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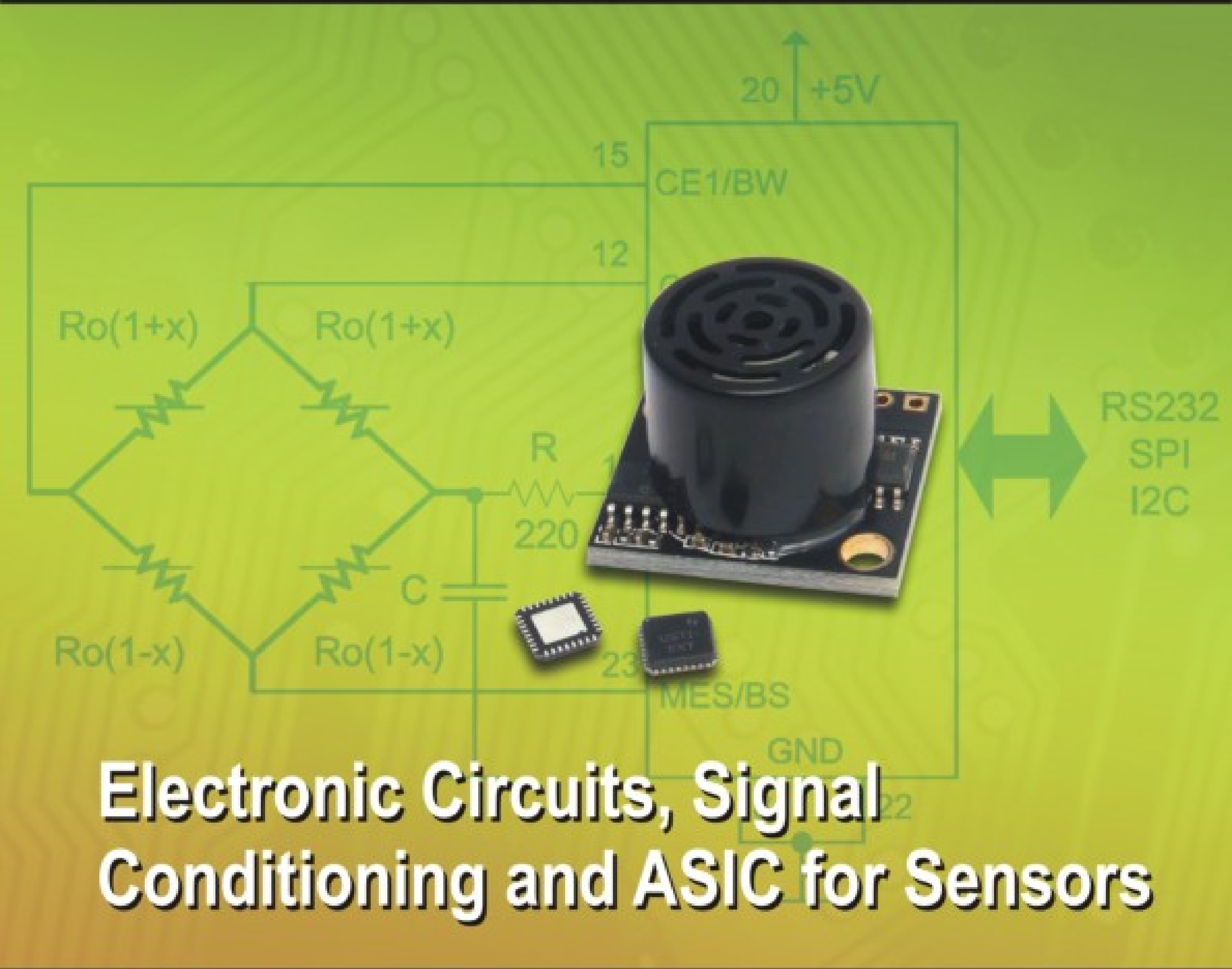

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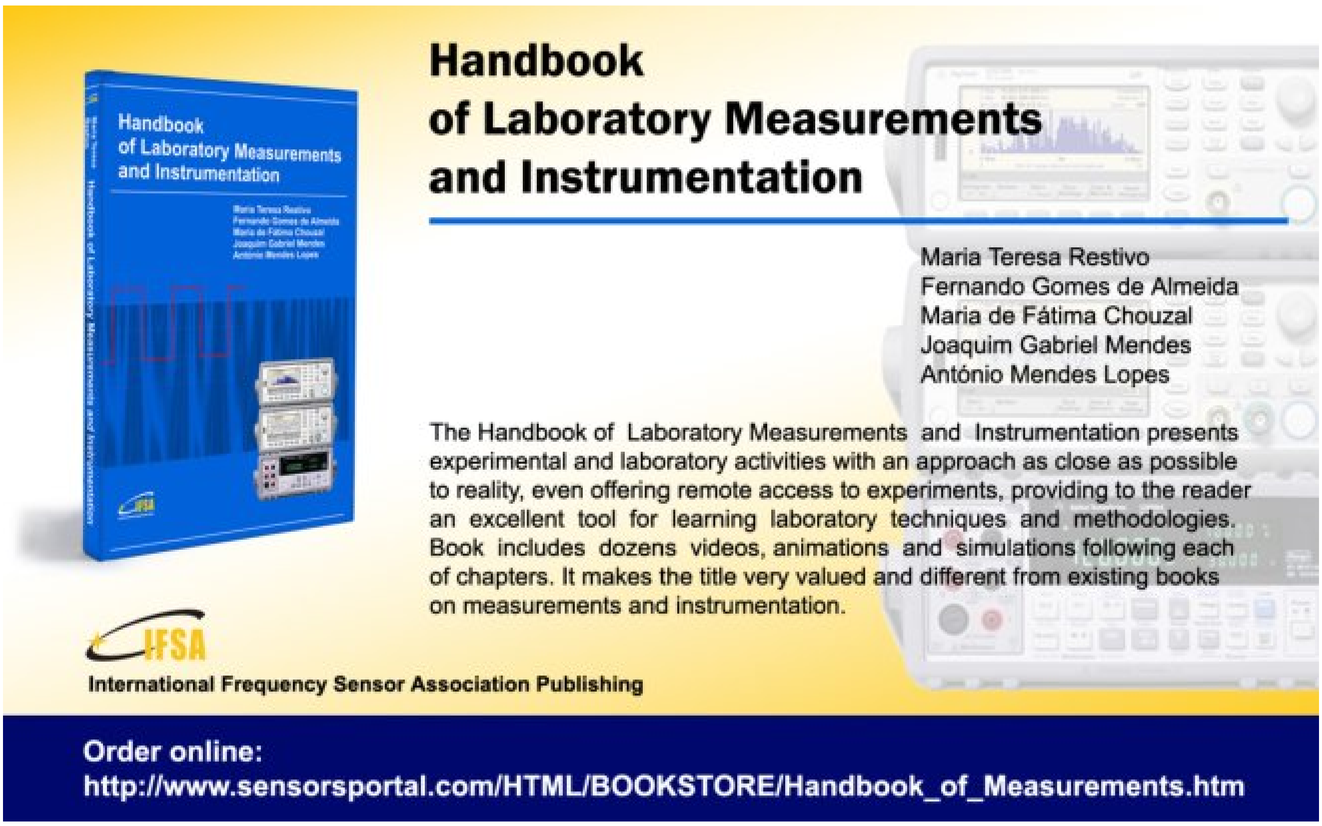

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The Design of a New Instrument for Pen-contact Force Information Acquisition During Handwriting

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Abstract: This paper describes a design and implementation of a new force-based instrument for the measurement of pen-contact force information. The instrument has the ability to detect 3-D forces and 2-D torques of writing force. Additionally, other handwriting information can be got through a special structure simultaneously. The condition design of the instrument is described for obtaining the force signals accurately, and the calibration is also discussed by applying a neural network algorithm. The experiments are carried out to validate the rationality and feasibility of the instrument to the potential applications. *Copyright © 2012 IFSA.*

Keywords: Pen-contact force, Handwriting, Visual feedback, Human computer interface.

1. Introduction

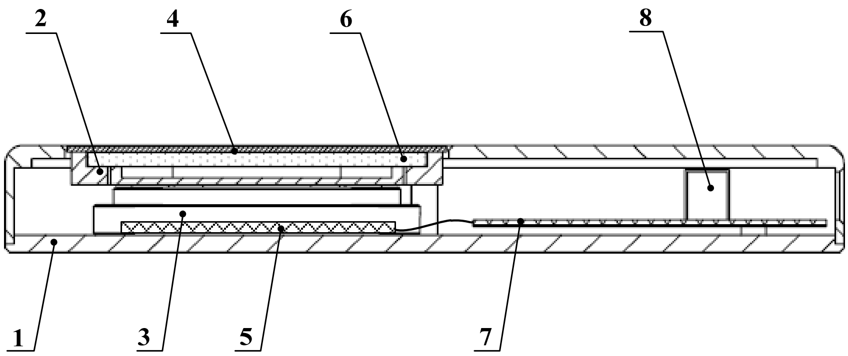
Pen-contact force information produced by pen movements while one is writing or signing provide useful information for handwriting research, particularly for applications like automatic signature verification[1-3]. Additionally, it is also important to improve the human computer interface in the field of haptic interaction and so on [4, 5].

Measurement of pen-contact forces is usually done with different types of sensors integrated into a pen or a tablet. At present, various systems for detecting pen-contact forces, such as use of strain gauges[6] or magnetoelastic sensors[7] or angle sensor[8], and combination of 1-D force sensors[9, 10], have been developed. Although most designed devices based on the above methods can capture the 3-D handwriting forces, the structures of these devices are complicated. For example, the weakness of the force-based pen [10] using a combination of five 1-D force sensors to detect the 3-D pen-contact force information, lies in the fact that the complex structure design speeds more time on computing which results in a poor real-time performance. On the other hand, most of these devices cannot work independently, but need external equipment to complete the pen-contact information acquisition.

In the present study, we propose a new instrument for pen-contact force information acquisition. The instrument can detect 3-D force and 2-D torque, and other pen-contact information such as trajectory, velocities, accelerations, and slants can be got simultaneously. Particularly, computing module and display module are added into the instrument to realize a stand-alone device and visual feedback for a natural human-computer interaction.

2. Instrumentation

The configuration of the F-Pad is shown by (Fig. 1).The instrument is based on the resultant force/torque balance method. A force sensor is countersunk into the cuboid box (1) to capture writing forces. A rigid adapter plate (2) is assembled between the sensor (3) and full-color liquid display (6) by four 5 mm-diameter nuts on the diagonal of the sensor, which ensure the consistency of the coordinate system. A pen-contact plate (4) is mounted on the top of the full-color liquid display. The conditioning circuit (5) and the digital processing circuit (7) are designed to complete analog sensor signals and digital sensor signals processing respectively. As a result, there attachments make the instrument simplified and more compact.



(a) Assembly photograph.

(b) Physical photograph.

Fig. 1. Internal view of the instrument.

The force sensor which can sense the five-dimension pen-contact forces is provided with a calibrated matrix calculated from a set of loading scenarios designed to cover the entire five-axis calibration range. The pen-contact forces are detected as follows: The forces resulting from handwriting on paper are transferred through the rigid adapter plate and captured in three perpendicular directions *o-xyz* by stain gauges which are placed to the cross beam of the sensor. We use metal strain gauges integrated in a full-bridge circuit. Their output signals are conditioned by a low pass filter and a single supply instrumentation amplifier providing signals in a dynamic voltage range of 4 V with sensitivity of about 0.2 V/Newton. The linear signals from the force sensor are digitized with a 14 bit A/D converter at a sampling frequency of 200 Hz.

3. Condition Design

The signals conditioning design is responsible for performing any required conditioning of the analog input signals to achieve digitizing and computing. The output of the condition is a stream of digitized data that can then be processed numerically by the digital process module.

Results from our research shows that the maxim pen-contact force during handwriting is about 5 N, so the instrument is designed to measure forces between 0~25 N (50 N in Fz for the strongest signers), and the system resonance frequency is 160 Hz (for capturing the dynamic handwriting signal without distortion).

The purpose of the conditioning design is to provide digitized force signals which are representative of the handwriting produced by pen movements. To achieve this, the conditioning design has to extract useful signals from the force sensor output signals that correspond to hand-pen movements while ignoring irrelevant signals.

3.1. Amplify

The raw analog signals from the force sensor are weak. The amplitude of the output voltage from the Wheatstone bridges is approximately 0.8~1.2 mV under full loading, which will be prone to be interfered by noise signals. Therefore, conditioning circuit is designed to amplify the weak signals so that the valuable signals are able to be extracted and processed subsequently.

Noise signals always generate in common-mode signals. In order to reduce the noise interference, the differential-mode signals are adopted as shown in Fig. 2. When the bridge circuit is out of balance, the differential value between IN+ and IN- respects the pen-contact force amplitude. A1 and A2 together constitute the differential amplifier for amplifying the differential value. The output of the amplified values can be expressed as:

$$V_o = (V_{IN+} - V_{IN-}) * G + V_{ref}, \tag{1}$$

where V*ref* is the reference voltage of the differential amplifier. And G is the gain which can be calculated as following:

$$G = (5 + \frac{200K\Omega}{R_o}), \tag{2}$$

where R_0 is the external gain resistance value with range of 20 Ω~ 40 kΩ. In order to guarantee the linearity of amplification, the selection value of R_O should make G value range from 1000 to 4000. In addition, the resistance accuracy and temperature drift coefficient of R_O itself will affect the stability of G. It is necessary to determine the Ro value selection according to the actual accuracy requirement of the system application.

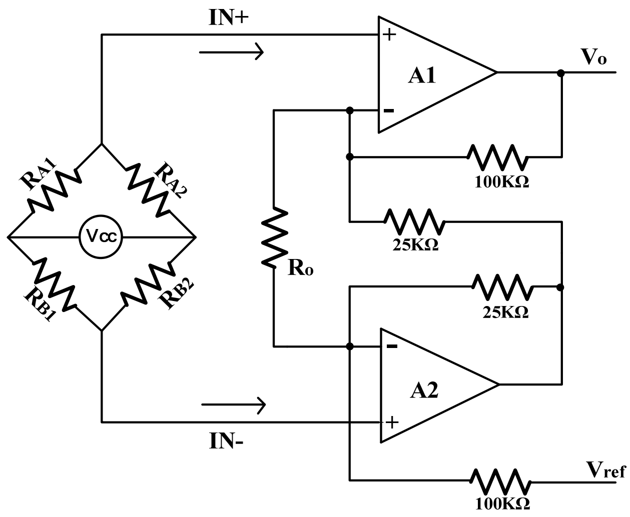


Fig. 2. Schematic of amplify circuit

3.2. Digital

The main task of the digital processing is to converter analog signals to digital signals so as to achieve digital transmission after amplifying. Therefore, an ADC component is adopted to ensure the accuracy of signal conversion. A 14-bit converter is required to gain a high resolution (0.125 mV LSB) to meet the quantization requirement for all signers with the instrument.

The structure of digital processing circuit is shown in Fig. 3. When SW2 is closed and SW1 is in Position A, the ADC starts an acquisition phase and the comparator is held in a balanced condition and the sampling capacitor acquires the signal on AIN. When the ADC starts a conversion, SW2 will open and SW1 will move to Position B causing the comparator to become unbalanced. The control logic and the charge redistribution DAC are used to add and subtract fixed amounts of charge from the sampling capacitor to bring the comparator back into a balanced condition. When the comparator is rebalanced, the conversion is complete. The control logic generates the ADC output code.

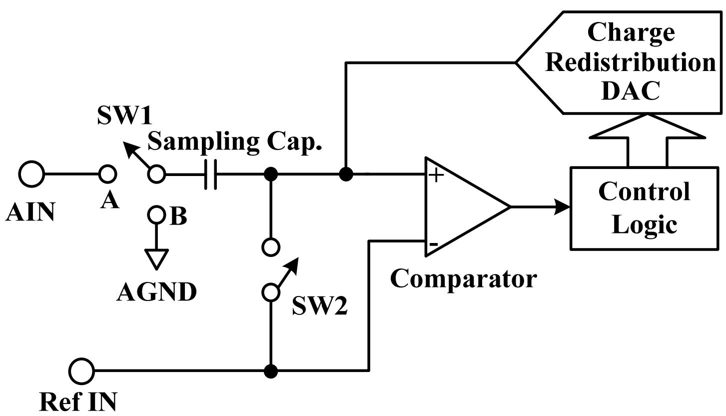
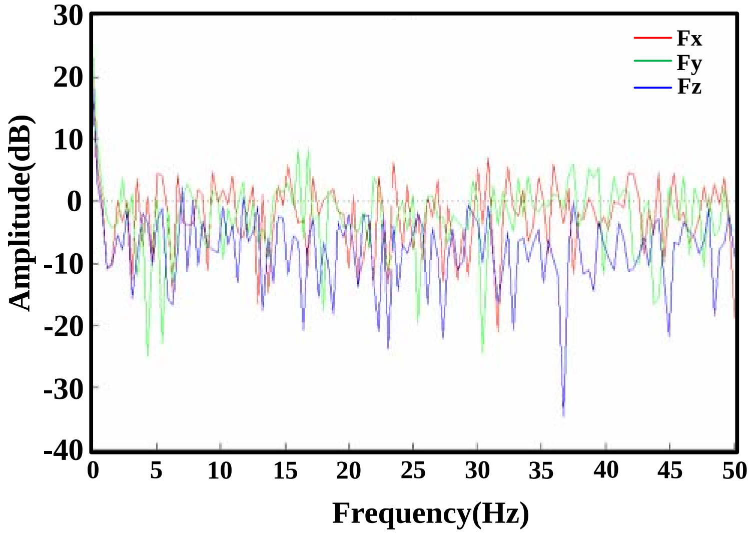


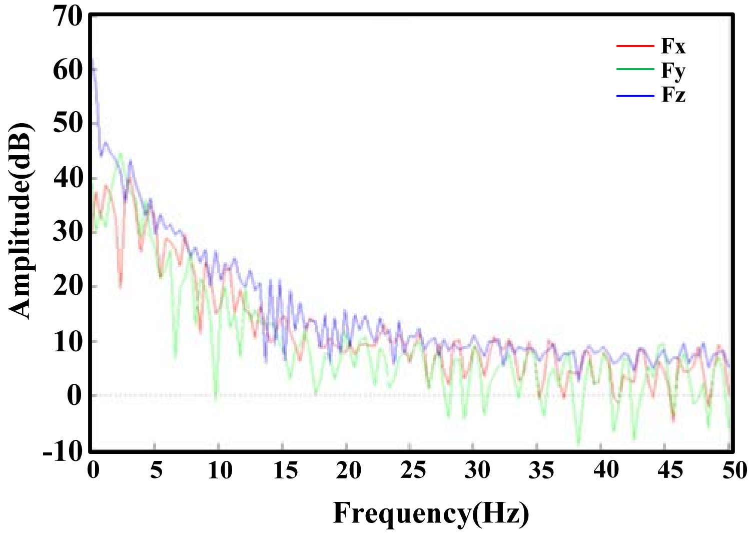
Fig. 3. Schematic of digital processing.

3.3. Filter

Upper frequency limit of human handwriting is 20 Hz [11], so the captured signals should be filtered out larger than 20 Hz. Due to the digital quantization error, there may have a deviation between the actual signal value and the theoretical value. As a result, the spectrum analysis is done on force signals and noise signals which are shown in Fig. 4.



(a) Noise signals spectrum.



(b) Force signals spectrum.

Fig. 4. The captured signals spectrum.

The noise signals shown in Fig. 4 (a) is a kind of white noise and distributes evenly in the whole frequency domain, while the force signals shown in Fig. 4 (b) is a low frequency and distributes between 0 Hz up to 40 Hz approximately. So, it is apparent that we should filter out the signals frequency larger than 40 Hz. A FIR low-pass digital filter is applied to achieve the above function, which the amplitude-frequency characteristics and phase-frequency characteristic curves are shown in Fig. 5.

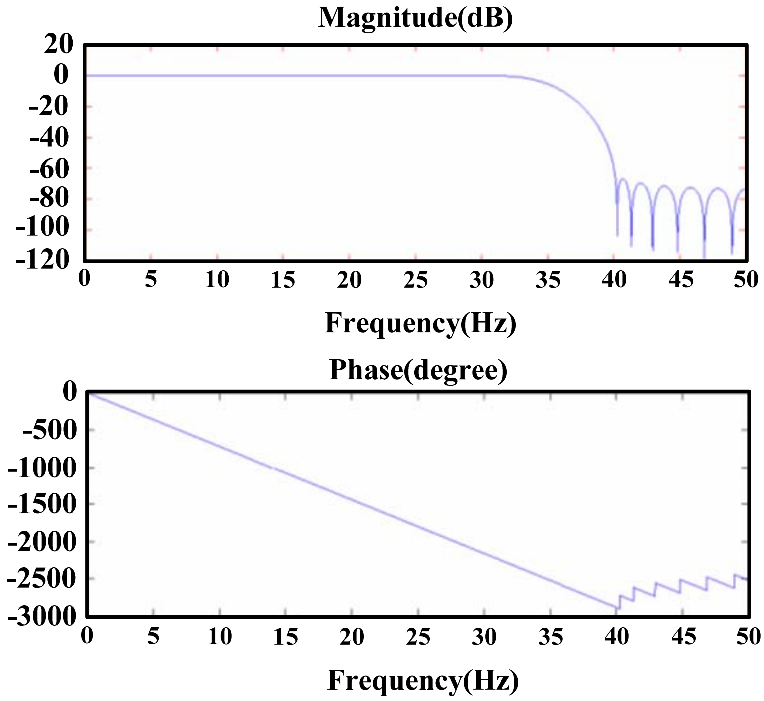


Fig. 5. The characteristic curves of the designed FIR.

4. Calibration

The force sensor integrated in the instrument can detect the 3-D forces and 2-D torques of pen-contact force information, which is developed using piezoresistive strain method. In order to acquire the force information accurately, the outputs of the force sensor must be calibrated.

4.1. Calibration Platform

The calibration platform for the sensor presented above is designed. It consists of five parts: sensor platform, rotary surface, loading cap, high-precision weights and angle regulator (Fig. 6).

In the calibration process, the force sensor is fixed on the sensor platform and the sensor platform is then mounted on the rotary surface. The loading caps are assembled to the force sensor rigidly, and the high-precision weights as the reference loading material are exerted to the force sensor via the loading caps. The *XY*-directional calibration of the force sensor is processed by adjusting the angle of the rotary surface though the angle regulator.

4.2. Calibration Method

Recently, many researchers realize sensor's calibration and nonlinear error's emendation using Neural Network [12]. In this paper, A kind of common multilayer feedforward ANN-backpropagation network (BP) is adopted to estimate measurement errors. Two BP networks were trained for estimating error. The networks have one hidden layer. Levenberg-Marquardt algorithm is used to calculate weight and offset, while sigmoid function and pureline function are chosen as transfer function of the hidden layer and transfer function of output layer respectively.

Fig. 6. Calibration platform.

5. Experiments

In order to critically evaluate the instrument features, several experiments are carried out in the lab.

5.1. Characteristic Test

Firstly, a verification experiment is done after calibration of the force sensor, which can determine the effectiveness of the calibration method. Fig. 7 shows the test result, and Table 1 gives the characteristic indexes of the instrument on the measurement of pen-contact force information after the experiment.

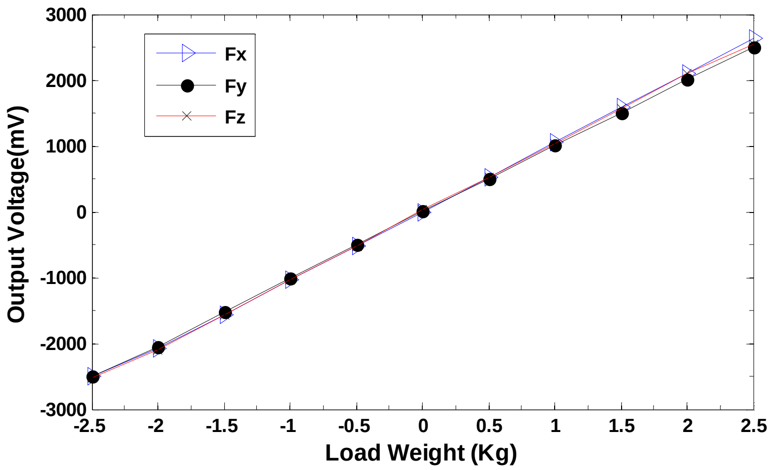


Fig. 7. Verification results.

Table 1. The characteristic indexes of the instrument.

Indexes	Fx	Fy	Fz	Mx	My
Sensitivity (N, N*m)	0.1	0.1	0.1	0.003	0.003
Nonlinearity (FS %)	0.07	0.06	0.05	0.13	0.21
Precision (FS %)	0.01	0.01	0.01	0.02	0.02
Stability errors (FS %)	0.05	0.05	0.05	0.05	0.05
Non-repeatability errors (FS %)	0.02	0.02	0.02	0.03	0.03

Fig. 7 shows the verification results for the 3-D forces (labeled as Fx, Fy, Fz) respectively. The horizontal axes of the graphs show the loading reference forces, while the vertical axes show the detected writing forces. The negative values indicate the case in which the force is applied in the negative direction. As we can see, the curves are almost linear which also illustrates the adopted BP method is feasible. Additionally, the characteristic indexed of the instrument is shown in Table 1 under repeated loading test experiments.

5.2. Forces Measurement

The primary feature of the instrument is that it can detect the pen-contact force information, including 3-D forces and 2-D torques. An experiment in which Chinese characters are written is performed. Any pen-like object can be used to writing and Fig. 8 shows an example of the obtained pen-contact force pattern when writing Chinese character "仲".

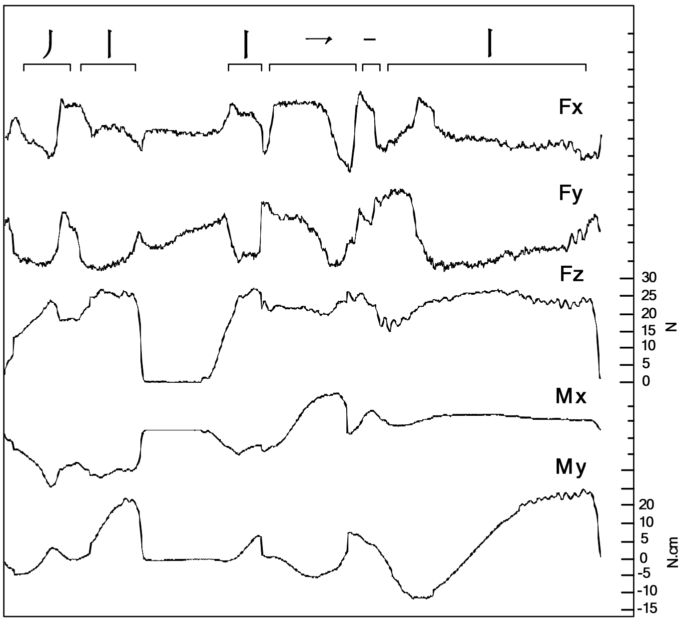


Fig. 8. Force outputs when writing the Chinese character "仲"

According to the Fig. 8, we can see that the instrument can get all pen-contact force information (Fx, Fy, Fz, Mx, My).

5.3. Other Information Measurements

Besides the obtained force information, the instrument can also get other further information during handwriting such as trajectories, velocities, accelerations and so on. Particularly, all these information are calculated and the writing results are displayed directly.

The coordinate of the instrument is illustrated in (Fig. 9). Suppose that a pen is writing at point P(x, y), the forces (i.e. Fx(ti), Fy(ti), Fz(ti), Mx(ti), My(ti)) is measured directly which are all functions of time ti. Then, the coordinates of the point P can be calculated as follows.

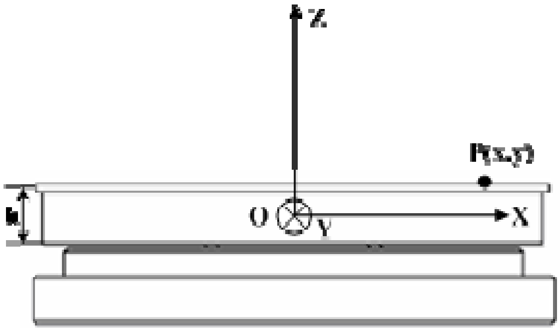


Fig. 9. the Coordinate system of the instrument.

$$x_p(t_i) = \frac{M_y(t_i) - F_x(t_i) * h}{F_z(t_i)}$$
$$y_p(t_i) = \frac{M_x(t_i) - F_y(t_i) * h}{F_z(t_i)} \quad (3)$$

where h denotes the distance between the pen-contacting plate and the origin of the coordinate of the force sensor. The velocities and accelerations are the derivative of the two coordinates, which can be expressed as (4) and (5).

$$v_x(t_j) = \frac{x(t_j) - x(t_{j-1})}{\Delta t}$$
$$v_y(t_j) = \frac{y(t_j) - y(t_{j-1})}{\Delta t} \quad (4)$$

$$a_x(t_k) = \frac{v_x(t_k) - v_x(t_{k-1})}{\Delta t}$$
$$a_y(t_k) = \frac{v_y(t_k) - v_y(t_{k-1})}{\Delta t} \quad (5)$$

According to (3) and (5), the instrument draws the writing trajectories and drives the data to the memory to complete the handwriting display. Fig. 10 shows a sample of handwriting with the instrument. Note that it is a real time process between the display and handwriting without disturbing users' attention.

Fig. 10. Sample of the handwriting with the instrument.

6. Conclusion

In this paper, we presented a new instrument for pen-contact force information acquisition during handwriting. With a force sensor and other modules integrated, the instrument can directly detect 3-D forces and 2-D torques during pen movements, and other pen-contact information such as trajectories, velocities, accelerations, and so on can be got simultaneously. In order to get a nature interaction and be a stand-alone device, in-system computing and visual feedback are applied to achieve the requirements when using in practice.

As all force information and other pen-contact information about the writers' handwriting can be got by the instrument, it may be a remarkable potential of the instrument for biomechanical application or person verification and identification.

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