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Application and induction properties of novel piezoelectric thin film material in the Wushu electronic gear

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Abstract. With the continuous evolution of Wushu competition and the implementation of the new rules, the Wushu martial arts equipment is no longer the pure armor, but an electronic body protect having the protective function to achieve intelligent identification of hitting, automatic scoring, display of strength value and other functions. By studying the advantages and disadvantages of martial arts electronic gear at present, we designed and produced a kind of E-Touch based piezoelectric thin film used embedded in the gear, without disturbance and anti-interference. We can make it into different kinds of universal sensor used in Wushu competition, and prepare for the following calculation of force size, duration, and force frequency, by taking the voltage follower with fast response and good following feature as the calibration result for the conditioning circuit. After the test, the martial arts electronic gear studied in this paper has rapid response, low power consumption, and low cost, meeting the application requirements, suitable for popularization in China Wushu team.

Key words. Electronic protector, piezoelectric film, martial arts.

1. Introduction

The electronic gear, from the beginning of development by Taishan Daedo and Lajust company, has been concerned and disputed. In recent decades, the Wushu electronic gear has been rapidly developed because the response is sensitive, it can determine the force source, and its disturbance is small, even up on the stage of the competition. But due to the rules of the game, the size and different gear using force sensor, non-contact induction chip and the ID chip of recognizing the action, the Wushu electronic gear sometimes take a long time to contact and sometimes can easily get the score by getting close to each other. As a result, the penalties of competition was sometimes questioned by the athletes, and the training difficulty greatly increased [1].

Similarly as the core components of the electronic gear, the acting force, anti-

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interference, service life and further problems directly affect the usage and development of the gear [2]. Aiming at the above problems and the impact of the electronic gear on the competition events, we designed a new replaceable force sensor E-Touch based on piezoelectric thin film without disturbance and anti-interference. There are many flat hole structures in the E-Touch piezoelectric films, and there are permanent positive and negative charges stored in these holes. When the piezoelectric film is subjected to dynamic stress, the thickness changes and produces the corresponding charge, and these charges accumulate in the electrode film, resulting in a charge [3] corresponding to the size of the force. Combined with the conditioning circuit, through the output waveform, we measure the force and the force time, calculate the force frequency, and determine the position of the force by the different parallel network areas. At the same time, according to the needs of different competition event gears, using requirements of athletes in different genders and levels of corresponding protective events, we produced force sensors that met different sizes and stress ranges of event requirements.

2. Methods

2.1. 2.1 System overall design

Wushu, as a competitive sport, the regulations of venue have been relatively perfect. Wushu competition venues are slightly different with the different projects, generally no-obstacle level with 14 meters in length and 8 meters in width, built on the platform with the height of 50 to 60 centimeters according to the needs [4]. Since that the physical fitness of different athletes is different, the gears will bear tens to hundreds of kilograms of power. At the same time, considering the sweat of athletes, the electronic gears need to be installed safely and reliably, and set some waterproof measures or have the function of working under a certain humidity [5].

According to the application features and function requirements of Wushu electronic gears, the whole system is composed of MSP430F149 microcontroller as the core processing chip, piezoelectric film sensor, charge amplifier circuit and wireless transmission module Bluetooth 4.0. Figure 1 shows the schematic diagram of the system.

In the gear part, we use the lightweight plastic of new piezoelectric thin film, design large-area thin film pressure plate to fully cover the effective part of gears, and then fill in the proper polyurethane high resilience foam to ensure the anti-resistance of piezoelectric film for being stricken. At the same time, we realize the basic functions of gears, and make use of piezoelectric features of piezoelectric sensor to output different amounts of charges for the hitting in different intensities. After suitable amplification of the charge amplifier, the current signal is transformed into a voltage signal convenient for monitoring.

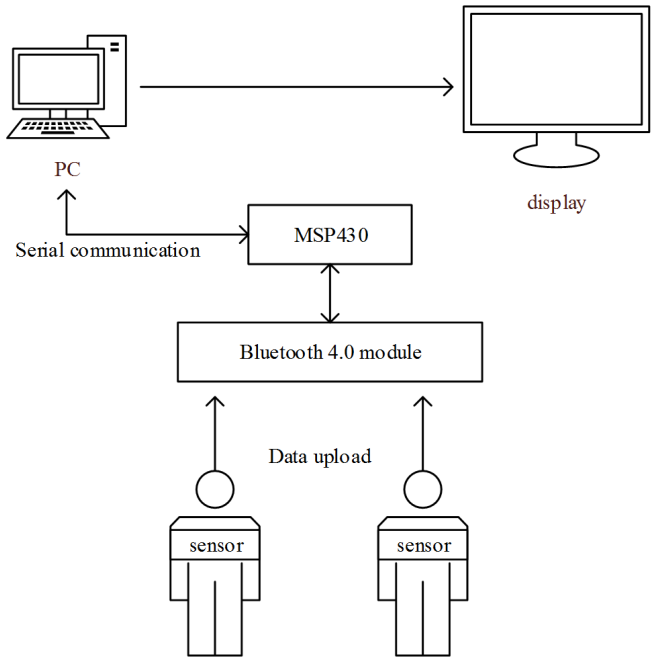

Fig. 1. Schematic diagram of the system

2.2. System hardware design

In sports, there is not much room for choice because it is complex and irregular and it cannot be monitored. In general, there are h kinds of sensors for measuring the force, resistance, capacitance and piezoelectricity. In general, the resistance is in block form, greatly affected by environmental conditions; the capacitive sensor structure has high requirements, not suitable for large area sensors, generally in cylindrical probe shape; and the acquisition of a capacitor and a resistor type sensor belongs to static acquisition, low in working frequency, and not timely in the response. The piezoelectric sensor was characterized by its high bandwidth, high sensitivity, high signal-to-noise ratio, simple structure, and light weight. The early piezoelectric materials were piezoelectric single crystals and common piezoelectric ceramics. In recent years, polyvinylidene fluoride (PVDF), as a new type of polymer piezoelectric material, has been widely used.

E-Touch piezoelectric thin film is a new organic film with patented technology, which was launched in October 2011 by Shanghai Mstar Technology Ltd. The widest application of E-Touch piezoelectric film is the sensor. In the field of sensor applications, it is necessary to package the piezoelectric film so as to protect it. The E-Touch-SS sensor consists of a E-Touch piezoelectric film, an upper and a lower electrode, a protective layer film or a shielding layer. In order to ensure the high sensitivity, it has the characteristics of good flexibility, waterproof, anti-wearing,

resistance and so on.

In the good arrangement of packaged sensors, the output signal is the charge of a small charge or voltage, cannot be directly accessed to the system. As a result, in the sensor and the system processor, it also needs to design a charge amplifier circuit, and to amplify the change of a small charge and voltage to the great voltage output that is easily recognized by the system. The basic principle of the charge amplifier is shown in Fig. 2.

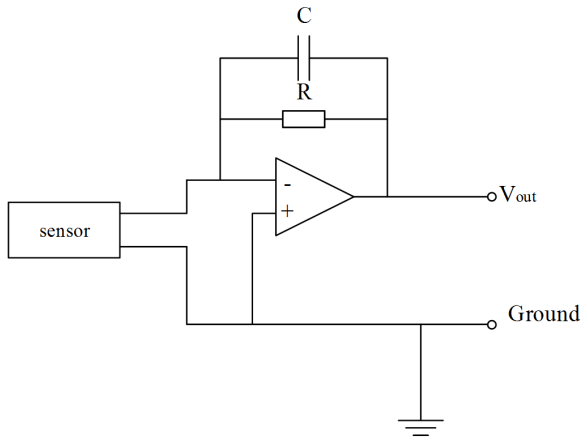

Fig. 2. Basic principle of charge amplification

The output value of the charge amplifier is determined by the piezoelectric charge coefficient and the capacitance of the sensor. The output frequency is determined by the ratio of capacitance and resistance of the RC circuit. When the frequency is greater than $(1/2\pi) \times R \times C$, the amplifier output voltage can be approximated as

$$V_{\mathrm{p}} = \frac{1}{C} \times d \times F_{\mathrm{p}} \tag{1}$$

In (1), F_{p} is the vertical force applied to the sensor surface.

2.3. System software design

The design selects the Bluetooth module BTMO608C2X following the Bluetooth 4 standard launched by Chongqing Jinli Science and Technology Development Co., Ltd. The module uses CSR8760 as the master chip, with built-in Bluetooth 4 driver, and down compatible the Bluetooth protocol of the first few versions.

Not stricken, the sensors that the system read are the stable voltage value with small amplitude clutters. When the strike occurs, the output voltage value began to rise until the hitting energy all transformed into the sensor material deformation. When the voltage value reaches the maximum value, then the combat force with draws, and the elastic material springs back, starting the reverse pull sensor and making the voltage decrease. At the same time, the piezoelectric material began

to conduct reverse electricity effect, and release the excess charge, so the voltage continues to decline, and gradually reduces the amplitude and tends to the initial state. In the process of the electronic gear utilization, the flow charts of PC terminal and gear terminal are shown in Figs. 3 and 4.

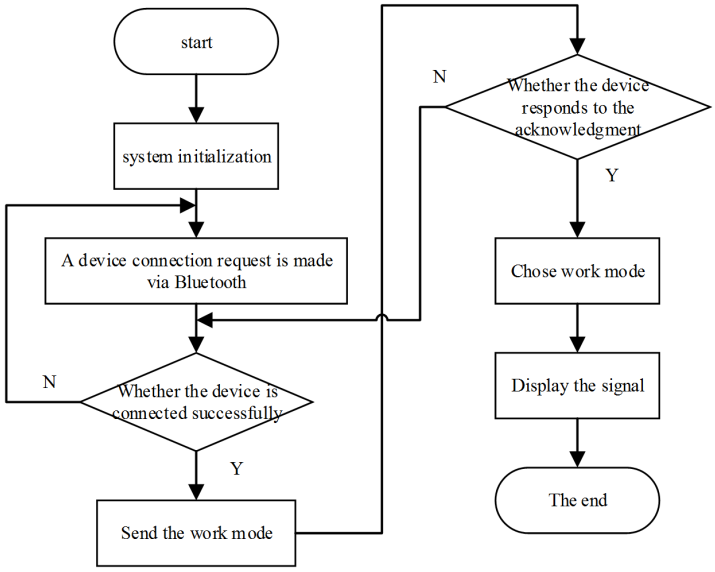

Fig. 3. Flow chart of PC terminal

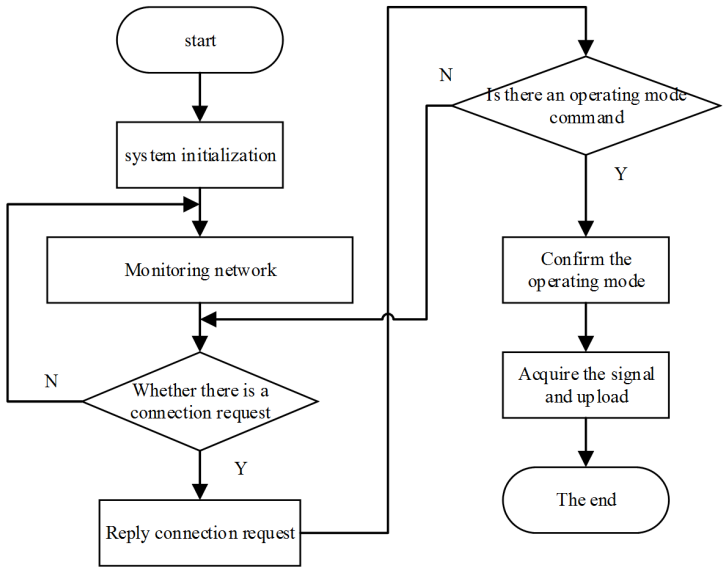

Fig. 4. Flow chart of gear terminal

3. Results and discussion

In the Wushu and other fighting projects the athletes get the score by hitting the effective region of each other. This paper argues that the strike effect should be determined by the change of momentum, that is, impulse. This design adopts the way of "rock fall" for impulse calibration. The specific method is to place a ball with the mass of m at a certain height of h, to allow it to fall freely and hit the packaged sensor placed horizontally on the ground. At the same time, the output voltage curve of the sensor is monitored in real time by oscilloscope, and the maximum voltage value and the strike time t in the strike process are read.

For heavy objects, before the collision, the gravitational potential energy is transformed to the kinetic energy. And then, according to the theorem of momentum, we can calculate the average momentum. The theoretical value of impulse is obtained by calculation, and the experimental data ($g = 10\,\mathrm{m/s^2}$) is obtained by reading the voltage variation through the oscilloscope. The most important data are listed in Table 1.

Table 1. Drop hammer realization data

Weight (g)	Height (cm)	Impulse (Ns)	Crash time (ms)	Maximum voltage (V)
500	10	0.707	38	0.82
500	20	1.000	74	1.20
500	30	1.225	74	1.46
500	40	1.414	67	1.72
500	50	1.581	65	1.88
1000	10	1.414	72	1.79
1000	20	2.000	64	2.16
1000	30	2.449	68	2.23
1000	40	2.828	72	2.34
1000	50	3.162	60	2.58

Compared with the experimental data, it is found that there is a clear relationship between the impulse theory value and the measured maximum voltage value. The relationship between the maximum voltage and impulse is shown in Fig. 5.

The experimental data showed that there is a good linear relationship between the maximum voltage and the impulse, and the ratio is relatively determined, relative to 1.1. In the program design, the voltage can be read directly through the impulse by a certain proportion of the sensor, and it can be used as the general strike effect characterization to effectively distinguish the strength of the strike.

3.1. System power consumption test

Through the tests of experiments for several times, the general strike action from contact to each other to discharge lasted in milliseconds. The power consumption contrast between Group A without adding low power consumption program implementation function and Group B with the design and writing of low power function

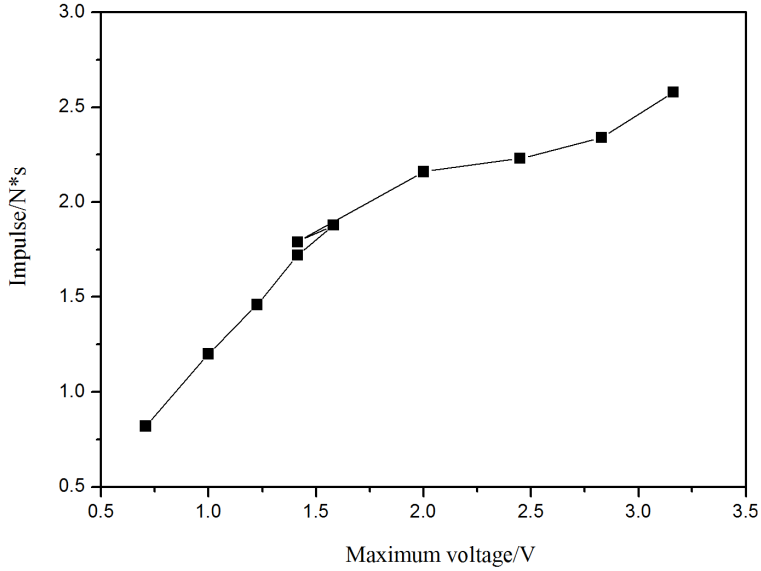

Fig. 5. Relationship between the maximum voltage and impulse

implementation code is shown in Table 2.

Table 2. System power consumption application

	Group A system	Group B system
Test duration	About three hours	More than 18 hours
Test results	Test accuracy without omission	A few omissions
System anomaly	Bluetooth module with serious burning	Good, no obvious abnormality

3.2. Cost calculation

This system only completed a set of functional prototypes, which does not involve the final product appearance and so on design costs. In the materials acquisition process, the main cost comes from the piezoelectric film. This design uses the gears in the middle level. Two sets of gears are purchased, and the price is 600 yuan in total. Electronic components, modules and related supplies are not more than 30 yuan per unit price, but generally needed to be purchased in bulk. For instance, the unit price of the resistance is a few cents, generally sold from 200–300. Currently, in the industry, a single plate with PCB opening below 100 mm×100 mm area is not more than 100 yuan. In the specific design, the system board opening is 60 yuan for 10 sets, and later, 5 yuan for one; charge amplifier circuit opening is 10 yuan for 10 sets, and later, 3 yuan for a piece. Based on the above situations, and compared the price of the electronic gears in the market, it is seen that the material cost of electronic gears in this design is relatively low. The main expenses

incurred during the development phase where different instrumentation is needed for repeatedly debugging, and finally specific equipment is needed for testing and calibration of the system. For example, heavy bond testing machine, the market price of a set of equipment is about fifty thousand. According to the estimation of some Wushu professionals, the demand of national Wushu electronic gear is about 100 sets per year. If the design can at last achieve mass production, after considering the premise investment, production costs and profits, the price is still lower than 70 % of the price of similar foreign products.

4. Conclusion

The research takes the electronic gear product realization as the ultimate goal. We completed the intelligent identification of strike effective value in Wushu movements, realized the scoring function of electronic gears used in the competition, and quantitative monitored Wushu specialized strike ability training. These preparations provide the theoretical basis for independent research and development of electronic gears used in Wushu competition. The purpose is to complete the autonomous design of electronic gear as soon as possible and the replacing of the existing foreign electronic gear products. In this way, unnecessary funds and energy investment for Chinese Wushu team to adapt to foreign products can be reduced, and the popularity of electronic gears can be further promoted.

References

[1] A. Khan, Z. Abas, H. S. Kim, I. K. Oh: *Piezoelectric thin films: An integrated review of transducers and energy harvesting.* Smart Materials and Structures *25* (2016), No. 5, 053002.

[2] J. Kim, H. Jung, M. Kang, K. Chung: *3D Human-gesture interface for fighting games using motion recognition sensor.* Wireless Personal Communications *89* (2016), No. 3, 927–940.

[3] M. A. Fraga, H. Furlan, R. S. Pessoa, M. Massi: *Wide bandgap semiconductor thin films for piezoelectric and piezoresistive MEMS sensors applied at high temperatures: An overview.* Microsystem Technologies *20* (2014), No. 1, 9–21.

[4] B. A. Griffin, M. D. Williams, G. Wang, B. V. Sankar, L. N. Cattafesta, M. Sheplak: *The electromechanical behavior of piezoelectric thin film composite diaphragms possessing in-plane stresses.* Journal of Micromechanics and Microengineering *27* (2017), No. 4, 045017.

[5] V. Ostaševičius, I. Milašauskaité, R. Daukševičius, V. Baltrušaitis, V. Grigaliunas, I. Prosyčevas: *Experimental characterization of material structure of piezoelectric PVDF polymer.* Mechanics *86* (2010), No. 6, 78–82.

[6] K. Shimizu, H. Hojo, Y. Ikuhara, M. Azuma: *Piezoelectric materials: Enhanced piezoelectric response due to polarization rotation in cobalt-substituted BiFeO3 epitaxial thin films.* Advanced Materials *28* (2016), No. 39, 8639–8644.

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