Construction of Traffic Control Vehicle Type Identification System Based on Piezoelectric Sensing and Laser Ranging

Chen Yao, Jiuchun Gu
Ludong University
Yantai 264000, China
yaoch2233@163.com

ABSTRACT: *This study constructed a vehicle type identification system that based on piezoelectric sensing and laser ranging, which could automatically identify vehicle types even the vehicles were in high-speed driving state, thus solved an urging problem of traffic management departments. The vehicle type identification system in this study used laser ranging sensor to measure the height of vehicles and in the meantime, it used driving speed and the laser frequency of laser ranging sensor to obtain vehicles' length. Vehicles' widths were measured by managing the pictures captured by webcam. Based on the vehicle type identification system that used piezoelectric film traffic sensor, this study additionally installed a laser ranging sensor and webcam, and used laser ranging sensor to obtain vehicles' height and used webcam to capture pictures to obtain vehicles' width, which did not only obtain chassis information of vehicles in real time, but also obtained vehicles' length, width and height at the same time. It covered main features of vehicles as well as improved veracity and reliability of vehicle type identification system.*

Keywords: Piezoelectric sensing; Laser ranging; Webcam; Vehicle type identification

Received: 13 September 2016, Revised 29 October 2016, Accepted 4 November 2016

1. Introduction

With the discovery of piezoelectric effect, more and more people began to do researches on piezoelectric materials since 1960's [1]. In 1969, some researches [2] verified that polyvinylidene fluoride (PVDF) could have powerful piezoelectric effect after polarization, thus drew high attentions on PVDF. Until 1980's, PVDF gained worldwide attentions because of its good performance, and more and more scientists began to do researches on it [3]. Compared with other piezoelectric materials, scientists found that PVDF had better sensing property because its voltage coefficient was several times higher than other piezoelectric materials [4]. Besides, the piezoelectric film of PVDF had good mechanical tenacity, which was soft, light and highly sensitive, thus was an outstanding strain transfer element.

This study introduced the structure and design process of vehicle information collecting system, which includes the design of piezoelectric thin-film sensor information collecting subsystem and laser ranging sensor and webcam information collecting subsystem.

2. Hardware

Vehicle information collecting system includes piezoelectric sensor, laser ranging sensor and webcam. Piezoelectric sensor was responsible for collecting chassis information such as vehicle's wheel base, numbers of axles, wheel track and numbers of tires, etc. Laser ranging sensor collected appearance information like vehicle's height, length, etc. Webcam would take pictures of vehicles and the pictures were not only kept as vehicles' traffic records, but were also used for obtaining vehicles' widths.

2.1. Piezoelectric Sensor

Macromolecular piezoelectric sensor [5] uses macromolecular piezoelectric materials and has high piezoelectric constant. For example, the piezoelectric constant of PVDF is over ten times higher than piezoceramics and its impulse voltage output can directly drive complementary metal oxide semiconductor (CMOS). Current piezoelectric sensors that used in intelligent transportation field are mainly two kinds, one is Roadtrax BL series piezoelectric film transportation sensor of MEAS company [6] and the other kind is Lineas series quartz piezoelectric sensor of Kistler company [7]. The size of Roadtrax BL series sensor is much smaller than Lineas series, like it shows in table 1. Besides, the Roadtrax BL series sensor is easier to be installed and the changes of surface evenness are smaller as well as the incision of road surface than Lineas series sensor, thus it has smaller damage to the road and is easier to be maintained, which shows higher cost performance.

Piezoelectric sensor	Voltage constant	Operating temperature	Size	Temperature sensitivity
Roadtrax BL	≥ 20 pC/N	-40°C - 80°C	16×1.6 (mm)	0.2%/°C
Lineas	≈1.75±5% pC/N	-50°C - 80°C	50×40 (mm)	0.3%/°C

Table 1. Performance comparison between Roadtrax BL series sensor and Lineas series sensor

2.2. Laser Ranging Sensor

Impulse type laser ranging sensor has high measuring frequency (1 Hz-200 Hz) while phase-shift laser ranging sensor has low measuring frequency (1 Hz-10 Hz). However, from measuring precision aspect, phase-shift type is preciser than impulse type. Next, this study analyzes the actual needs of system and thus to determine the type of laser ranging sensor according to this.

General heights of vehicles are 1.5 m to 3.5 m. Suppose laser ranging sensor is installed 7 m above road surface, then the actual measuring distance of laser ranging sensor is 3.5 to 5.5 m. Suppose commonly used precision is 2.5 and error level is 2.5, then the biggest error should be 0.0875 m to 0.1375 m, thus the upper limit of error is about 10 cm. More height information of vehicles can be obtained form more height data, thus the measuring frequency should be high. However, the increase of measuring frequency will result in the reduction of laser ranging sensor's measuring precision. Therefore, measuring frequency should be determined by practical conditions. In general cases, with a certain measuring frequency, the data obtained from vehicles which are short and in high speed by laser ranging sensor are few, thus the measuring frequency should at least meet the needs of small vehicles. After comparing the practical needs, RF200-905 laser ranging sensor [8] meets the requirements.

2.3. Webcam

The webcam in the system was not only used for taking pictures as vehicles' traffic records, but also used to obtain vehicles' widths, thus the camera should have high pixels. American ArecontVision AV5105 series cameras were chosen to be webcams [9].

3. Construction of Piezoelectric Thin-Film Sensor Information Collecting Subsystem

Subsystem was designed to use single chip computer as the core and use single chip computer connected with peripheral chip as extension, which consisted of piezoelectric sensor set (three piezoelectric thin-film sensors) [10-11], signal amplification and filter, analog to digital (A/D) conversion, single chip computer central processing and level conversion, etc. Signals went into the single chip computer through A/D conversion and were analyzed by single chip computer. After transformed through level converting circuit, signals communicated with personal computer through the serial port. Figure 1 shows the block diagram of this subsystem.

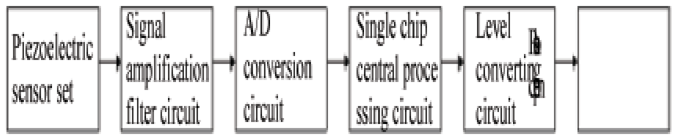

Figure 1. Block diagram of piezoelectric thin-film sensor information collecting subsystem

3.1. Signal Amplification and Filter Circuit Design

Figure 2 is the charge source actual equivalent circuit of charge amplifier. C_s refers to the natural capacitance of piezoelectric element while C_c refers to the equivalent capacitance of input cable. C_i is the input capacitance of amplifier and C_f is feedback capacitance. C_c is the leakage conductance of input cable, C_i is the input conductance of amplifier and C_f is feedback conductance.

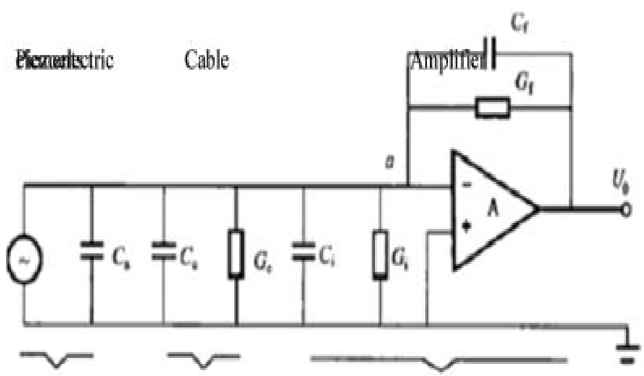

Figure 2. Charge resource actual equivalent circuit of charge amplifier

Using voltage source to replace the charge source in figure 2, then according to equivalent circuit, the following equation is obtained:

$$(e_s - U_a)\, j\omega\, C_s - U_a[G_c + G_i) + j\omega\, (C_c + C_i)\,] = (U_a - U0)\,(\,G_f + j\omega C_f) \qquad (1)$$

U_a is the voltage of a point. Because a point is a virtual point, thus:

$$U_a = \frac{-U_0}{A_d} \qquad (2)$$

Substituting U_a into equation (1):

$$U_0 = \frac{-j\omega C_s A_d e_s}{(G_f + j\omega C_f)\,(1 + A_d) + G_i + G_c + j\omega(C_c + C_i + C_s)}$$

$$= \frac{-j\omega A_d Q}{G_f(1 + A_d) + G_i + G_c + j\omega C_f(1 + A_d) + j\omega(C_c + C_i + C_s)} \qquad (3)$$

Because G_c, G_i and G_f are very small, thus:

$$U_0 = \frac{-A_d Q}{C_c + C_i + C_s + (1 + A_d)\, C_f} \qquad (4)$$

In general cases, equation (4) can be simplified as:

$$U_0 = \frac{-A_d Q}{(1 + A_d) C_f} \approx \frac{Q}{C_f} \qquad (5)$$

As shown in equation (5), the output voltage U_0 of charge amplifier is in direct proportion to electric charge Q of piezoelectric sensor and is hardly affected by cable capacitance C_c.

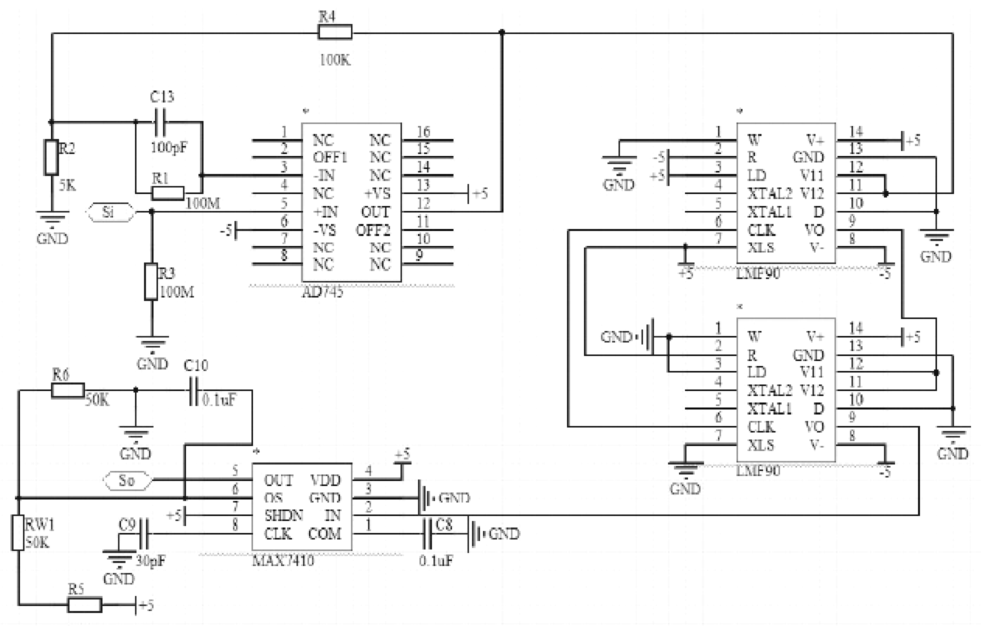

Figure 3. Schematic diagram of signal amplification and filter circuit

Figure 3 is the schematic diagram of signal amplification and filter circuit obtained after analysis and design. This circuit used AD745 amplifier of American AD company as the pre-amplification electric circuit and used LMF90 band trap of American National Semiconductor company as power frequency and frequency multiplication trap circuit, as well as used MAX7410 semiconductor integrated chip of Dallas Semiconductor company to implement the design of filter circuit. This signal amplification and filter circuit has favorable properties like high signal to noise ratio, low noise, good repeatability and stability, etc [12].

3.2. Design of A/D Conversion and Single Chip Computer Central Processing Circuit

Before designing the circuit, the types of single chip computer and A/D conversion chip should be decided. The type selection of single chip computer is critical because it is the core of piezoelectric thin-film sensor information collecting subsystem. This study integrated theories with practice, and considering that the information collecting subsystem is working outdoors every minute and every day, and there is strong interference around the road, thus the system should have strong anti-interference ability and good robustness. Besides, the system collects and manages signals in real time and communicates with upper computer through serial port, which requires the single chip computer to have high processing speed. At last, based on upper considerations, the product should be mature and reliable, thus the AT89C51 single chip computer of American ATMEL firm was selected [13-14].

Figure 4 is the connecting circuit of the chip and 51 single chip computer. The output signals of piezoelectric sensor are processed through amplification and filter as well as the conversion of A/D module, and then were processed by single chip computer. Figure 5 is the structure diagram of single chip computer processing signal information. When a car is driving into the detection zone and passing induction coil, phase locked loop can detect whether a car is passing. Figure 6 shows the structure of phase locked loop.

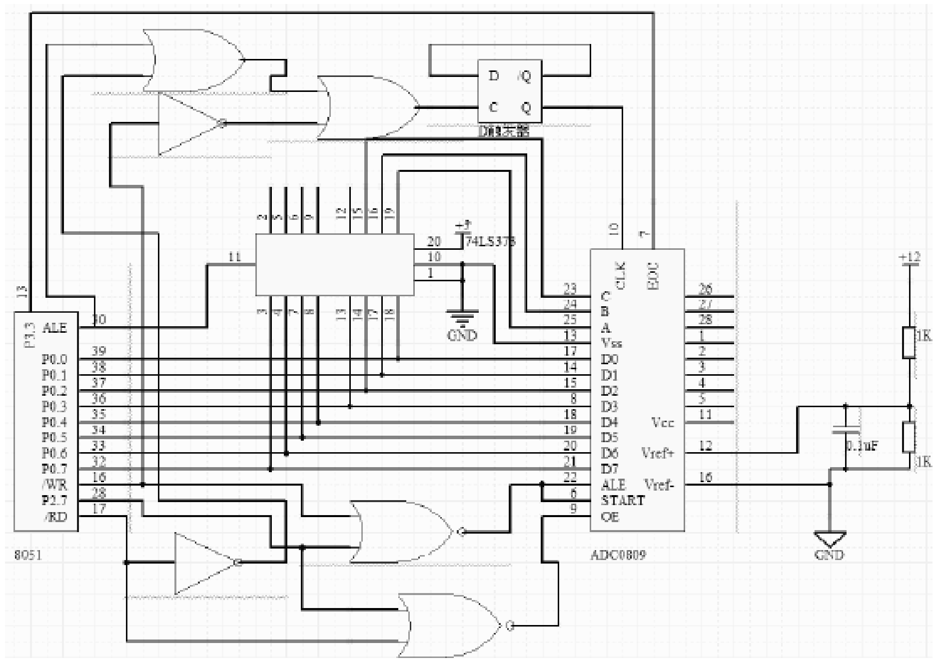

Figure 4. Sketch map of the connection of ADC0809 and 51 single chip computer

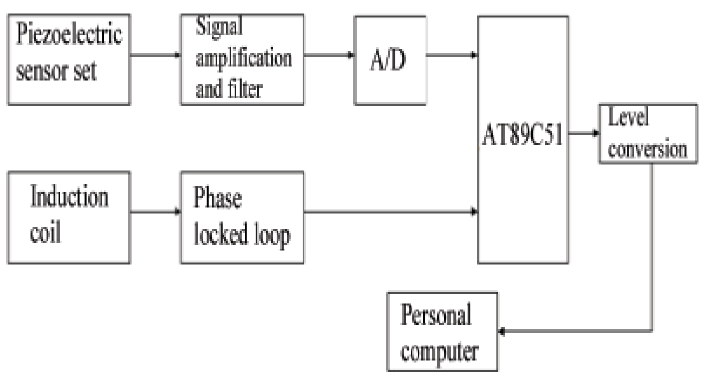

Figure 5. Structure diagram of single chip computer processing signals

In phase locked loop, LM567 chip is used to detect the change of induction coil frequency and thus detects the pass of cars. In LM567, pin 1 and 2 are usually connected with the ground through a capacitance respectively to form a single loop low-pass filtering and output filtering network. Pin 3 is input terminal and the input shouldn't be less than 25 mV. The pull-in bandwidth BW of phase locked loop is determined by the capacitance connected with pin 2.

$$BW = 1070\sqrt{\left(\frac{u_1}{f_1 C_2}\right)} \qquad (6)$$

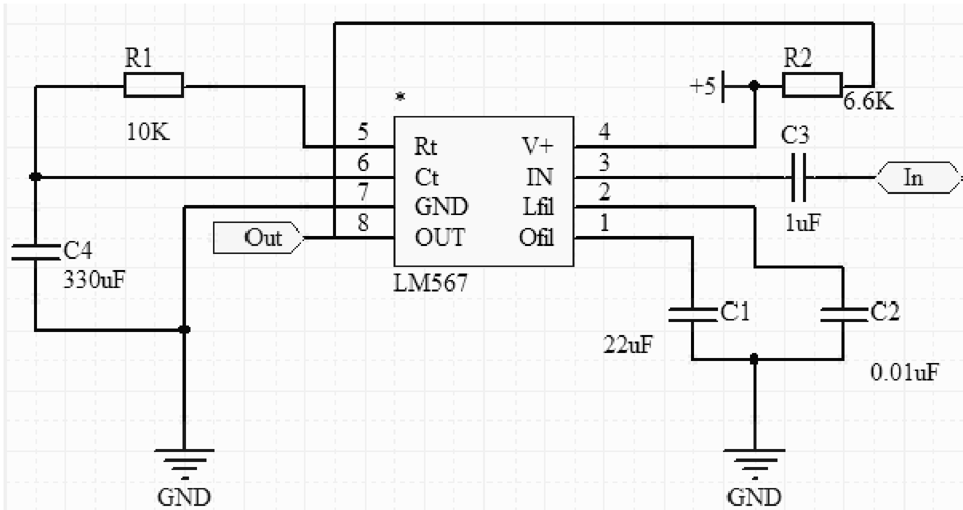

Figure 6. Sketch map of phase locked loop

u_1 refers to the virtual value of input signals, C_2 refers to filter capacitor while f_1 is the center frequency of internal voltage control oscillator, f_1 = 1/1. 1*RC*, which is determined by capacitance and electrical resistance of chip's pin 5 and pin 6. Under an appropriate pull-in bandwidth BW, when there is no car in detection zone, the oscillation frequency of circuit will be kept in transmission bands range, and the phase locked loop will lock signals and pin 8 of LM567 chip will output low level. When a car is driving pass the detection zone, the oscillation frequency will have strong changes and thus the frequency is no longer in the transmission bands range, then pin 8 output high level. Therefore, the level variation of pin 8 can trigger the external interruption of single chip computer as well as detecting the pass of cars.

3.3. Design of Level Converting Circuit

Because the electrical level of single chip computer does not match with PC, thus level conversion should be added in between the input/output (I/O) objects and ports. This study used common MAX232 chip to have level conversion. Figure 7 is the sketch map of level conversion circuit.

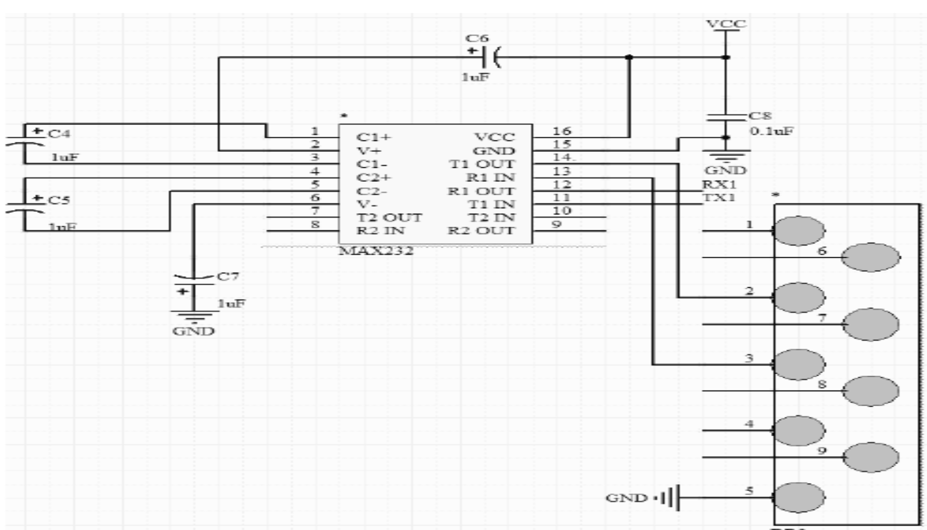

Figure 7. Sketch map of level conversion circuit

4. Construction of Laser Ranging Sensor and Webcam Information Collecting Subsystem

The information collecting subsystem in this study mainly includes two facilities, which are laser ranging sensor and webcam. The communicating structure between two facilities and industrial control computer has been shown in figure 8.

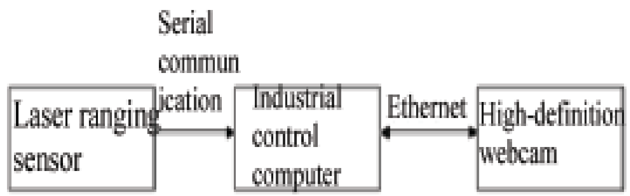

Figure 8. Diagram of communicating structure

Industrial control computer communicates with laser ranging sensor through 485 control bus and communicates with webcam through RJ45 port [15-16]. The industrial personal computer (IPC) in this study is far from the laser ranging sensor and webcam on portal frame, and RS-485 port has far transmission distance. Therefore, to insure the quality of serial communication, this system used RS-485 to have communication between industrial control computer and sensor.

When a car is passing the detection zone and is captured by induction coil, two text files will be established which are "E:\Data\Auto\1.txt" and "E:\Data\Auto\1th.txt", and thus the webcam will be triggered to take a picture. The time at that point is recorded in 1. txt and the picture is saved in "E:\Photos". The width of the car is obtained from the picture. After the car drives passing piezoelectric sensor and its driving speed and chassis information are obtained, the car will arrive under the portal frame. At that point, the output value of laser ranging sensor will become smaller compared to its installation height value, and if the output values are virtual height values of the same car, the collecting program will read the height values from serial port of laser ranging sensor and write them into 1. txt one by one until the output value becomes the installation height value again. The length of the car can be obtained from following equation (7) that based on data from 1. txt and car speed obtained from piezoelectric sensor:

$$L = vt = \frac{vn}{f} \qquad (7)$$

In the equation, n is the number of detected data, v is the car speed obtained from piezoelectric film traffic sensor, t is the time a car uses to pass the portal frame and f is the inherent measuring frequency of laser ranging sensor.

At last, the car length and car height obtained from laser ranging sensor, car width obtained from webcam and wheel base, wheel tract, number of axles and number of tires are recorded in 1th.txt.

5. Conclusion

This study discussed about the design process of vehicle information collecting system, including the design of piezoelectric thin-film sensor information collecting subsystem and the construction of webcam information collecting subsystem. First, this study selected ideal hardwares of collecting system according to engineering needs. Then the study introduced the construction of piezoelectric film sensor information collecting subsystem which mainly includes the design of signal amplification and filter, A/D conversion, single chip computer central processing and level converting circuit. At last, the study designed laser ranging sensor and webcam information collecting subsystem, which mainly introduced the communication between laser ranging sensor and webcam and industrial control computer as well as introduced the restoring process after sensor obtained data.

References

[1] Bleustein, J. L. (1968). A New Surface Wave in Piezoelectric Materials, *Applied Physics Letters* 13 (12) 412-413.

[2] Murayama, Naohiro. (1975). Persistent polarization in poly(vinylidene fluoride). I. Surface charges and piezoelectricity of poly(vinylidene fluoride) thermoelectrets. *Journal of Polymer Science* Polymer Physics Edition. 13 (5) 929–946.

[3] Matsushige, K., Takemura, T. (1983). Crystal Transformation, Piezoelectricity, and Ferroelectric Polarization Reversal in Poly(Vinylidene Fluoride)// Structure-Property Relationships of Polymeric Solids. Springer US. 115-137.

[4] Niezrecki, C., Cudney, H H. (1994). Improving the power consumption characteristics of piezoelectric actuators. *Journal of Intelligent Material Systems & Structures*. 5 (4) 522-529.

[5] Ueberschlag, P. (2001). PVDF Piezoelectric Polymer. *Sensor Review*, 21 (2) 118-126.

[6] Kanda, K. (2012). Influence of Parasitic Capacitance on Output Voltage for Series-Connected Thin-Film Piezoelectric Devices. Sensors.12 (12) 16673-16684.

[7] Zhao, L B., Liang, J Q., Zhao, Y. L. (2011). Analysis and Research of Piezoelectric Dynamic Weighing Sensor. Key Engineering Materials. 483. 643-646.

[8] Xian, Y., Tang, Z., Li., B. (2014). Application of TDC-GP2 in Laser Range Sensor// Future Information Technology. Springer Berlin Heidelberg. 325-330.

[9] Mclaughlin, P. (2012). Editor's Picks, *Cabling Installation & Maintenance*. 53 (5) 3-5.

[10] Lou, L. (2006). The Vibrational Modal Analysis of Piezoeelectric Thin Film Microsensor, *Journal of Vibration & Shock*. 25 (4) 165-169.

[11] Wang, Y. Q M. (2006). Transient response of piezoelectric thin-film vibration sensor under pulse excitation, *Journal of Applied Physics*. 99 (1) 14107-14111.

[12] Guo, Z., Huang, Y., Li, L. (2011). Research and design preamplifier circuit of atmospheric electric field meter/ Lightning (APL), *In*: 2011 7th Asia-Pacific International Conference on. IEEE. 2011. 504-507.

[13] Prajapati, R C., Shrestha, C L., Chhetri, B B. (2007). Noise Measurement in Low-Voltage Powerline for Modem Design and Serial Dataacquisition// Information and Communication Technology, *In*: ICICT '07. International Conference on. IEEE. 2007 113-116.

[14] Guo W T. (2010). The Design of Stepper Motor Control System Based on THB6064H and MCU. Microcomputer Information. 26 (8) 105-107.

[15] Yeh, Y L., Jang, M J., Shen, C H. (2010). The measurement of the methanol concentration of liquid solution based on laser interferometer// Computer Communication Control and Automation (3CA), *In*: International Symposium on. IEEE. 2010. 302-305.

[16] Haselich, M., Bing, R., Paulus, D. (2012). Calibration of multiple cameras to a 3D laser range finder/ Emerging Signal Processing Applications (ESPA), *In*: IEEE International Conference on. IEEE. 2012 25 - 28.