New Type Multielectrode Capacitance Sensor for Liquid Level

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Abstract. This paper introduces the design of a new type multielectrode capacitance sensor for liquid level. The system regards electric field sensor MC33794 as the core and applies microcontroller MC9S12DJ128 to realize intelligent liquid level monitoring system, which overcomes the disadvantages of the traditional capacitance sensor, improves on the anti-jamming ability and the measurement precision and simplifies the system structure. Finally, the paper sums up the design of the system.

1. Introduction

Capacitance sensor is a kind of sensor, which transforms non-electrical variety into capacitance variety. Comparing with other sensors, capacitance has four advantages that are high resolution, rapid dynamic response, obtaining little energy from signal and simple mechanism. So capacitance sensor is important in precision measurement.

Commonly the precision of a measurement system mostly lies on sensor and signal processing circuit. Currently single electrode capacitance sensor is broadly applied, which easily emerges multivaluedness and low precision with different surroundings. Signal processing circuit has complex structure and powerful jamming [4] The diagram of signal processing is presented in figure 1.

![Signal Amplifier Detector Amplifier](image)

**Figure 1.** The block diagram of signal transformation.

In this paper, a new type of sensor for measuring system—multielectrode capacitance sensor is designed. It has remarkable advantages such as simple structure, high precision, powerful anti-jamming ability, low cost and strong flexibility. The paper introduces the design of sensor, signal transformation and finally draws some conclusions.

2. Structure and hardware

MC33794 gets the changing capacitance signals induced by the level changing. Then we can get 0-5V DC signals from MC33794. The analog signals are transformed into digital signals through internal
ATD module of MCU. Liquid level values are got by software programming and displayed in LED. Meanwhile office control can be realized through communication module, which can send signals to PC. Figure 2 shows the detailed structure.

2.1. The principle of capacitance sensor
According to different principle of capacitance sensor, capacitance sensors are divided to the alterable-clearance, the alterable-variable and the alterable-area ones. The capacitance sensor that we use here is the alterable-variable one.

For liquid level measuring, the cylinder structure is preferable. Figure 3 shows the cylinder structure of a variable capacitance sensor.

\[
C = \frac{2\pi\varepsilon_0 h}{\ln\left(\frac{r_2}{\eta_1}\right)} + \frac{2\pi(\varepsilon - \varepsilon_0)h_x}{\ln\left(\frac{r_2}{\eta_1}\right)}
\]

\(h\)-height of the cylinder; \(r_1\)-the outer diameter of inner cylinder; \(r_2\)-the inner diameter of outer cylinder; \(h_x\)-height of the measured liquid; \(\varepsilon_0\)-the permittivity of free space (8.85 x 10-12 F/m); \(\varepsilon\)-dielectric constant of the measured liquid.

2.2. Design of new type capacitance sensor [5]
To overcome the defects of traditional capacitance sensors, we design multielectrode capacitance sensor. Its structure is presented in figure 4. The outer cylinder is designed as a whole while the inner cylinder is divided into n sections (n≤9). Δ expresses distance between sections. The height of each electrode is \(h\). The equivalent circuit is presented in figure 5. When the measured liquid exists, the dielectric constant of working area change, which results in the changes of capacitance. We can get height of the measured liquid according to the relationship liquid level and capacitance.

According to the classic theory, the capacitances are same in the area where the same dielectric is if the sizes of the electrodes are same. The capacitance sensor in this system works basing on this theory. Each section capacitance is made in the same size, so we know that:

\[C_1=C_2=C_3=\ldots=C_i=\ldots=C_n;\]

When there is no measured dielectric or there is only air, we get the following equation naturally:

\[C_{01}=C_{02}=C_{03}=\ldots=C_{0i}=\ldots=C_{0n};\]
In the circumstance of having dielectric (such as water), for example, if the level is located at section $i$, the dielectric are full from the section 1 to section $(i-1)$. Then we have the following equation:

$$C_{i1} = C_{i2} = \ldots = C_{ii} = \ldots = C_{in};$$

The dielectric is air from section $(i+1)$ to section $n$. So we get the following equation:

$$C_{0(i+1)} = C_{0(i+2)} = \ldots = C_{0n};$$

$C_i$ expresses the capacitance of the section $i$.

The total liquid level is $H_X$:

$$H_X = (i - 1)h + (i - 1)\Delta + h_x = (i - 1)(h + \Delta) + h_x \quad (2)$$

In this equation, $h_x$ is calculated according to the equation of cylinder capacitance sensor. We must note that the equation (2) comes into existence no other than enough small $\Delta$.

Besides, we find that every section electrode has its own linear range by experiments. When $\Delta$ is not enough small, $H_X$ can be got according to the linear relation of different electrodes.

2.3. Signal processing

After capacitance changing is processed by MC33794, we can get 0-5V analog signals. The 0-5V analog signals are imported to a PAD port of MC9S12DJ128B, then we program for the system and get the experiment results. The experiment results are displayed and transmitted to PC according to require, complete signal processing.

2.3.1. The principle of MC33794 [1]. The MC33794 is intended for applications where non-contact sensing of objects is desired. The IC generates a low-frequency sine wave. The sine wave has very low harmonic content to reduce harmonic interference. The MC33794 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

(1) Figure 6 shows the principle of MC33794. When E-field of electrodes changes, capacitance also changes. Detector and low pass filter (as shown in figure 6) are integrated in MC33794.

MC33794 has two important advantages:

Firstly, shield driver capacity. Electrode with Shield Drive and No-Shield Drive Electrode are presented in figure 7.

Secondly, the proper use of REF_A and REF_B of MC33794 can detect short-term and long-term changes due to objects in the electric field and significantly reduce the effect of temperature and time-induced changes. A typical measurement algorithm may refer [1].

(2) Precision of MC33794. The MC33794 does not contain an ADC. It is intend to be used with an MCU that contains one. Capacitance values of electrodes that can be detected are of the range from 0pF to 100pF. Because the value of series resistance (22kΩ) is chosen to provide a nearly linear relationship over a range from 10pF to 100pF, an 8-bit ADC can resolve around 0.4pF of change and a 10-bit converter around 0.1pF. High resolution results in more distant detection of smaller objects.
2.3.2. **Microcontroller** [2]. MC9S12DJ128 has stronger function modules, for example, a 16-bit central processing unit, 128K bytes of Flash EEPROM, 8K bytes of RAM, 2K bytes of EEPROM, 10-bit analog-to-digital converters (ADC), etc. In addition, it has abundant function modules, low power consumption and powerful anti-jamming ability. So we select MC9S12DJ128 as master control chip.

![Image](image.png)

**Figure 6.** The principle diagram of MC33794

2.4. Theoretic precision and measurement range

(1) Theoretic precision.

a. Enough small $\Delta$. The system precision lies on $h_x$. We suppose that the voltage value measured is $U_i$, the voltage for two known value capacitors (attached to REF_A and REF_B) are $U_A$ and $U_B$. According to the principle of MC33794 and equation (1), we can get the capacitance value $C_i$ corresponding with $U_i$ and the relationship between $\Delta C_i$ and $\Delta h_x$. Therefore the minimal resolution of $\Delta h_x$ is $\left[ \ln\left( \frac{r_2}{r_1} \right) \right] \times 0.1 \text{pF} / 2\pi (e-\varepsilon) 0$.

b. Not enough small $\Delta$. Theoretical precision of the system is related to the linearity of every electrode. Theoretical precision of the sensor is $\pm 0.29\% - \pm 0.66\%$ by experiment and calculation.

(2) Measurement range. Measurement range of the system is related to the size of sensor. The measurement range of the system is 0–140mm.

3. Experiment data and analysis

According to the above introduced scheme, we experimentize. The experiment adopts four electrodes for finer results on account of limited container. We get experiment results as follows.

Table 1 shows measured liquid level datum of 0–140mm. By analyzing datum we know that error is bigger when liquid level is low, the most error is 1.95%. The higher precision is due to higher ADC resolution and integration component. Besides we can design different level sensors based on the theory for other liquids.
4. Conclusion

We draw a few conclusions by experiments and design.

(1) Power supply: MCU need power of 5V, 50mA and BDM need power of 5V, 95mA, but MC33794 only provides power of 5V, 75mA. So we should pay more attention to power supply to protect chip from burned out.

(2) Shield drive: In the design, MC33794 is an integrated chip, whose anti-jamming is very good. So we should stress shield problems from capacitance sensor to MC33794.

(3) Sensor design [4]: Every electrode should adopt resisting corrosion material. The size design of sensor should be considered according to actual need, machine machining and fringe effect.

(4) The system adopts MCU with BDM, which reduces cost and makes the field exploiting and the system upgrading more convenient.

References

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