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A Measurement System of Electric Signals on Standing Trees

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Abstract: The standing tree electric signal (STES), defined as the electric potential difference between standing trees and the surrounding soil, can be utilized to reflect the biological nature of the trees. This signal should be measured precisely because it can also be collected and used as the electric power energy. In this paper, the automatic measurement system of standing tree biological electric signal based on MSP430 MCU. First of all, the basic structure of the presented system is introduced and it includes three modules: amplification module of the standing tree electric signal, the acquisition and processing of the signal module and the serial communication module. Then, the performances of the built system are respectively validated by the Poplar, Planetree, and Platanus in Beijing Forestry University. The result indicated that the relative error of this system is less than 2 %. The presented system can be considered as the foundation of the subsequent study on the mechanism of the biological electric signal and the application of the biological electric energy on standing trees. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Biological electric potential difference, Amplifying circuit, MSP430 MCU, Serial communication.

1. Introduction

The continuous electric potential difference between the electrodes inserted in the phloem of the tree and in the surrounding soil is discovered by J. P. Wright in 1981 [1, 2]. After that, these phenomena are also found between xylem or leaves and surrounding soil [3]. Generally speaking, the electric potential difference is defined as the standing tree electric signal (STES). The measurement of the STES plays an important role in the further application of this signal. Firstly, the STES is the physical foundation for studying the generation mechanism of itself [4]. Secondly, the biological features of the standing tree can be analyzed by monitoring the STES [5], for example, the growing state. Last but not the least, STES is the small energy, which can be utilized to supply the power to the firing monitoring devices in the forest after the large collection [6]. Andreas Mershin from MIT used two identical electrodes (one was inserted in the xylem of the tree, the other in the different standardized water content soil solution of variable pH and identical pH with different sorts of ions) and the high-impedance voltmeter ($>10G\Omega$) to detect and research the potential difference problem [5]. The method which is used by András Koppán is that: 16 non-polarizing different electrodes were evenly divided 4 four groups and were inserted into the sapwood in 4 levels (corresponding to East, South, West and North sides of the tree) and 4 electrodes were installed in each level. The potential difference was measured between the sapwood electrodes and a common ground [7]. Dominique Gibert conducted a similar experiment: 26 electrodes were inserted into the tree in different levels and different directions of each level, and other 5 electrodes were inserted in the root of the tree. The potential difference was also measured between the electrodes and the soil [8]. From above analysis, it is clear that the potential difference between the tree and the ground is continuous and stable. The experimental result of Andreas Mershin showed that the value of that potential difference can be up to 200 mV. In China, Professor Li in Beijing Forestry University have done many researches on the STES. The results indicated that the electric potential between different plant and soil are really different and the range of the values is varied from -57 mV to 553 mV according to different trees. The experimental steps of Professor Li can be conducted as follows: a resistance (2 MΩ) is employed to connect 2 electrodes (One is in the tree, the other is in the soil) and a common voltmeter is utilized to measure the voltage between two electrodes. The principle of this method is measuring the electric potential based on the multi-meter with large impedance. In conclusion, there are many methods have been proposed to measure the electric potential. However most of the methods has the following disadvantages: 1) the measuring accuracy and efficiency are both low; 2) it is hard to implement the real time measurement; 3) it is also difficult to simultaneously measure the potential difference in the different conditions, for example, electrodes are inserted into different depth of trees and soil. In order to overcome the mentioned drawbacks, it is very necessary to design a standing and automatic measurement system for the real-time and the long time measuring of the value of the potential difference effectively and accurately. Furthermore, considerable amount of data should also be transmitted to the computer for further analysis through the communication system.

To measure the potential difference more efficiently and real-timely, a standing tree automatic measurement system of biological electric signals needs to be designed to achieve real-time monitoring of the value of the potential difference and prolonged monitoring of biological electric signals. Furthermore, considerable amount of data can also be transmitted to the computer for further analysis through the system.

In this paper, the automatic measurement system of standing tree biological electric signal is designed based on MSP430 MCU. The proposed system contains three parts: the amplification module of the standing trees electric potential difference, the acquisition and processing of signal module and the serial communication module with PC. The amplifying circuit can realize the adjustable gain to amplify different voltage and can convert negative potential difference to positive one; MCU acquisition and processing of signal is responsible for converting analogue voltage as input to digital signals and analyzing them; the serial communication with PC is used to transmit the digital signals to PC.

2. The Structure of the Designed Measurement System

In this section, the basic structure of the designed measurement system is introduced. First of all, the amplification module is used to amplify the biological electric signals and convert it into the inputting signal for the MSP430 MCU. Then, the acquisition and processing of signal module is the core of the measured system. It is utilized to analyze the amplified signal and extract the useful information. Furthermore, the serial communication module is applied to transfer the digital signals to PC and display the results.

2.1. The Amplification Module

Generally speaking, the range of the processable signal for the MSP430 MCU is 0~3.3 V. According to the former results from Professor Li in Beijing Forestry University, the value of the potential difference is -53 mV~553 mV. Therefore, it is necessary to amplify the measured signal and convert it into the processable signal. The amplifying module mainly consists of three chips: AD620, ICL7660 and LM2576-ADJ. The function of each chip is introduced respectively.

AD620 with high precision, simple operation, low noise and low power consumption is responsible for amplifying and converting input; ICL7660 with large range of input takes responsibility of converting positive voltage to negative voltage, and supply AD620 as negative energy resource; LM2576-ADJ with simple operation, easy design and adjustable output is used as a positive energy resource for AD620, and its output is used as input of ICL7660.

The amplifying circuit is supplied by a 9 V battery. The negative voltage generated by ICL7660 is divided to be the input of $-V_{IN}$ pin of AD620, which is equivalent to a negative reference voltage. The conversion of negative biological electric signals to positive ones can be realized through equation (1). $+V_{IN}$ pin is connected to standing tree biological electric signals.

The value of V_{out}:

$$V_{out} = (\frac{49.4K\Omega}{R_5} + 1) \times \left[+V_{IN} - (-V_{IN}) \right], \quad (1)$$

The schematic of the amplifying module is shown in Fig. 1.

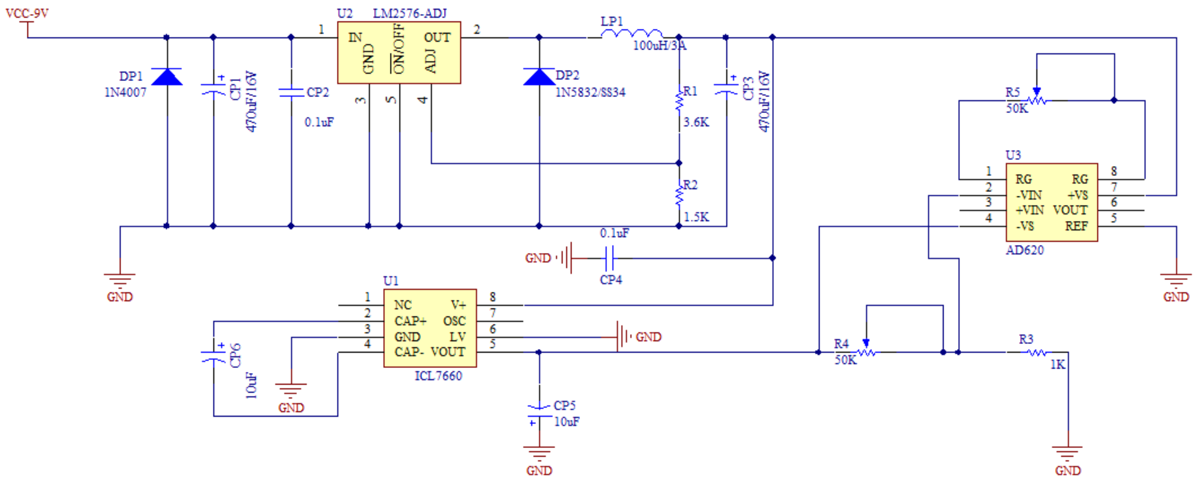

Fig. 1. The schematic of amplifying circuit.

A certain voltage (7~40 V) can be converted to an unchanged one through LM2576-ADJ whose value can be determined by equation (2). The target output of LM2576-ADJ is 4.2 V which is used as the energy resource of AD620 and input of ICL7660; ICL7660 converts 4.2 V to -4.2 V, which is used as the negative energy resource of AD620 and can be divided to be the input of AD620 supplying the reference voltage whose value can be determined by equation (3). AD620 is the core of the amplifying circuit and its gain is regulated by R_5 (Fig. 1) whose value can be determined by equation (4). Finally, the 6 pin of AD620 is connected to I/O input of MSP430 MCU.

The output of LM2576-ADJ:

$$V_{out} = V_{ref} \times (\frac{R_1}{R_2} + 1), \quad (2)$$

where $V_{ref} = 1.23V$.

The value of reference:

$$-V_{IN} = -4.2 \times \frac{R_3}{R_4 + R_3}, \quad (3)$$

The gain of AD620:

$$K = \frac{49.4K\Omega}{R_5} + 1, \quad (4)$$

where K represents the gain of AD620.

2.2. The Acquisition and Processing of Signal Module

MSP430F149 MCU with 12-bit ADC conversion accuracy module is used in the system, and the ADC module can be used to make the hardware circuit of the system more integrated and smaller. In the system, external analog signals are be connected to A0 passage, next, set the A/D converter interrupt through basic timer, when receiving timer interrupt request, the system starts the process of sampling of standing tree biological electric signal and the converted digital signals are stored in the register [9, 10]. To reduce sampling error, take the average of 10 samples for the final sampling results.

The flow chart of A/D converter is shown in Fig. 2.

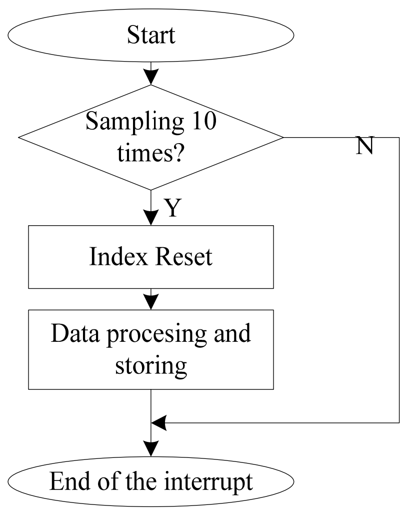

Fig. 2. The flow chart of A/D converter.

The basic schematic of MCU is shown in Fig. 3.

2.3. The Serial Communication Module

The system is connected to PC through the serial asynchronous communication and RS232 protocol conversion electrical level. USART0 and USART1 module are included in the MSP430F149 MCU.

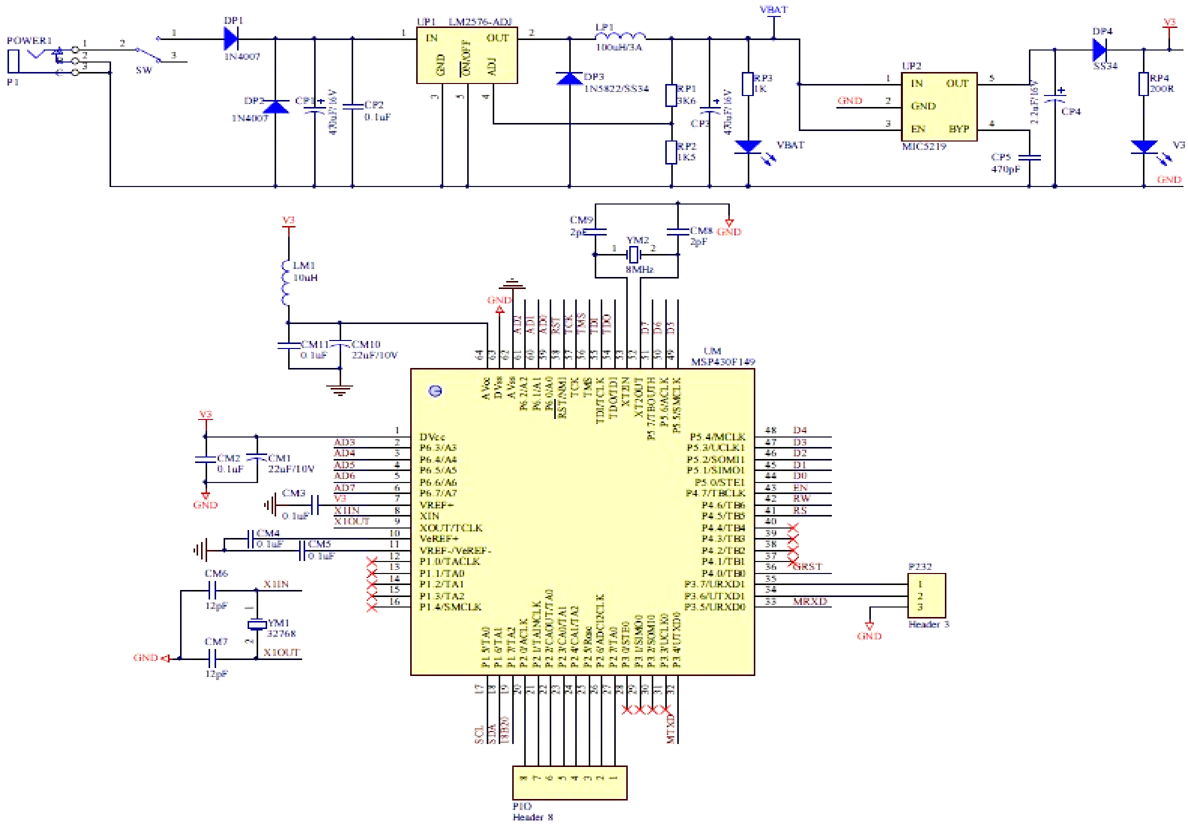

Fig. 3. The basic schematic of MCU.

In the system, the USART0 asynchronous communication module is used through "ME1 | = UTXE0 + URXE0" command to enable UART0 to send and receive data. The system also uses MAX3232 to convert electrical level to communicate with PC. When pressed key interrupt is triggered, through setting the serial communication initialization parameters and "TXBUF0 = DATA [i]" command, the data acquired through the A / D conversion and then stored in the register is written to the transmit data buffer UTXBUF in the form of ASCII code and is transmitted to the PC through UTXD0. After completing the data transfer, empty the register and jump out the interruption. The project team collects the data stored in MSP430 MCU every once in a while.

The flow chart of the serial communication is shown in Fig. 4.

3. Experiment and Analysis for the Result

3.1 Amplification Circuit Test

In order to verify the validity of the amplifying circuit, a practical test was conducted. Before the test, three kinds of trees named Canadian poplar, London Planetree, and Platanus occidentalis in Beijing Forestry University were chosen as experiment objects. Two identical electrodes were prepared for each tree in the test, and one was inserted into the tree, the other into the surrounding soil. Before the measurement, all terminals which were connected to the surrounding soil in the amplifying circuit were linked together; use a voltmeter to measure the size of the input signal; then, according to the size of the input signal, appropriate gain of the amplifying circuit and reference voltage value were chosen out; then, use another voltmeter to measure the size of output of AD620; finally, all different standing tree bioelectrical test data was recorded.

The Schematic diagram is shown in Fig. 5.

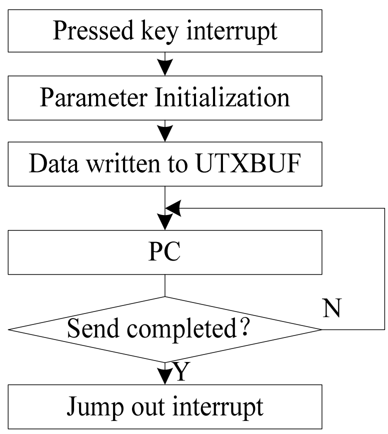

Fig. 4. The flow chart of the serial communication.

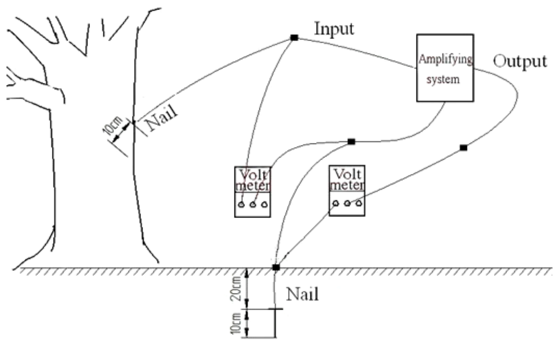

Fig. 5. The schematic diagram of testing.

3.2. Test Data Analysis

According to the above schematic, firstly, make the reference voltage value 0 V and change the gain of the amplifying circuit (Table 1); secondly, set the reference voltage value -141 mV and -406 mV and keep the same gain (Table 2). In two tables, "Theoretical Gain" is determined by equation (4); "Output" means the value measured with the voltmeter; "Theoretical Value" is determined by equation (2); "Relative Error" is determined by the actual and theoretical values.

Table 1. Testing Data with no reference voltage.

Species	Input（mV)	Theoretical Gain	Output (mV)	Actual gain	Relative error
Platanus occidentalis	-91	13	-1182	12.99	-0.08 %
	-39	13	-504	12.92	-0.59 %
Canadian poplar	-115	13	-1514	13.17	1.27 %
	-108	13	-1427	13.21	1.64 %
Platanus occidentalis	-92	17	-1575	17.12	0.70 %
	-49	17	-820	16.73	-1.56 %
Canadian poplar	-114	17	-1964	17.23	1.34 %
	-108	17	-1845	17.08	0.49 %
Platanus occidentalis	-100	23	-2300	23.00	0.00 %
	-65	23	-1515	23.31	1.34 %
Canadian poplar	-117	23	-2687	22.97	-0.15 %
	-107	23	-2497	23.34	1.46 %
Platanus occidentalis	-100	25	-2505	25.05	0.20 %
	-66	25	-1650	25.00	0.00 %
Canadian poplar	-116	25	-2921	25.18	0.72 %
	-108	25	-2650	24.54	-1.85 %

Table 2. Testing data with the reference voltage.

Species	Input(mV)	Theoretical Gain	Reference Voltage (mV)	Output (mV)	Theoretical Value (mV)	Relative Error
London Planetree	710	2.05	-141	1744	1744.55	0.03 %
	-50	2.05	-141	188	186.55	0.78 %
Platanus occidentalis	-345	2.05	-141	-418	-418.2	0.05 %
	-278	2.05	-141	-280	-280.85	0.30 %
Canadian poplar 1	657	2.05	-406	2156	2179.15	1.06 %
	-48	2.05	-406	734	733.9	0.01 %
Canadian poplar 2	-343	2.05	-406	129	129.15	0.12 %
	-277	2.05	-406	266	264.45	0.59 %

3.3. Measurement System Testing and Data Analysis

After the intact measurement system designed, the same trees as the above were chosen as experiment objects.

By comparing the data measured with voltmeter and stored in PC, the data comparison chart was plot with "Number of measurements" as abscissa and "Absolute error" as ordinate.

The date comparison chart is shown in Fig. 6:

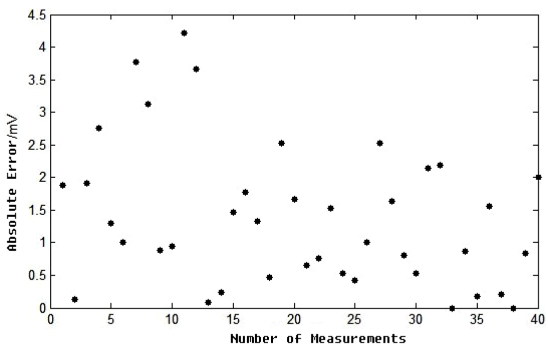

Fig. 6. The date comparison chart.

By analyzing the Fig. 6, the maximum error between the data measured with the system and with voltmeter is less than 4.5 mV, which indicates that the system can be applied to measure the standing tree electric potential signal.

4. Conclusion

The paper presents a real-time standing tree bioelectric measurement system, which can amplify the standing tree bioelectric signal and convert the negative potential difference to positive one; on the other hand, the preliminary processing analog voltage can be stored in MSP430 MCU temporarily through A/D conversion; moreover, through the serial communication, the data in MCU can be transmitted to PC to complete real-time measurements. Through the test on the trees in Beijing Forestry University and comparing the data measured with voltmeter and stored in PC, it is concluded that the system can meet the requirement of measuring the standing tree potential difference, can be utilized for further study, and simultaneously, means a lot to analyze the characteristic of the standing tree potential difference. The further work is to develop software running in PC in order to analyze the amount data.

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