Paper counting display device based on STM32F103 single chip computer

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Abstract. This system uses the STM32F103 single-chip microcomputer as the control center, and the capacitance-to-digital converter FDC2214 collects the current paper value, performs data collection and transmits it to the main control single-chip microcomputer. Methods: Calculate accurate data through Kalman filtering, and accurately calculate and display the number of measured paper sheets on this basis. The device also sets a buzzer to accurately short circuit alarm. The circuit structure of the entire system is simple, and the reliability is high. Results: The system has high precision and fast speed, and can complete the basic requirements and expansion requirements of the problem. Although it is limited by time and venue, it can also have a high reference value for the design of practical applications such as detecting the number of banknotes. Conclusions: Experimental test results show that this design can complete the basic indicators required by the topic and play part of the content. This paper focuses on the hardware design, software design and test result analysis of the system.

1. Background

1.1. System design requirements
(1) Basic requirements

The metal electrode parts on the electrode plate A and the electrode plate B are squares with a side length of 50 mm ± 1 mm, and the lengths of the wires a and b are 500 mm ± 5 mm. The measurement display circuit should have the function of "self-calibration", that is, before the formal test, the paper of different sheets placed between the two polar plates is measured to obtain measurement calibration information.

The measurement and display circuit can self-check and report whether the electrodes of plate A and plate B are short-circuited.

Measure the given number of sheets ranging from 1 to 10 sheets placed between the two plates [1]. Each time the paper to be tested is placed between the plates and fixed, one-key measurement is started, the number of papers to be tested is displayed and a buzzer sounds. The time from pressing the same measurement start key to beeping for each measurement shall not exceed 5 seconds, during this period, there shall be no manual intervention on the measurement device [2].

(2) Play part

1) The polar plates and wires are unchanged, and the number of given paper ranging from 15 to 30 sheets placed between the polar plates is measured [3,4]. The relevant requirements for the measurement start key, display beep, measurement time, and no manual intervention are the same as "Basic Requirements (3)".
2) The polar plates and wires are unchanged, and the number of papers given above 30 sheets placed between the polar plates is measured [5]. The relevant requirements for the measurement start key, display beep, measurement time, and no manual intervention are the same as "Basic Requirements (3)".

1.2. Overall design
Due to the problem, the two copper sheets on the top and bottom of the paper can only be connected to the wire, and there can be no other additional components. The following three schemes can be used to detect the number of paper systems:

Option 1: Mechanical pressure, using a screw stepper motor to apply a fixed downward pressure on the plane of data collection, and can accurately obtain the increased paper thickness between the two plates, use a single-chip microcomputer to record this data and divide by a single sheet 70gA4 The thickness of the paper, and data analysis of the collected multiple sets of data to accurately obtain the number of paper.

Solution 2: Hall sensor, through which the thickness of the paper can be accurately measured.

Solution 3: Collect the capacitance value between the two plates through the capacitance-to-digital converter FDC2214, and analyze the collected data. After collecting a large amount of data and fitting the data, we can approximate an exponential function, but this The range covered by the function is limited. If we want to further improve the measurement range, we must process the collected data in sections. The initial test can be obtained within the range of 30 sheets. The data obtained is approximately linear, but after exceeding the range of 30 sheets The trend of increasing data is small or even decreasing. Through experiments, it is found that adding a weight above the pole plate can shift this peak backwards. It can be obtained by analyzing the formula of capacitance (C=εS/4πkd). Under other circumstances where the other factors remain unchanged, the smaller the value of d, The larger the value of C, the more convenient it is for us to collect data. The final peak value is roughly set at about 40 sheets. After this range, we use Kalman filtering to process the data collected by each channel to accurately measure large amounts of paper.

In summary, the data collected and analyzed by the capacitance-to-digital converter can have very accurate results. And the circuit is simple and easy, and can also display the data of each acquisition channel in real time, so we choose the software timing in scheme three.

2. Theoretical analysis and calculation

2.1. Analysis and calculation of measurement principle
First, self-calibration reads the data of each piece of paper, reads 80 pieces of data per piece of paper, and applies Kalman filtering to these data to obtain accurate values, which are stored in an array. When testing the number of papers, the data of the current paper is obtained in the same way, and compared with the data in the array to obtain the accurate number of papers.

2.2. Anti-interference analysis
Shielding, grounding, filtering, isolation and absorption. Under normal circumstances, the spatial interference is much smaller than the interference from other channels, and can be effectively solved with good shielding, correct grounding, and filter filtering.

Therefore, the data collection system should focus on preventing interference between the power supply system and the process channel. The interference sources of each part of the system will have some emphasis and different impacts, so the anti-interference measures taken will be different.

We use data filtering to reduce or weaken the impact of the environment on metal electrodes through certain calculation or judgment procedures.
2.3. Error Analysis
When the contact surface of the electrode plate is different, the capacitance is different, so errors will occur in the measurement, so make sure that the contact surface of the electrode plate is the same for each measurement;
When the paper is loaded, the data generated by the different gravity will also be different, so the gravity should be fixed to ensure that the external gravity generated each time the paper is measured is the same.
Then carry on Kalman filtering to the data to reduce the error of each measurement.

3. Circuit and programming

3.1. Circuit design

3.1.1. Data collection section. Due to the design problem, the metal electrode parts on the polar plate A and the polar plate B are squares with a side length of 50mm±1mm, and it is stipulated that if a double-sided board is used, a square with a side length of 50mm±1mm is processed on one side of the double-sided board. On the other side of the copper-clad electrode plate, only via pads and leads for soldering wires a and b are allowed, no copper-clad mesh is allowed, and it is forbidden to use multi-layer plates to make polar plates. Therefore, we use a brass plate as the polar plate, which has the advantage of being flat and not easily deformed.
FDC2214 accurately collects multiple channels of data and performs Kalman filtering. The FDC2214 series has many advantages over other capacitive sensing integrated circuits. FDC2x1x-Q1 is an anti-noise and EMI, high-resolution, high-speed, multi-channel capacitor-to-digital converter series for capacitive sensing solutions. This series of devices supports a wide excitation frequency range, which can bring flexibility to system design.
The FDC221x has been optimized with a resolution of up to 28 bits and a maximum measurement of 250nF. The FDC211x has a sampling rate of up to 13.3ksps, making it easy to implement applications that use fast moving targets.

3.1.2. Display circuit. Use LCD to display two-way FDC data and display learning.

3.1.3. Alarm circuit. The alarm signal is output from the P3.0 port of the single-chip microcomputer, and a short-circuit alarm is issued through the buzzer. The circuit diagram is shown in Figure 1 below.

![Figure 1. Alarm circuit diagram](image)

3.2. Software design
The device is divided into two working states:
State 1: Self-calibration of the whole machine, reading the capacitance value of each paper superimposed multiple times, and adopting the Kalman filter algorithm to obtain the most reliable value in the middle.
State 2: Read the paper number multiple times, use the Kalman filter algorithm to obtain the most reliable value in the middle, determine the range of the value, determine the number of papers placed at this time and display on the LCD screen.

4. Test methods and test results

4.1. Test methods and test instruments
Learn by sampling one by one, and test after completing self-calibration.

(1) First determine the paper in the range of 1-15 sheets, and repeatedly test to determine its accuracy.
(2) Re-test the paper in the range of 16-30 sheets, and repeatedly test to determine its accuracy.
(3) Wait for 30 sheets of paper that can be accurately measured within a test range of 60 sheets, and repeatedly test to determine their accuracy.

Because the difference between the two values measured above 60 sheets is not obvious, the value was not continued.

| Table 1. Paper detection record |
|-------------------------------|
| frequency | Number of sheets | Accuracy% |
|-----------|-----------------|------------|
| 10        | 1               | 100        |
| 10        | 2               | 100        |
| 10        | 3               | 100        |
| 10        | 4               | 100        |
| 10        | 5               | 100        |
| 10        | 6               | 90         |
| 10        | 7               | 100        |
| 10        | 8               | 100        |
| 10        | 9               | 100        |
| 10        | 10              | 100        |
| 10        | 11              | 100        |
| 10        | 12              | 100        |
| 10        | 13              | 100        |
| 10        | 14              | 100        |
| 10        | 15              | 100        |
| 10        | 16              | 100        |
| 10        | 17              | 100        |
| 10        | 18              | 90         |
| 10        | 19              | 100        |
| 10        | 20              | 100        |
| 10        | 44              | 100        |
| 10        | 45              | 90         |
| 10        | 46              | 100        |
| 10        | 47              | 100        |
| 10        | 48              | 100        |
| 10        | 49              | 100        |
| 10        | 50              | 100        |
| 10        | 51              | 100        |
| 10        | 52              | 100        |
| 10        | 53              | 100        |
| 10        | 54              | 100        |
| 10        | 55              | 100        |
| 10        | 56              | 100        |
| 10        | 57              | 100        |
| 10        | 58              | 100        |
| 10        | 59              | 100        |
| 10        | 60              | 100        |

Error analysis: The upper and lower plates do not cause a great error in the device measurement.
5. Summary
This system has completed the design of a paper count display device. The characteristic of this design is that through the design of a stable electrode plate design, the capacitance value of different papers is obtained through a high-precision capacitance value sensor, and the accurate value is obtained through Kalman filtering, thereby calculating the number of papers to be measured. The system has high precision and fast speed, and can complete the basic requirements and expansion requirements of the problem. Although it is limited by time and venue, it can also have a high reference value for the design of practical applications such as detecting the number of banknotes.

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