Journal of Theoretical and Applied Information Technology
31st March 2013. Vol. 49 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

STUDY ON A PIPELINE TENSION DETECTION METHOD FOR AERO-PIPELINE SPRAYING SYSTEM IN PADDY FIELD

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ABSTRACT

Aero-Pipeline Spraying System is a special ultra-working-width precision pesticide sprayer, which can broaden working scope, improve working efficiency, precisely transfer feed liquid to farm field that need to be sprayed, spray pesticides to crops in a very close range, and then improve working precision and reduce the losses of liquid materials such as pesticides. During the ultra-working-width spraying operations in paddy fields, the suspension spraying aero-pipeline unable to automatically retractable, are prone to sagging and winding, then it affect the operational efficiency and spraying effect. The Aero-Pipeline Tension Detection System (APTDS) is the essential part of the ultra-working-width paddy field pesticide sprayer. The pipeline can maintain a tension state through an automatic winding system based on the APTDS. It is very useful to expand the working width and to improve the working efficiency of the ultra-working-width paddy field pesticide sprayer. RESULTS: An APTDS based on the C8051F040 MCU was developed, include the power system, the tension sensors, the conditioning circuits for the sensors and the motor control system. The tension sensors were calibrated by a linear equation. The program of the tension detection and the motor control system were developed by programming language C51. The results showed that the average errors of the tension detection used by the APTDS was about 1.8N, the standard deviation was about 0.6548N, and the response time from the tension detection to the operation of the automatic retracting was about 100ms. CONCLUSIONS: The presented APTDS based on C8051F040 single chip microcomputer basically satisfies the ultra-working-width spraying requirements of the paddy field pesticide sprayer.

Keywords: *Ultra-Working-Width, Paddy Field, Aero-Pipeline, Sprayer, Tension Detection*

1. INTRODUCTION

According to a statistics, it is irreplaceable in a very long period of time that pesticides are used on crop protection for the use of pesticides can reduce the loss of grain about 15% [1]. However, Backward spraying equipment and low effective utilization of agricultural resources not only cause huge economic losses, but cause serious water and soil resources pollution, ecological system imbalance, quality decline of agricultural products as well as other human health threat problems [2].

Nowadays, there are lots of advanced spraying technologies are used in agricultural production, including automatic target sprayer[3], air-assisted low-volume sprayer[4], electrostatic spraying[5, 6], recycling sprayer[7], reduced drift sprayer[8], aero plane sprayer[9], large-scale boom sprayer[10], etc.

As for the limits of the rice-growing agricultural requirements, such as smaller row space (always less than 30cm, especially when the rice grow to the row-sealed stage, line ridge is not clear)[11, 12], poor performance of the trafficability (compared with the dry land, the flatness of paddy field mud bottom is uncontrollable, invisible, tilt, and the agricultural machinery is easier to get stuck in the mud), etc, it is difficult for the paddy field sprayer to enter into paddy field[13]. All the mentioned above technologies, therefore, have their own advantages and disadvantages in rice pesticide application.

For example, spray-boom spraying machine usually is tractor-mounted. The large-scale boom sprayer, such as GreenSeeker RT200 sprayer (Ntech Inc.), UX series sprayer (AMAZONE Inc.), 4030 series sprayer (John Deere Inc.), 3WQX air-

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

assisted boom sprayer (Chinese Academy of Agricultural Mechanization Sciences), etc, has higher efficiency, and its working width can up to 36cm. However, along with the working width increase, there are lots of problems when the machine works in paddy field, including more total weight, more mating power, and then poorer performance of the trafficability, energy consumption and operation cost increasing[14]. Increase of working width requires larger power machine, and thus whole weight of spraying machine increases, passage performance of farm working drops, energy consumption and working cost increase; during spraying work, spray boom swings easily when traveling because of rugged farmland, and therefore it is hard to keep parallel traveling between spray boom and land surface; balance of spray boom is harder to control along with increase of spray boom length, two ends touch land surface easily which will damage machine components; moreover, along with the working width increase, longer spray booms are needed, a litter vibration when traveling with power machine at the machine's hitch position can cause a violent swing at the end of the boom, which may cause serious damage to the spray boom[15]. According to the rice-growing agricultural requirements, its row space always less than 30cm, especially when the rice growth to the row-sealed stage, it has narrow row spacing and unclear field ridge, it is hard for spray-boom spraying machine to enter farm field to spray pesticides, the spraying functions of the boom sprayer are seriously restricted.

As a result, according to shortcomings of existing technologies, to design a special ultra-working-width precision pesticide sprayer is needed, which can broaden working scope, improve working efficiency, precisely transfer feed liquid to farm field to be sprayed, spray pesticides to crops in close range, improve working precision and reduce the losses of liquid materials such as pesticides, herbicides, foliar fertilizer, etc. (as shown in Figure 1)[16]. It is an important function module of this machine that the suspension spraying aero-pipeline able to automatically retractable; real-time detection on aero-pipeline tension is required during automatic stretching of pipeline. Therefore, the Aero-Pipeline Tension Detection System (APTDS) is the essential part of the ultra-working-width paddy field pesticide sprayer. In this text, on basis of detection method of existing tension, according to motor drive knowledge, single chip microcomputer interface technology, circuit diagram design software (ProtelDXP) and simulation software (Protues), an APTDS was designed based on C8051F040 single chip microcomputer, and relevant tests about its working performance of the APTDS were conducted.

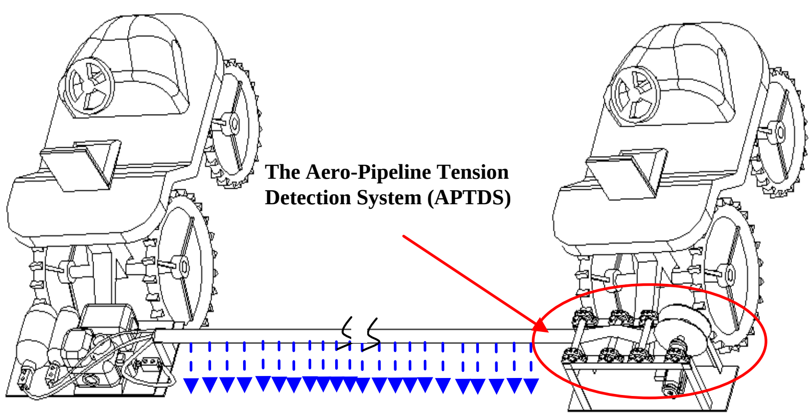

Fig. 1. The Ultra-Working-Width Aero-Pipeline Precision Pesticide Sprayer

Journal of Theoretical and Applied Information Technology
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2. OVERALL SOLUTION DESIGN OF THE SYSTEM

2.1 Overall Structure of the System

Aero-pipeline dynamic tension detection system takes C8051F040 single chip microcomputer as main control chip, and externally expanded with RS232 serial interface, keyboard, overload protection, display and motor control module; this system coordinates the work of each component through software, to realize convenient installation and low cost of pipeline tension dynamic detection device. The block diagram of the system is shown in Figure 2.

2.2 Function Module of the System

The aero-pipeline tension detection system mainly contains the following function modules:

(1) Sensor and signal conditioning circuit: This module realizes pipeline tension detection and transforms strain tension signal to voltage signal. The sensor uses YZC-1B strain weighing sensor; two sensors are fixed at two sides of pipeline support by bearing blocks, and when the pipeline generates pressure on the support from tension, voltage signal is acquired. Signal conditioning module picks up pipeline tension signal and realizes amplification of voltage signal and low-pass filtering. Signal amplifier uses AD623 of ANALOG Company, which can work with single supply +5～+12V and an external resistor, to realize programmable control amplifier gain.

(2) Main control module: This module realizes A/D transformation, data processing, keyboard scan, data transmission of upper computer, information display, overload protection and motor control of automatic winder. MCU uses high-speed SOC single chip microcomputer C8051F040 of Cygnal Company, which has 64 digital I/O pins and integrates a CAN2.0B controller within the chip.

(3) Communication module: This module uses MAX232 level conversion chip to realize communication between RS232 interface and PC machine, and transfers test data to PC machine to facilitate observation and data recording.

(4) Clock module: In this system, management of system time requires externally expanded clock calendar chip. DS1302 of American DALLAS Company is used as clock calendar chip to manage the time.

(5) Keyboard operation and LCD module: This module is used to realize operation information input, parameter setting, system status display and other functions.

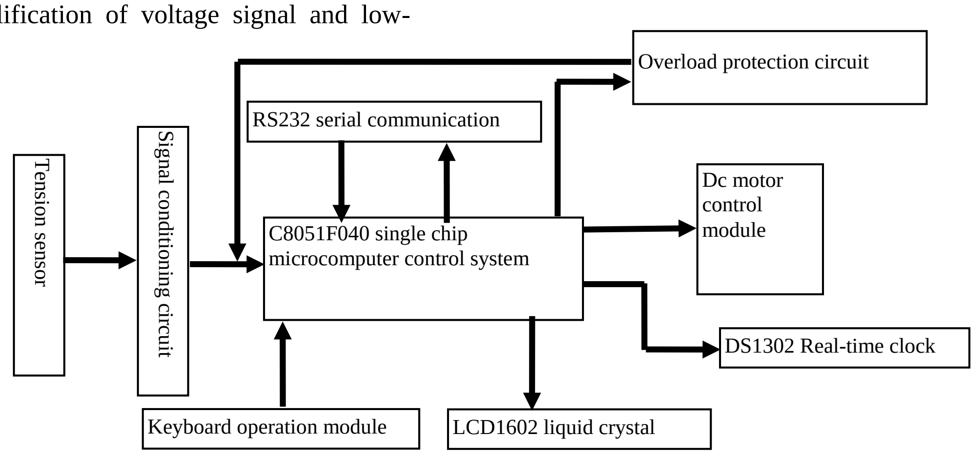

Fig. 2 The block diagram of the Aero-Pipeline Tension Detection System (APTDS)

3. REALIZATION OF THE SYSTEM

3.1 Installation and Calibration of the Sensor

Tension sensor uses YZC-1B weighing sensor. Installation method is shown in figure 3.

Tension sensors are calibrated with 1.25kg, 1.5kg, 2.5kg, and 5kg standard weights. Voltage signal output by strain signal conditioning circuit is linear with aero-pipeline tension; for any voltage value, tension can be directly calculated through linear transformation relation. When module transformation result is 1685 and corresponding tension is 50Kg, so tension indicated by each quantization electrical level is: 50Kg /1685

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

=0.0297, and thus it theoretically reaches 30g in resolution. Transformational relation between voltage and tension is shown in figure 4.

3.2 Hardware Circuit design of the System

Hardware circuit of the system is shown in figure 5. Internal strain gauge of tension sensors is connected by Wheatstone bridge, and differential output of Wheatstone bridge is connected to differential input of signal conditioning input. Signal conditioning circuit is composed of signal amplification chip AD623 and its peripheral components. C8051F040 ADC0 is used to acquire output voltage of AD623, and acquisition scope is 0 ～2.43V. Reference voltage is generated within single chip microcomputer.

3.3 Software Design of the System

Software design of the APTDS mainly contains design of master control program, data processing, LCD display program, each interface driver and so on; development tools used are Silicon Laboratories IDE and Keil C51. The software diagram of the system is shown in figure 6.

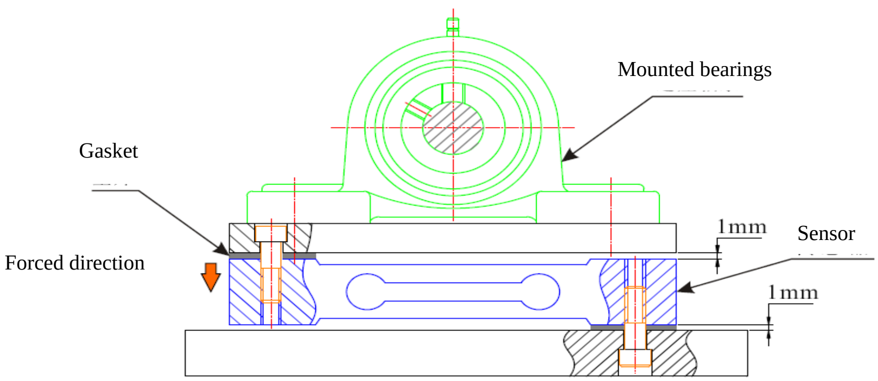

Fig. 3 The installation method of the tension sensors

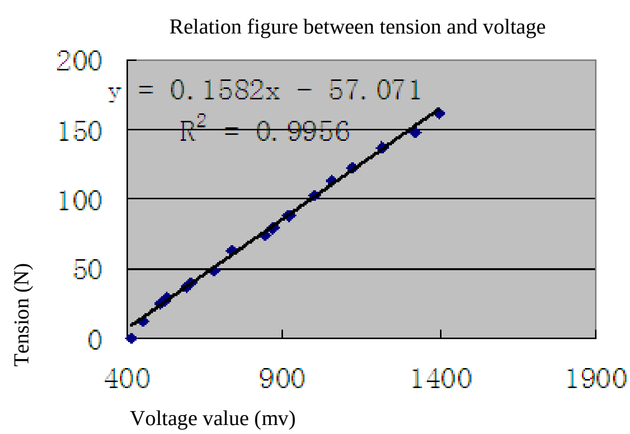

Fig. 4 The calibration for the tension sensors

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

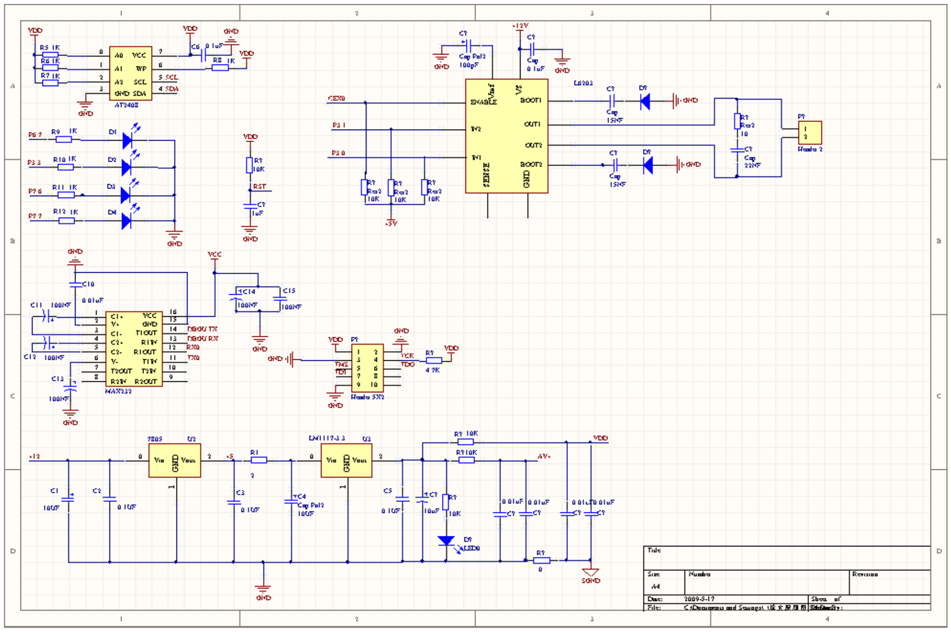

Fig. 5 The hardware circuit of the Aero-Pipeline Tension Detection System (APTDS)

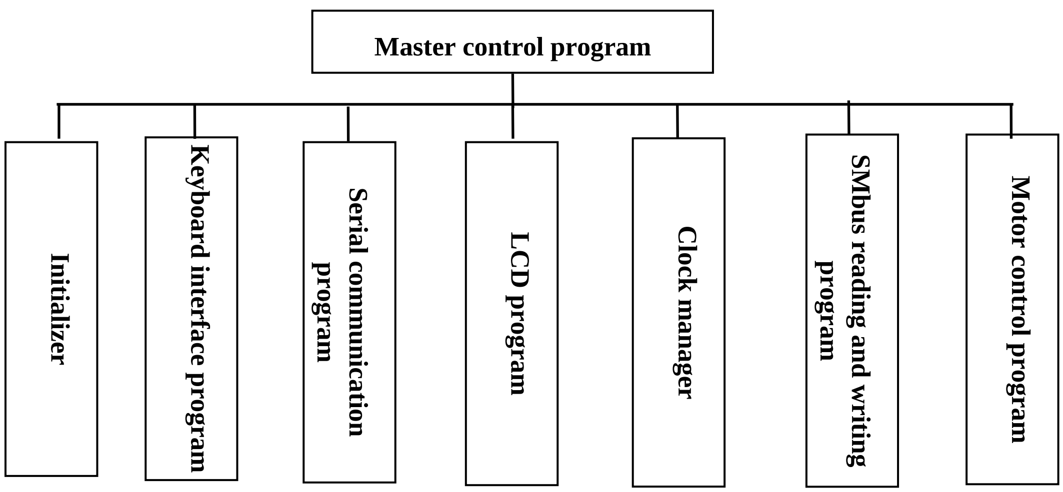

Fig. 6 The software diagram of the Aero-Pipeline Tension Detection System (APTDS)

4. TEST RESULTS AND DISCUSSION

4.1 Precision of Tension Detection

To detect measuring precision of the APTDS, relevant tests about its working performance of the APTDS were conducted. Several standard weights (1.25kg, 1.5kg, 2.5kg, 5kg) were used in laboratory static measurements. The measuring result is shown in Table Ⅰ.

Mean error of calibration tests can be figured out from formula (1).

$$E(X)=\sum_{k=1}^{k=\infty} x_k p_k \quad (1)$$

Where k indicates test times, x_k indicates each error value of tests, and p_k indicates probability of each error. In this test, 17 times were measured, from which it can be seen that $E(X)=29$ (mV), and mass mean value of weights is M=7.8kg. So, $E(X_0)=$ 29/7.8/500=0.185kg. Mean value of tension error is 0.185×9.8=1.8N. Standard

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

deviation is $D(X_0)=\sqrt{D(X)/500}$ =0.2345*kg*, and thus standard deviation of tension is 0.6548*N*.

4.2 Response Time of the System

Response time of the system means time interval between two AD conversions. Time interval between two AD conversions has much to do with the program calculation workload and its programming rules. Program optimization helps improve response time of the system. Response time of this system calculated from program simulation is about 100ms, which is enough to meet ultra-working-width efficiency and precision pesticide spraying requirements for paddy fields.

TABLE I. TENSION MEASURING DATA OF THE AERO-PIPELINE TENSION DETECTION SYSTEM (APTDS)

Weight of weights (kg)	Tension (N)	Summing output voltage (mV)	AD register (ADC0)	AD converted voltage (mV)	Voltage errors (mV)
0	0	442	701	415	27
1.25	12.25	472	758	449	23
2.5	24.5	532	857	508	24
2.75	26.95	545	876	519	26
3	29.4	552	892	529	23
3.75	36.75	608	989	586	22
4	39.2	620	1010	599	21
5	49.0	746	1144	678	68
6.5	63.7	802	1235	732	70
7.5	73.5	861	1420	842	19
8	78.4	887	1453	864	23
9	88.2	937	1542	915	22
10.5	102.9	1022	1681	997	25
11.5	112.7	1084	1784	1058	26
12.5	122.5	1148	1888	1120	28
14	137.2	1243	2047	1214	29
15	147.0	1348	2228	1322	26
16.5	161.7	1425	2356	1398	27

4.3 Error Analysis

From table 1, it can be concluded that the APTDS has good working performance in pipeline tension detection. Voltage quantitative values of AD register are almost the same with those of circuit output, which is consistent with theoretical analysis. However, error still exists, which comes from:

(1) Precision of AD conversion.

(2) Circuit connection from summing circuit output voltage to AD conversion interface is easily affected by external environmental factors.

(3) Data processing capability of the MCU.

According to above error sources, the measuring precision can be improved from the following aspects:

(1) Increase the sampling frequency and then take an average.

(2) Precisely adjust the installation position of the sensors.

5. CONCLUSIONS

The article puts forward a new aero-pipeline tension detection system based on C8051F040 single chip microcomputer. The C8051F040 single chip microcomputer is used as core control chip to realize dynamic aero-pipeline tension measurement. Relevant signal conditioning circuit, data acquisition circuit, upper computer communication, human-computer interface keyboard and display circuit are designed. And then the aero-pipeline tension sensors are calibrated. The C51 language is used to realize program design of the aero-pipeline tension detection and motor control system software. Special tests are designed to detect its measuring precision of the system. The interference factors affecting tension detection data and handling methods are analyzed. The test results show that mean error of tension detection values output by APTDS is 1.8N, standard deviation is 0.6548N and response time of the system is 100ms, which basically meet the pipeline tension detection requirement in ultra-working-width efficiency and precision pesticide spraying for paddy fields.

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