# Design and implementation of an infrared radiation sensor based on STC12C5A

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ABSTRACT. *This paper attempts to develop a non-contact temperature measurement tool with high accuracy and fast speed. Therefore, an infrared temperature measurement system was designed with STC12C5A as the core. In the system, the STC12C5A controls infrared temperature sensor MLX90614 to obtain surface temperature of the target, and displays the processed temperature data on the LCD1602. If the displayed data exceeds the pre-set range, an alarm will be released by a buzzer in the alarm module. Then, the measuring accuracy and measurement distance of the system were verified through system tests. The results show that the proposed system is more accurate than the reference sensor; the optimal measurement distance is less than 2cm, for the corresponding mean error is below 0.88%. The proposed system clearly outperforms the traditional contact measurement method in speed, accuracy and safety and enjoys a strong potential of application.*

RÉSUMÉ. *Cet article tente de développer un outil de mesure de la température sans contact avec une précision élevée et une vitesse rapide. Par conséquent, un système de mesure de température infrarouge a été conçu avec STC12C5A comme noyau. Dans ce système, STC12C5A contrôle le capteur de température infrarouge MLX90614 pour obtenir la température de surface de la cible et affiche les données de température traitées sur le LCD1602. Si les données affichées dépassent la plage prédéfinie, une alarme sera déclenchée par un avertisseur sonore dans le module d'alarme. Ensuite, la précision de mesure et la distance de mesure du système sont vérifiées par des tests du système. Les résultats montrent que le système proposé est plus précis que le capteur de référence; la meilleure distance de mesure est inférieure à 2 cm, car l'erreur moyenne correspondante est inférieure à 0,88%. Le système proposé surpasse clairement la méthode de mesure de contact traditionnelle en termes de vitesse, de précision et de sécurité et bénéficie d'un fort potentiel d'application.*

KEYWORDS: *infrared temperature measurement, STC12C5A, non-contact, MLX90614.*

*MOTS-CLÉS: mesure de température infrarouge, STC12C5A, sans contact, MLX90614.*

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## 1. Introduction

In temperature measurement, the sensor is either in contact with or not in contact with the object. As a result, the current temperature measuring methods can be divided into contact and non-contact categories (Matsukawa *et al.*, 2000). The contract temperature measuring methods are time-consuming and susceptible to external disturbance, for the object and sensor must reach thermal equilibrium before the measurement. By contrast, non-contact temperature measurement boasts wide range, fast speed, good accuracy and high safety (Wang *et al.*, 2014), and has been widely applied in medical treatment, metallurgy, transport and the power industry. Many non-contract temperature sensors rely on the principle of infrared heat radiation to quickly measure the infrared radiation energy emitted from the target surface, and use the black body radiation law to calculate received infrared energy, converting it to the target temperature.

Despite the advantages of non-contact temperature measurement, there are many more studies on contact temperature sensors than those on non-contact sensors. For instance, Reference (Pathak *et al.*, 2017) develops a temperature sensor using nanomagnetic fluid bearing that achieves a high accuracy 3.7mK through contact measurement. Based on radiofrequency identification (RFID), Reference (Amendola *et al.*, 2016) designs an epidermal sensor for remote temperature monitoring, but the sensor needs to be attached onto the skin. Reference (Blasdel *et al.*, 2015) proposes a multifunctional fabric nanocomposite resistance temperature detector, which can detect the temperature in smart clothing and prosthetic sockets. Reference (Manara *et al.*, 2016) creates a long wavelength infrared radiation sensor for non-contact temperature measurement in gas turbines. Reference (Barry *et al.*, 2011) presents a self-calibrating infrared sensor for low-temperature measurement.

In view of the above, this paper designs an infrared radiation measurement system based on STC12C5A and verifies its measuring accuracy and distance through tests. The remainder of this paper is organized as follows: Section 2 describes the design principles of the measurement system; Sections 3 and 4 introduce the hardware and software designs of the proposed system, respectively; Section 5 tests the measuring accuracy and distance of the proposed system; Section 6 wraps up this paper with several conclusions.

## 2. Design principles

### *2.1. Black body radiation law*

Objects in nature constantly radiate, absorb and emit electromagnetic waves. The radiated waves differ greatly in band and spectral distribution. The latter mainly depends on the features and temperature of the object. The spectral radiation is also known as the thermal radiation (Surdin *et al.*, 1966). To eliminate the effects of physical properties of the object on the law of thermal radiation, physicists have defined an ideal object called black body: this body can absorb external electromagnetic radiation without any reflection or transmission. The relationship between the spectral radiant power $P_b$ and temperature T of black body in nature can be expressed as:

$$P_b \lambda T = \frac{c_1 \lambda^{-5}}{\exp(c2/\lambda T)^{-1}} \tag{1}$$

where $c_1$ and $c_2$ are the first and second radiation constants. It can be seen from formula (1) that the electromagnetic radiation energy of black body increases with temperature. This is the theoretical basis of single wave sensor. With the growth in temperature, the wavelength of radiant peak moves in the shortwave direction. Therefore, an object in short wavelength band must have a high temperature and the inverse is also true (Wang *et al.*, 2014).

### *2.2. Stefan-boltzmann law*

Integrating all wavelengths of formula (1), the total radiant power of black body radiation per unit area into a hemisphere space can be obtained as:

$$P_b T = \int_0^\infty P_b \lambda T d\lambda = \sigma T^4 \tag{2}$$

where σ is Stephen-Boltzmann constant; T is the thermodynamic temperature.

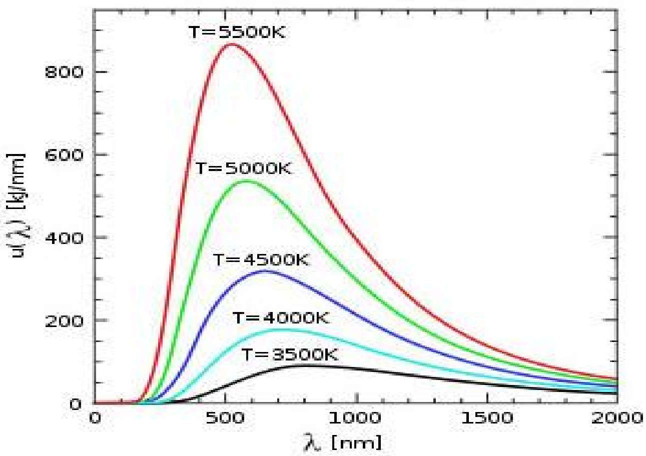


*Figure 1. Black body radiation curves*

The relationship between the radiance of black body and wavelength is shown in Figure 1. It can be seen that, the radiance of an object in one wavelength is always below the radiant power of the black body, while other conditions remain constant. In other words, the monochromatic radiance of an object is smaller than that of black body, whose ratio is called monochrome blackness $\varepsilon_\lambda$ (Fujishima *et al.*, 1994).

$$\varepsilon_\lambda = \frac{P_T}{P_b T} \tag{3}$$

An object whose monochrome blackness is invariant with wavelength can be called a gray body. The blackness of the gray body can be expressed as:

$$P_T = \varepsilon P_b T = \varepsilon \sigma T^4 \tag{4}$$

Finally, the temperature of the object can be obtained as:

$$T = \sqrt[4]{P_T / \sigma\varepsilon} \tag{5}$$

Formula (5) shows the intensity of infrared energy radiated from the object surface (Kouzai, 2010), which is closely related to the surface temperature. This correlation lays the theoretical basis for infrared temperature sensors. Such a sensor receives and measures the infrared energy emitted from the object surface, and quickly and accurately determines the object temperature through signal processing.

## 3. Hardware design

The infrared wavelength of human radiation falls between 9 and 10 microns, and the infrared energy of the body surface is not absorbed by the air. According to black body radiation law, the body temperature can be obtained accurately by measuring the infrared radiation energy of the body surface.

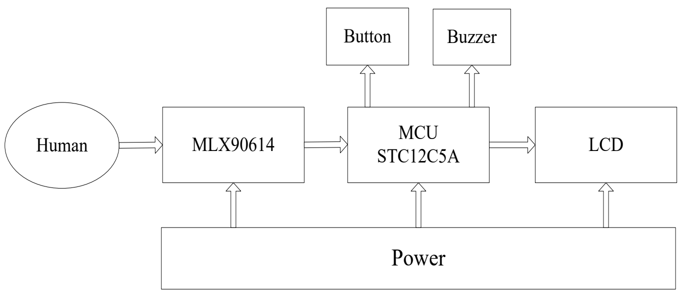


*Figure 2. Hardware design of infrared temperature measurement system*

As shown in Figure 2, our infrared temperature measurement system consists of a measurement module, an STC12C5A minimum system, a liquid crystal display (LCD) module, and an alarm module. During measurement, the infrared radiation sensor MLX90614 acquires the infrared radiation energy of body surface, converts it into temperature value, and sends the value to the microprogrammed control unit (MCU) STC12C5A for processing; after that, the processed temperature is displayed on the LCD 1602. In addition, a temperature threshold can be set by pressing the button to enable the alarm function. Once the detected temperature surpasses the threshold, the buzzer will be activated to issue an alarm.

### *3.1. Measurement module*

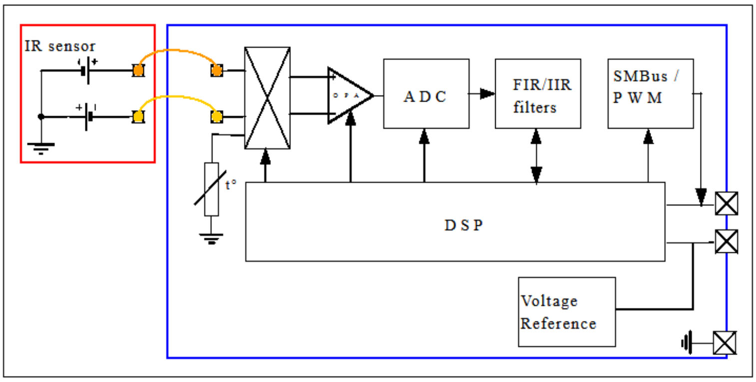


*Figure 3. Internal structure of MLX90614*

The measurement module centers on the MLX90614 thermometer (Melexis, Belgium) known for its high precision, high integration, high resolution and wide range. As shown in Figure 3, the MLX90614 integrates an infrared temperature sensor, an analog/digital (A/D) converter, a low noise amplifier, a digital signal processor (DSP) unit, a pulse width adjustment circuit, a logic control circuit, etc. During measurement, the infrared sensor measures the infrared light emitted by the object, converts the collected signal into an electrical signal, and transmit the electrical signal to the amplifier for amplification; the amplified signal will then be converted at the A/D converter into a digital signal, and screened by finite impulse response (FIR) filter or infinite impulse response (IIR) filter; the filtered signal will enter the DSP unit for arithmetic processing, and then reach the MCU in the form of system management bus (SMBus) or pulse-width modulation (PWM).

### *3.2. STC12C5A minimum system*

The STC12C5A is the core of our measurement system, as it controls the operation sequence of each module. It is a 51-core 8-bit MCU with rich hardware resources, including an 8kB flash drive, a 412B random access memory (RAM), a 4kB electrically erasable programmable read-only memory (EEPROM), a watchdog timer, a 16B timer, four external interrupts, full duplex serial port and other peripherals.

The minimum system refers to the minimum hardware unit circuit required for the normal operation of the MCU, which includes the power supply, the clock circuit and the reset circuit. As shown in Figure 4, a 5V direct current (DC) power source is adopted as the power supply, a 12M crystal oscillator is selected for the clock circuit, while the reset circuit is used to restore the MCU to the initial state.

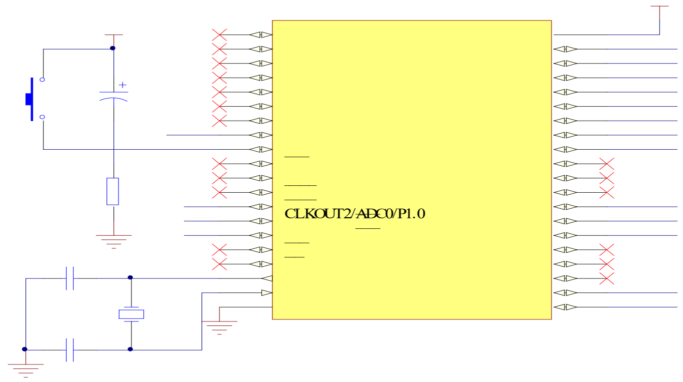


*Figure 4. The STC12C5A minimum system*

### *3.3. Alarm module*

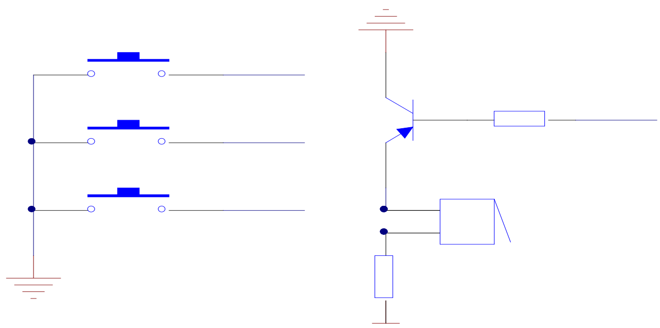

*Figure 5. The alarm module*

As shown in Figure 5, the alarm module is mainly composed of button circuits and a buzzer circuit. There are three independent buttons, respectively denoted as K1, K2, and K3, which are connected to MCU pins of P3.2, P3.3, and P3.4. Button K1 is used to set the range of alarm temperature, including the upper and lower bounds; Button K2 is used to increase the temperature threshold; Button K3 is used to decrease the temperature threshold. During measurement, the buzzer will sound an alarm if the measured temperature exceeds the pre-set range.

### *3.4. LCD module*

Here, an LCD 1602 (working voltage: 4V; working current: 2mA) is adopted to display the pre-set temperature range and the measured temperature. There are two lines on the LCD, each of which can display 16 characters. As shown in Figure 6, the LCD1602 is connected to the IIC port and P0 port of the MCU for data transmission. To control the working mode, the RS, RW and EN pins of the LCD are respectively connected to the P2.5, P2.6, and P2.7 pins of the MCU. Other pins are connected to the positive and negative poles of the power supply.

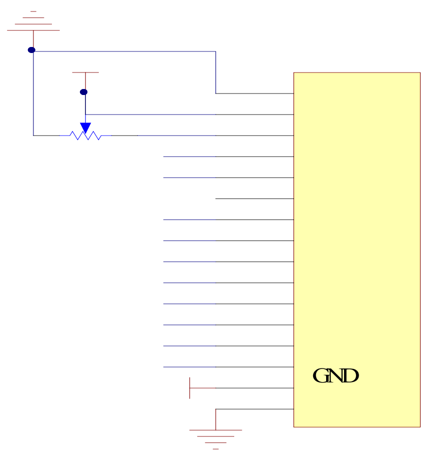


*Figure 6. The LCD module*

## 4. Software design

### *4.1. STC12C5A program flow*

The software design mainly deals with the software program in STC12C5A. The program flow in STC12C5A is shown in Figure 7. First, the system should be initialized, including the measurement module, alarm module and LCD module. Second, set the alarm temperature range and display it on the LCD. Third, measure body temperature and display the result processed by STC12C5A on the LCD. Finally, compare the measured temperature against the pre-set range and issue an alarm if necessary.

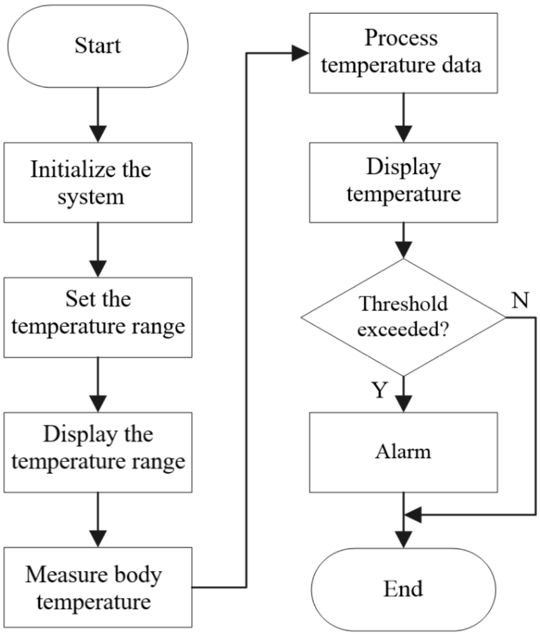


*Figure 7. STC12C5A program flow*

### *4.2. Temperature data processing*

The processing of temperature data is an important part of the system design, because the precision of the measured data directly bears on the accuracy of the entire system. Two measures were adopted to ensure the data precision: (1) Any temperature value outside the normal temperature range of body surface (34~42°C) should be discarded; (2) The average of five continuous measurements should be taken as the final measured value.

## 5. System verification

This section attempts to verify the measuring accuracy and distance of the proposed system.

### *5.1. Measuring accuracy test*

*Table 1. Results of measuring accuracy test*

| No. | PT100 /°C | MLX90614 /°C | Relative error/% |
|---|---|---|---|
| 1 | 35.12 | 34.95 | 0.48 |
| 2 | 36.08 | 35.28 | 0.55 |
| 3 | 37.20 | 37.02 | 0.48 |
| 4 | 37.51 | 37.36 | 0.40 |
| 5 | 38.03 | 37.85 | 0.47 |
| 6 | 39.14 | 38.83 | 0.79 |
| 7 | 40.37 | 40.03 | 0.84 |
| 8 | 41.89 | 41.52 | 0.88 |

In this test, the human body is simulated by water. Five beakers were filled with water of different temperatures in a lab when the ambient temperature was 27.5°C. The proposed measurement system and a high precision thermal resistance sensor PT100 were used to measure the water temperature at the same time. During the measurement, the system and the sensor were aligned with the target beaker and kept a 2cm from that beaker. The measured results are listed in Table 1 below. It can be seen that the proposed system achieved better accuracy in the measurement test.

### *5.2. Measurement distance test*

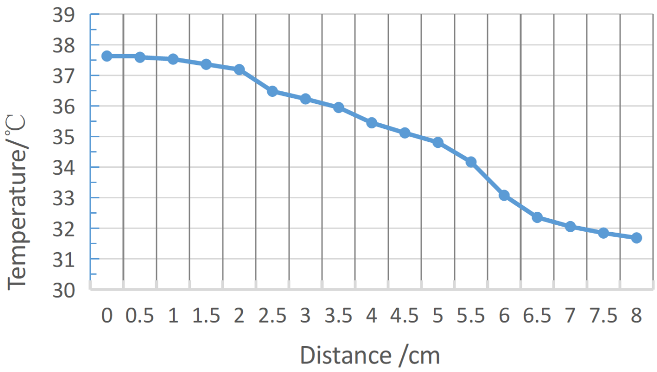


*Figure 8. The relationship between measurement distance and measured temperature*

The amount of infrared radiation energy is captured by the MLX90614 is negatively correlated with the distance between the measurement system and the target. Thus, it is necessary to test the influence of measuring distance on measured results. The proposed system was used to measure a target, whose surface temperature was measured as 37.51°C by the PT100, at difference distances. Figure 8 displays the relationship between the two factors reflected in the measurement distance test.

As shown in Figure 8, the longer the measurement distance, the smaller measured temperature value. When the measurement distance was less than 2 cm, the measured temperature was the closest to the true temperature.

## 6. Conclusions

This paper designs an infrared temperature measurement system with STC12C5A as the core. In the system, the STC12C5A controls infrared temperature sensor MLX90614 to obtain surface temperature of the target, and displays the processed temperature data on the LCD1602. If the displayed data exceeds the pre-set range, an alarm will be released by a buzzer in the alarm module. The measuring accuracy test and measurement distance test show that the proposed system can accurately measure target temperature without contact, and outperform the traditional contact measurement method in speed, accuracy and safety. The proposed system enjoys a strong potential of application.

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