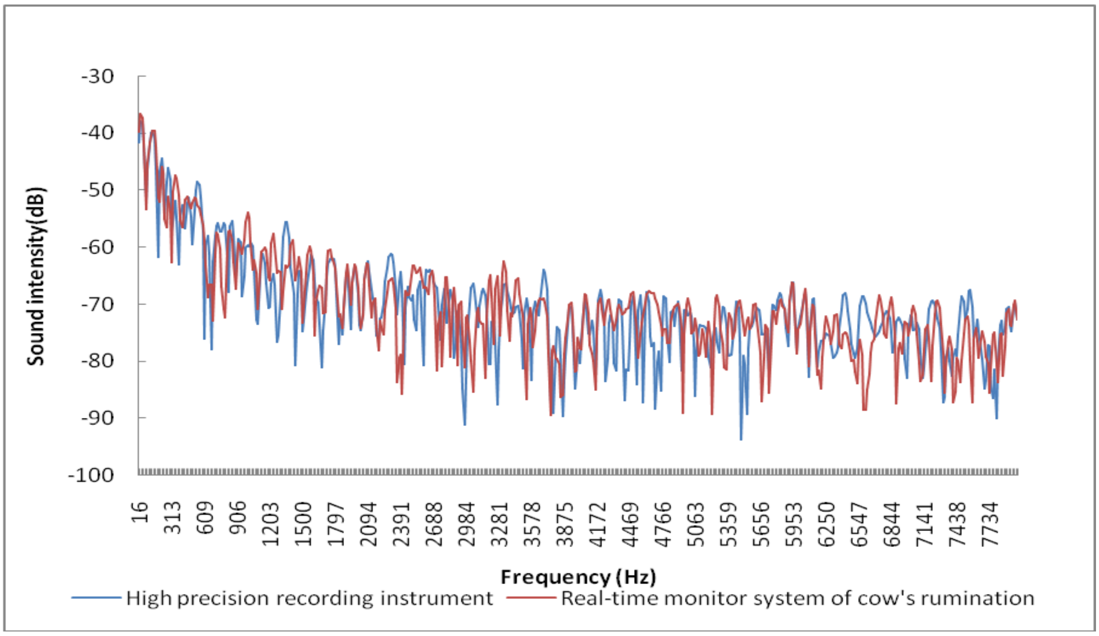

Figure 8. Comparison of the Spectrum between Two Instruments

Because the external environment influence the rumination and the system is currently in the experimental stage, a high precision recording instrument is used for the sound collection of 5 days of eating and rumination on a cow. In order to make the data processing more efficient, we selected some quiet place to do the simulated experiments. We use the high precision recording instrument to simulate 50 groups of different time on rumination. The system monitors the rumination time every two hours. Using the upper computer, we observed the change of the rumination sound spectrum and record the simulated data. Then SPSS software is used to give the 50 groups of the simulated experiments a linear analysis. The results are shown in Table 1.

Table 1. Data Analysis of the Two Instruments

Instruments	Sample quantity	Mean error	R^2	Pearson
Recording instrument	50	0.38	0.999	0.999
System	50	4.38	0.877	0.936

As shown in Table 1, in the comparison of the high precision recording instrument and the artificial observation, the R^2 value of the high precision recording instrument is 0.999, and pearson correlation is 0.999. It can prove that the reliability of the high precision recording instrument is higher. And also we can use it to do the simulated experiments of the cow rumination. In the comparison of the system and the artificial observation, the R^2 value of the system is 0.877, and pearson correlation is 0.936. Sound signal acquisition is more accurate and they are a significant strong correlation. The two curve fitting image is shown in Figure 9.

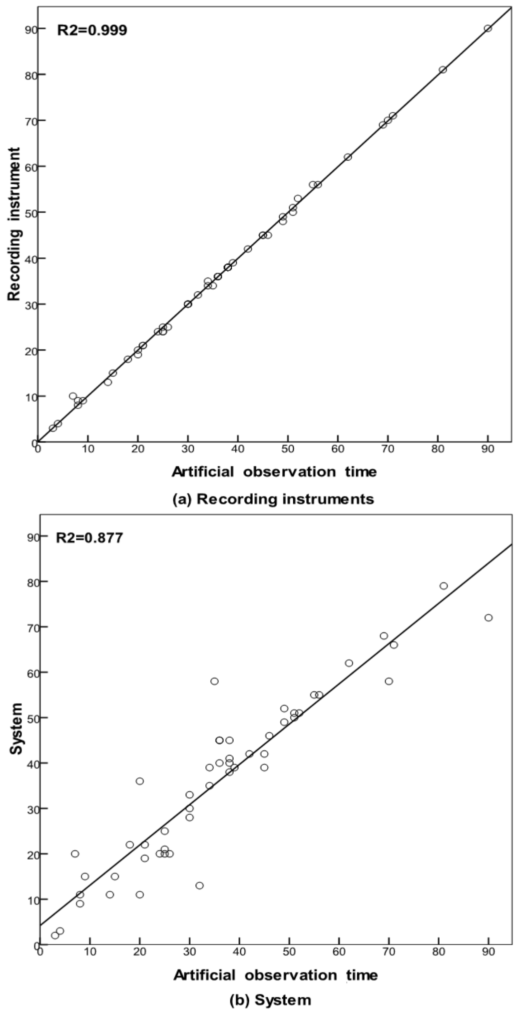

Figure 9. Linear Fitting Image of the Two Instruments

From the picture above, the sound signal collected by the high precision recording instrument is more accurate. So we can use it to do the simulated experiments. After doing the simulated experiments, we find that the accuracy of the system can meet the requirements, the mean error of the system is 4.38. The R^2 value is 0.877. The accuracy of the system is more than 95%. But the system still needs to be improved.

4. Conclusion

Firstly, the real-time monitoring system of the cow's rumination realizes the collection of sound signals, data transmission and other functions, and also can be displayed by LCD. At the same time, this system can monitor the cow’s rumination time and PC can give the warning judgment. Through the simulated experiments, we have found that the accuracy of the system is more than 95%. The system can meet the requirements, but still need to be improved.

Secondly, it has a special design for the ADC module and the amplification and filtering process. This paper have selected the ADC0809 module. This system uses the endpoint detection and audio signal sequence and window function algorithm to collect effective sound spectrum. In the comparison of the high precision recording instrument and the artificial observation, the sound signal collected by the high precision recording instrument is more accurate. So we use the high precision recording instrument to simulate 50 groups of different time on rumination. By this way, we have proved that this system is more accurate. The R^2 value of the system is 0.877, and pearson correlation is 0.936. This system helps to identify the cow rumination and the system is provided with accuracy.

Lastly, there is a small delay problem in the time and the system remains to be improved. For example, the aspect of the pratical needs, the accuracy of the system and so on. In power consumption, the system still needs to be strengthened. As rumination has an important influence on cow's health and estrus, so regarding cows of different regions, temperatures, ages, varieties and genders, further experimental analysis is needed.

Acknowledgements

This work was supported by the project of tackling key problem of Heilongjiang province (GC12B305); the pre research and development projects of the industrialization of Heilongjiang province university science and technology (1253CGZH33); the project of tackling key problem of Harbin science and technology (2014AB1BN035).

References

[1] Mengmeng Wang. Exchange of New Technologies to Promote New Products and Improve the Development of the Dairy[J]. China dairy. 141(36), **(2013)**.

[2] U.Braun, S.Zürcher, M.Hässig. Eating and Rumination Activity in 10 Cows over 10 Days[J]. Research in Veterinary Science. 101, 196-198**(2015)**.

[3] Adin, G., Solomon, R., Nikbachat, M., Zenou, A., Yosef, E., Brosh, A., *et al*. Effect of Feeding Cows in Early Lactation with Diets Differing in Roughage-neutral Detergent Fiber Content on Intake Behavior, Rumination, and Milk Production[J]. Journal of Dairy Science. 92, 3364-3373**(2009)**.

[4] Fogsgaard, K.K., Røntved, C.M., Sørensen, P., Herskin, M.S. Sickness Behaviour in Dairy Cows During Escherichia Coli Mastitis[J]. Journal of Dairy Science. 95, 630-638**(2012)**.

[5] Zhaochun Jiang, Chunhua Tang. Healthy Breeding and Disease Prevention of Dairy Cow[M]. Agricultural Press of China. 153-157**(2010)**.

[6] Zimov, J. L., N. A. Botheras, W. P. Weiss, and J. S. Hogan. Associations among behavioral and acute physiologic responses to lipopolysaccharide-induced clinical mastitis in lactating dairy cows[J]. Am. J. Vet. Res. 72: 620–627**(2011)**.

[7] Cyples, J. A., C. E. Fitzpatrick, K. E. Leslie, T. J. DeVries, D. B. Haley, and N. Chapinal. Short communication: The effects of experimentally induced Escherichia coli clinical mastitis on lying behavior of dairy cows[J]. Dairy Sci. 95: 2571–2575**(2012)**.

[8] Shengli Li. The Development of Dairy Cow Breeding Industry in China[J]. Chinese Journal of Animal Science. 44(10), 44-49**(2008)**.

[9] Shengrong Li. Preliminary Study on Oestrus Identification and Breeding Time[J]. China Animal Husbandry & Veterinary Medicine. 33(11), 36-37**(2006)**.

[10] Pingzeng Liu, Weimin Ding, Xiao Wang, Yongqian Ding, Changhua Lu. Design of Automatic System to Detect Cow Oestrus[J]. Measurement and Control Technology. 25(11),**(2006)**.

[11] Maohua Wang. Engineering Science and Technology for Modern Intensive Sustainable Agriculture[J]. Transactions of the Chinese Society of Agricultural Engineering. 14(3), 1-9**(2008)**.

[12] Cummins, S.B., Lonergan, P., Evans, C.O., Butler, S.T. Genetic Merit for Fertility Traits in Holstein Cows: II. Ovarian Follicular and Corpus Luteum Dynamics, Reproductive Hormones, and Estrus Behavior.J. Dairy Sci. 95, 3698-3710**(2012)**.

[13] Yuning Cui. The Design of Body Balance System Based On MSP430[D]. Dalian University of Technology. 14-17**(2008)**.

[14] Dake Hu. Principle and Application of MSP430 series with low power and 16 bit[M]. Beijing University of Aeronautics and Astronautics Press. 152-154**(2008)**.

[15] Xiaolong Wei. The interface Technology and System Design Examples of MSP430 Series[M]. 132-133**(2010)**.

[16] MSP430x15x, MSP430x16x, MSP430x161x mixed signal microcontroller. Texas Instruments Company. **(2009)**.

[17] Fuyang Tian, Fade Li, Jinyang Li. Design and Research of Testing Instrument for Cow's Feed Intake[D]. Shandong Agricultural University. 8-10**(2006)**.

[18] Yi Yao. The Research on Dairy Ruminant Information Acquisition System

[19] Based on ANT[D]. Donghua University. 12-15**(2015)** .

Authors

Zhongbin Su. Zhongbin Su (1965-), male, Ph.D.,professor, president of the college of electrical and information in Northeast Agricultural University, mainly engaged in the research and application of information technology in agriculture.

