

# Design and Implementation of Paper Number Measurement Based on Improved Least Square Method

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**Abstract**—In view of the weak capacitance generated by placing paper between two copper clad plates and the interference of strong parasitic capacitance around the wires connecting the measured capacitance and the measuring circuit, this paper proposes a design of measuring the number of paper based on improved least square method. The capacitance value is converted into oscillation frequency by 555 oscillation circuit, and the frequency is measured accurately by STM32F103RCT6 microcontroller. And an anti-interference unit is designed to eliminate parasitic capacitance interference, The paper frequency track was recorded in the early learning stage to eliminate the interference of temperature and humidity on the paper dielectric constant. According to the experimental data, the number and frequency relationship model was obtained by using the two-parameter sinusoidal curve fitting algorithm. The measured frequency in the current environment was recorded at the learning stage, and the paper number prediction model was constructed by parametric fitting of the relationship model according to the improved least square method. In the measurement stage through the frequency value accurately determine the number of paper.

**Keywords**—least square method; Sinusoidal curve fitting; oscillation frequency; STM32F103RCT6

## I. INTRODUCTION

Paper counting is very common in daily life, with the increase in the number of paper, manual counting in human and material consumption and low accuracy. Accordingly, according to the property that the paper is placed between two copper clad plates as a dielectric to generate capacitance value, the capacitance value is converted into frequency by oscillation. The dielectric constant of paper is affected by the material, thickness of paper and environment, Therefore, this paper proposes to build a paper number prediction model under the current environment. In the learning stage, the frequency value is recorded, and the number of paper prediction model is constructed by using the improved least square method under the current environment. After entering the measurement stage, the paper number can be measured.

## II. DESIGN PRINCIPLE

The paper is placed between two parallel plates, the paper is the dielectric between plates. The capacitance between the electrodes of the copper clad plate is:

$$C = \frac{\epsilon S}{4\pi kd} \quad (1)$$

According to formula (1), when the plate area is fixed, the only factor affecting the capacitance between the plates is the distance between the two plates. The value of the distance is the thickness of the paper between the plates, the number of paper is proportional to the thickness, so the number of paper can be measured according to the capacitance between the poles. If other constant coefficients in formula (1) are equivalent to constant K, the capacitance between the poles is:

$$C = K \frac{1}{nd_1} \quad (2)$$

The  $d_1$  is the thickness of a piece of paper.

A piece of paper between the copper clad plate produced between the electrode capacitance is extremely weak, the presence of dielectric in the air will also produce a weak capacitance. In addition, many factors such as the total stray capacitance of circuit and conductor in the system affect the circuit. Paper dielectric constant is also affected by the external environment, such as temperature, humidity. At the same temperature, the moisture content of the medium increases after hygroscopic, and the dielectric constant is proportional to the water content. Under the same humidity condition, the dielectric constant decreases with the increase of temperature.

According to formula (2), there is a functional relationship of Power between the capacitance between poles and the number of papers. When the number of paper is small, the curve change rate is large, and with the increase in the number of paper, the curve change rate gradually decreases, the paper resolution is reduced. More paper on the circuit resolution

requirements to improve the number of paper to determine the difficulty. The capacitance range of each paper quantity is shown in figure I .

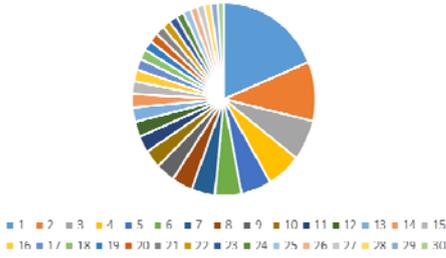


FIGURE I. FCAPACITANCE RANGE FOR DIFFERENT AMOUNTS OF PAPER

### III. THE SYSTEM DESIGN

#### A. Structure of the System

In order to ensure that the only factor affecting the inter-electrode capacitance of the system is the number of paper, two square copper-clad plates with the same side length are glued to the same position of two 1kg boards respectively. The weight of the boards can reduce the gap between the papers. Install baffle diagonally in the bottom plate to prevent the copper-clad plate from changing the area in front during operation.

#### B. Design of the Anti-interference

In order to eliminate the interference of parasitic capacitance to the measured capacitance  $C_x$  , automatic calibration is carried out before measuring the capacitance value. Place the plates vertically before measurement, measure the capacitance  $C_0$  generated by the surrounding environment and the interfering capacitance  $C_0$  should be subtracted from the actual measured capacitance.

#### C. Design of the Oscillation Cell

Considering the complexity of using capacitance to determine the number of paper, this paper USES oscillation to convert capacitance value into frequency value and USES frequency value to determine the number of paper. In this paper, the capacitance value is converted to the frequency value by 555 timer, and the two input terminals of 555 timer are connected together as the signal input terminal, and then the RC integral circuit is connected back to the input terminal to obtain the multi-resonance oscillation circuit, as shown in figure II :

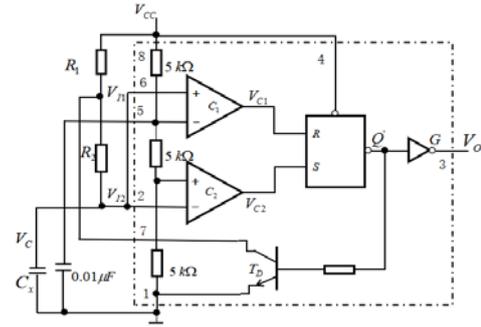


FIGURE II. MULTI-RESONANCE OSCILLATION CIRCUIT CONNECTED WITH 555 TIMER

When the circuit is connected, the voltage  $v_c$  on the capacitor will oscillate between  $V_{T+}$  and  $V_{T-}$  with a frequency of

$$f = \frac{1}{T} = \frac{1}{(R_1 + 2R_2)C \ln 2} \quad (3)$$

According to formula (2) and formula (3), the functional relation model of frequency value and paper quantity is derived:

$$f = \lambda n \quad (4)$$

The  $\lambda$  is a constant coefficient.

The function relation model between the number and frequency is obtained by fitting experimental data. The frequency value recorded in the learning stage is fitted by the algorithm, that is, the paper number prediction model is obtained in the current environment. The frequency of the measurement stage can be corresponding to the range of the number of paper, at this time the number of paper is generally decimal, rounding is the number of paper measured.

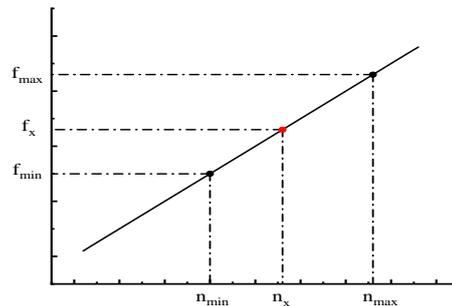


FIGURE III. RELATION BETWEEN NUMBER OF PAPERS AND FREQUENCY VALUE

#### D. Design of Frequency Measurement

In order to accurately measure the oscillation frequency, the external interrupt and timing function of STM32F103RCT6

microcontroller is used. First, the external interrupt is set, and when the falling edge is detected, the interrupt service is triggered for pulse counting. Start the timer at the same time, calculate the number of pulses in a certain time to get the frequency value. The results show that the method is feasible and the error is small because the output square wave period is stable.

IV. ALGORITHM DESIGN

A. Construction of Paper Number Prediction Model

In paper counting, the dielectric constant is affected by the thickness of the paper or the material and the external environment, so the frequency value will change under different conditions. Therefore, the paper number prediction model under measurement environment should be constructed accurately. The relationship model between the number of papers and the frequency was determined after many experiments, and the parameters in the relationship model would change under different circumstances. In this paper, the construction of paper quantity prediction model is decomposed into two steps: The first step is to fit the form of the functional relation model between the number of papers and the frequency value according to the experimental data, the second step is to fit the parameters of the relationship model according to the frequency values recorded in the learning stage. In this paper, the least square method is further improved and applied to the paper number prediction model.

B. Improved Least Square Method

The principle of the least square method is to select the parameters of the function relation model according to the minimum condition of the square sum of deviations, It is more applicable to fitting polynomial functions. After many experiments and simulations, the relationship between number of papers and frequency can be well fitted by cubic polynomial. The relationship model is:

$$f(n) = an^3 + bn^2 + cn + d, (v=1,2,3...) \quad (5)$$

n is the number of papers, and  $f(n)$  is the frequency value.

When the upper limit of paper number is 60 in the learning stage, the paper number prediction model is shown in figure IV. As can be seen from the figure, there are limitations in the application of polynomial function fitting relation model. The slope of the function will change suddenly after reaching the number of paper set in the learning stage, and the number of paper set after the set value cannot be further predicted.

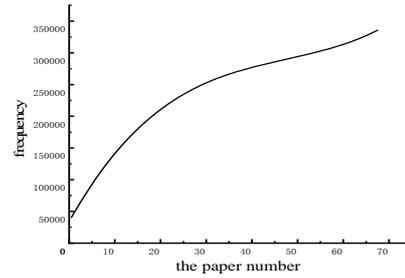


FIGURE IV. PAPER NUMBER PREDICTION MODEL UNDER CUBIC FITTING

Therefore, in this paper, the two-parameter sinusoidal curve fitting method is adopted to fit the existing frequency values to obtain the relationship model.

$$f(n) = a_1 \sin(b_1n + c_1) + a_2 \sin(b_2n + c_2), (v=1,2,3...) \quad (6)$$

At this time, the paper number prediction model is shown in figure V. Compared with figure IV, it can be seen that the relationship model obtained under the two-parameter sinusoidal curve fitting algorithm can predict the number of papers after the number of papers is partially set.

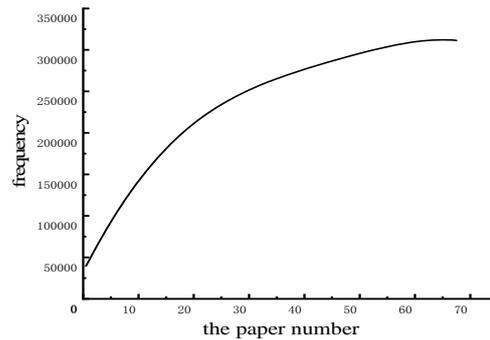


FIGURE V. SINE FITTING THE PAPER SEVERAL PREDICTION MODELS

According to the principle of the least square method, select the parameters a, b, c, d, e, f, such that  $n= 1,2,3...$ . The difference between the value of the function and the experimental data is very small, which is to minimize the sum of squares of deviation. The sum of deviation squares function model is:

$$M = \sum_{n=1}^{60} [y(n) - a_1 \sin(b_1n + c_1) - a_2 \sin(b_2n + c_2)]^2, (v=1,2,3...) \quad (7)$$

According to the idea of single objective optimization, the frequency value recorded in the learning stage is substituted into the objective function to solve the combination of parameter values corresponding to the minimum M of the objective function. The number of paper prediction model under the current environment is obtained by substituting the parameters into the relational model.

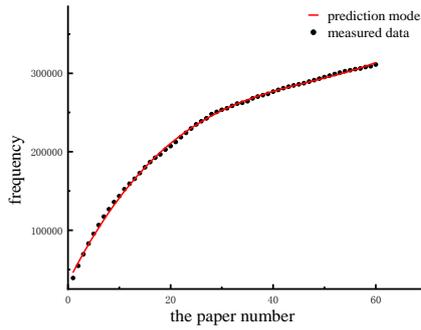


FIGURE VI. PAPER QUANTITY PREDICTION MODEL

## V. TEST RESULTS AND ANALYSIS

### A. The Test Results

Test conditions: in different environments, test the number of paper for several times and calculate the error rate, as well as the corresponding frequency value and capacitance value of paper generated in the device. The test results are shown in table 1:

TABLE I. PAPER MEASUREMENT TEST SHEET

Actual number of paper	Frequency measurement/Hz	Capacitance measurement/pF	The amount of paper measured	Measurement accuracy
1	42945	273.395	1	100%
5	93096	122.298	5	100%
10	134570	82.219	10	100%
20	209899	51.301	20	100%
40	264337	39.851	40	100%
60	285783	35.120	60	100%

### B. Analysis of Test Results

As can be seen from table 1, the paper quantity measurement design based on improved least square method proposed in this paper can effectively measure the quantity of different types of paper in various environments. On the basis of accurately judging the number of paper, this model can also measure the capacitance value of paper generated in the device.

## VI. SUMMARY

In this paper, a paper quantity prediction model is constructed based on the improved least square method. Among them, the two-parameter sinusoidal curve fitting method can better fit the empirical formula between the number of papers and the value of frequency, and according to the frequency value obtained at the learning stage, the improved least square method can better fit the parameters of the empirical formula, thus obtaining the paper number prediction model under the current environment. On the hardware, 555 oscillator is used to convert the measurement of paper capacitance into frequency, which reduces the redundancy of the system. The former anti-interference module is designed on the software to eliminate the interference of parasitic capacitance and the anti-humidity module is designed to filter the influence of temperature and humidity on the

dielectric constant of paper. After testing, the design in this paper can accurately measure the number of different types of paper in different environments, can accurately measure more than 60 pieces of paper. In addition, the system proposed in this paper can also be applied to the measurement of micro-capacitance, which can be accurate to 1pF capacitance value.

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