Design of Temperature Compensation System for MEMS Gyroscopes Based on STM32

Youqi Jiang\textsuperscript{1,a,*} and Yiding Zhao\textsuperscript{2,b}

\textsuperscript{1}Northeastern University, 110819, Shenyang, China. \textsuperscript{2}Northeastern University, 110819, Shenyang, China

E-mail: \textsuperscript{a}jiangyouqi_neu@163.com, \textsuperscript{b}zhaoyiding@vip.163.com.

Abstract. Temperature drift is one of the main error sources of mems gyroscope. This paper introduces a temperature control system which uses the pid control algorithm that optimized by ant colony algorithm to realize the accurate control of temperature. This paper introduces the overall block diagram of the system, focusing on the temperature collecting and control module and the flow chart of software programming. And the experiment is carried out on the basis of the designed system, the experimental data is displayed in the upper computer software via wireless module and serial port, and the data is analyzed. The analysis results show that the designed system can achieve high precision temperature controlling.

1. Introduction

The precision of mems gyroscope directly affects the accuracy of the measurement results. Temperature drift is an important factor that affects its accuracy, because its accuracy will shift as the temperature changes. The temperature compensation methods of bp neural network and lm_bp neural network are used in reference [1] and [2], respectively. This paper uses the stm32 mcu as the control core to realize the automatic and accurate control of temperature, the pid algorithm that optimized by ant colony algorithm is used. Compared with the traditional pid algorithm used in references [3] and [4], the pid algorithm optimized by the ant colony algorithm can accelerate the response of the system, and can reduce the overshoot and increase the stability of the system. Compared with neural network algorithm, ant colony algorithm is a new universal heuristic method for solving combinatorial optimization problems. And the system can also add wireless modules and other functional modules.

Based on the above description, the temperature control system is designed and many experiments are carried out. In this paper, the working characteristics of mems gyroscope are introduced firstly, including the effect of temperature on the accuracy of measurement. Then the temperature control system is introduced, including the overall block diagram of the system, temperature collecting module and the pid algorithm used by temperature control module and software design flow chart. The temperature curve is displayed in real time in the upper computer software. Finally, the data are analyzed and the conclusion is drawn.

2. Working characteristics of mems gyroscope

The mems gyroscope to be introduced in this article is adxrs620; the adxrs620 is a complete angular rate sensor that can measure yaw rate within ±300°. The output signal, rate out, is a voltage that is proportional to angular rate about the axis normal to the top surface of the package. The datasheet of adxrs620 shows that at a calibrated operating temperature of 25°C, the zero output of pin rateout is 2.5V and the sensitivity is is 6mv/°/sec.

After collecting the data with adxrs620 sensor, we need to convert the voltage value to the angular
velocity value. The process of processing the data requires the operation with the zero output voltage value and the sensitivity value. The angular velocity value is:

\[ \omega = \frac{(\text{measured value} - 2.5) \times 1000}{6} \]  

Therefore, we must ensure the accuracy of the zero output voltage and the sensitivity, otherwise the value of operation with the measured data will be greatly reduced. So we need to maintain the temperature of the sensor’s working environment at 25°C.

3. Hardware design of temperature control system

3.1. Block diagram

The block diagram of the overall structure of the system is shown in Fig. 1. It is consisted of temperature collecting and control module and wireless module and serial port module. In this system, the working environment temperature of the MEMS sensor can be real-time collected by the ds18b20 temperature sensor and transmitted to MCU, and the collected temperature data will be saved to the flash and transmitted to wireless modules, then displayed in the computer software.

![Figure 1. The system block diagram for the control system.](image)

3.2. Temperature collecting module

Temperature collecting module is digital temperature sensor ds18b20, when connecting with MCU it needs only one interface line to realize the two-way communication with MCU. The resolution of the ds18b20 is configurable (9, 10, 11, or 12 bits), equates to a temperature resolution of 0.5°C, 0.25°C, 0.125°C, or 0.0625°C, can realize high precision temperature measurement. The expected temperature control precision of the temperature control system designed in this paper is 0.5°C, so the resolution of the ds18b20 temperature sensor is programmed to be 11 bits, therefore it can distinguish the temperature of 0.125°C. It can ensure that the control precision of the temperature control system reaches 0.5°C.

3.3. Ant colony optimization of pid parameters

The driving control module adopts the l298n chip that can be controlled by the PID algorithm. The three parameters in the PID algorithm have different influence on the performance of the system, the proportional coefficient Kp affects the response speed of the system, the integral coefficient Ti influence the stability of the system, the differential coefficient Td influence the dynamic characteristics of the system. Therefore, it is necessary to optimize the three parameters in order to control the temperature accurately and enhance the stability of the system. In this design, ant colony algorithm is used to optimize PID parameters. In the PID controller system, let r be the input, y be the output, the control quantity u and the deviation e = (r - y) satisfy the difference equation that shown as formula (2).

In formula (2), u(n) is the control quantity, e(n) is the deviation, T is the sampling period. When the controlled object model and T are known, the PID controller only needs to determine the parameters of Kp, Ti, and Td. The moment integral of absolute error that shown as formula (3) is usually used as the
performance index in engineering.

\[ u(n) = K_p (e(n)) + \frac{1}{T_i} \sum_{i=0}^{n} e(k)T + T_d \frac{e(n) - e(n-1)}{T} \]  \hspace{1cm} (2)

In formula (3), DT is simulation calculation step, LP is simulation calculation points. Formula (3) can also be expressed in continuous form as shown in formula (4).

\[ Q = DT^2 \sum_{i=1}^{LP} i |e(i)| \]  \hspace{1cm} (3)

\[ Q = \int_{0}^{\infty} t|e(t)|dt \]  \hspace{1cm} (4)

The ant colony algorithm is used to optimize pid parameters, assume the total number of ants is n. for each ant i, the corresponding objective function value is defined as \( Q_i \).

\[ \Delta Q_{ij} = Q_i - Q_j, \forall i, j \]  \hspace{1cm} (5)

Define the transition probability of ant i at time t:

\[ P_{ij}(t) = \begin{cases} \frac{[\tau_{ij}(t)]^\alpha [\Delta Q_{ij}(t)]^\beta}{\sum_{r \in allowed} [\tau_{ir}(t)]^\alpha [\Delta Q_{ir}(t)]^\beta}, & j \in allowed \\ 0, & else \end{cases} \]  \hspace{1cm} (6)

In formula (6) : allowed represents the set of path points that ant i is allowed to pass next; \( \tau_{ij}(t) \) is the pheromone intensity at time t in the neighborhood of ant i.; \( \alpha \) represents the relative importance of the trajectory, reflecting the role of the information accumulated by ants during their movement, the greater the value, the more inclined the ant to choose the path of other ants, and the stronger the cooperation between ants; \( \beta \) indicates the relative importance of visibility, which reflects the importance of heuristic factor in ant selection path. The larger the value, the closer the transfer probability is to greedy rule. When searching for optimization, the ants are scattered on the dividing points according to the random principle, and record the elvish ants with the best evaluation function value, then, moving each ant according to the transfer probability given by formula (6). In the process of search, the adjacent search mechanism is embedded, when \( \Delta Q_{ij}(t) > 0 \), ant i moves from its neighbourhood to the neighbourhood of ant j by probability p;when \( \Delta Q_{ij}(t) \leq 0 \), ant i conducts its own neighborhood search to find a better solution. As time goes on, the amount of pheromones left behind is decreasing, here, \( \rho \) \((0 \leq \rho < 1)\) is the pheromone residue coefficient used to indicate the persistence of pheromone substances; \( 1 - \rho \) is called the pheromone volatility, it is directly related to the global search ability and convergence speed of ant colony algorithm. Because of the volatilization of pheromone, when the problem is large, it reduces the amount of information on the path that has never been searched to close to zero, so the global search ability of the algorithm is reduced, when the pheromone volatilization is too large, the possibility of the previously searched path being re-selected increases, which will also affect the global convergence performance of the algorithm [5, 6].

After k units of time, the pheromone intensity of the path moved by ants was adjusted according to the formula (7) and (8):

\[ \tau_{ij}(t + k) = \rho \tau_{ij}(t) + \Delta \tau_{ij} \]  \hspace{1cm} (7)
\[ \Delta r_{ij} = \sum_{t=1}^{n} \Delta r'_{ij} \]  

(8)

In formula (8), \( \Delta r'_{ij} \) denotes the unit length of pheromone material left by ant \( l \) on path \( ij \) in this cycle. \( \Delta r'_{ij} \) can be calculated according to formula (9):

\[ \Delta r'_{ij} = \begin{cases} 
\frac{F}{Q_l}, & \text{ant } l \text{ pass path } ij \text{ in this cycle} \\
0, & \text{else}
\end{cases} \]  

(9)

In formula (9): \( F \) is constant; \( Q_l \) represents the value of the target function of ant \( l \) in this cycle.

After each search, the ant will update according to the update rules of ant pheromone given by formula (6) ~ (8). By repeatedly repeating the above process, the ant colony will eventually find the optimal solution of the \( pid \) controller parameter. The specific implementation steps are:

1. Parameter initialization, let time \( t = 0 \) and iterations \( N = 0 \);
2. Put \( n \) ants in their respective initialization neighborhood, each ant is moved according to the transfer probability given by the formula (6);
3. Calculate the objective function of each ant \( Q_l \) (\( l = 1, 2 \ldots n \)), and record the current optimal solution of \( pid \) Controller.
4. Modify the pheromone strength according to the pheromone update equation given by formula (6) ~ (8).
5. Cycles \( N+1 \).
6. If \( N < \) the number of scheduled iterations, turn to step (2).
7. Output the optimal solution of \( pid \) Controller.

The parameters of the \( pid \) controller optimized by ant colony algorithm are brought into formula (2) and the control quantity is calculated. Therefore, \( pwm \) wave with different duty ratio is generated according to the control volume, input to the drive chip \( l298n \), and then control the working power of the semiconductor cooler \( tec \). The choice of cooling and heating mode of semiconductor cooler is controlled by \( mcu \), when the collected temperature value is higher than the target temperature value, the \( mcu \) generates the control signal to drive the \( tec \) refrigeration, and else the \( mcu \) generates the control signal to drive the \( tec \) to heat. The \( pid \) controller optimized by ant colony algorithm can improve the response speed of the system and reduce the overshoot and increase stability of the system [3].

3.4. Hardware Improvement of Temperature Control System

In order to ensure the accuracy of temperature measurement and speed up the response. The box that containing the \( mems \) gyroscope needs to have good temperature preservation. Therefore, a kind of low thermal conductivity and good thermal insulation material, glass cotton, was selected and installed inside the box containing \( mems \) gyroscope, \( mems \) gyroscope is a device for measuring the vibration angular velocity of an object, and the glass cotton has a small bulk density, so it is light and does not affect the vibration of the object. With this material, it is easier to maintain a constant temperature environment; the measured temperature data are also more reliable. And the temperature sensor \( ds18b20 \) works in high precision mode, and the distinguishable temperature value is 0.125 °C, so the temperature control system can achieve the goal of 0.5 °C control precision.

In this design, a wireless chip \( cc1101 \) with strong penetration ability is selected. The temperature data can be transferred from the box that containing the \( mems \) gyroscope to the \( mcu \) outside the box, and then transmitted to the host computer through the serial port module, and the wireless chip has low power consumption and long transmission distance. It can adapt to the complexity of the working environment of \( mems \) gyroscope, and it is also very important that the packet error rate of the chip is very low, which can ensure the accuracy of the transmitted temperature data.
3.5. Software Design of Temperature Control System
The software design flow of the temperature control system is shown in Fig. 2. After power on, the functional modules of the system are initialized, then set the temperature value we need, and the ds18b20 temperature sensor will collect the temperature value. In order to reduce the accidental error in acquisition, take the average value of 20 consecutive samples and compared to the setted temperature value. Then the difference is obtained by the pid algorithm optimized by the ant colony algorithm and the control quantity is obtained. The power of the semiconductor cooler is controlled by pwm with different duty cycle, and the temperature is transmitted to the wireless module. The state of refrigeration or heating is determined by the difference between the average value of the collection temperature value and the set value. During the working process of tec, the temperature values are collected by ds18b20 temperature sensor every second. When the temperature value falls 0.5 °C above or below the setted temperature value, that is [24.5 °C, 25.5 °C], tec stop work. And then start the next cycle.

![Figure 2. The flow chart for temperature control system.](image)

4. Experiment and conclusions

4.1. Cool test
Before the experiment, the temperature in the box installed with mems sensor is 23 °C. The target temperature is 15 °C, and the dynamic data curve is shown in Fig. 3.

4.2. Heat test
Before the experiment, the temperature in the box installed with mems sensor is 23 °C. The target temperature is 30 °C, and the dynamic data curve is shown in Fig. 4.

It can be seen from Fig. 3 and Fig. 4 that the refrigeration and heating function of the temperature control system of tec is normal. The temperature is basically stable near the target temperature after one or two oscillations. The response time is less than 3 minutes. The response speed is fast, and after 15 minutes of system operation, the temperature curve still maintains good stability, and there is no big fluctuation.

The temperature control accuracy of tec temperature control system is tested. The laboratory temperature was 23 °C at the time of the test. The target temperatures are 35 °C, 30 °C, 25 °C, 20 °C, 15 °C, respectively. Each of the five target temperatures was tested for temperature control. Let the system run for 15 minutes. When the system enters the stable state, the temperature is measured. The measurement results are shown in table 1.
5. Conclusions
According to the data analysis of the test results, the maximum deviation of the temperature control of the system is 0.5 °C after the system has entered the steady state for a long time. That is to say the temperature control precision can reach 0.5°C, so the design of temperature control system meet the requirements.

![Figure 3. The cool test.](image3)

![Figure 4. The heat test](image4)

Table 1. The deviation at different target temperatures.

| Group | Target temperature(°C) | Stable temperature(°C) | Deviation(°C) |
|-------|------------------------|-------------------------|---------------|
| 1     | 35                     | 35.3                    | 0.3           |
| 2     | 30                     | 29.7                    | 0.3           |
| 3     | 25                     | 25.2                    | 0.2           |
| 4     | 20                     | 19.9                    | 0.1           |
| 5     | 15                     | 15.5                    | 0.5           |

6. References
[1] Qintuo Zhang, Compensation of temperature drift of MEMS gyroscope using BP neural network, 2009 International Conference on Information Engineering and Computer Science.
[2] Dacheng Xu, A Temperature Compensation Method for MEMS Accelerometer Based on LM_BP Neural Network, Instrument Technique and Sensor, No.11 (2015).
[3] Hui Huang, Design of a small Temperature Control System Based on TEC, 2016 9th International Symposium on Computational Intelligence and Design.
[4] Yue Caiqing, Based on MCU AT89S52 Temperature Control System, Applied Mechanics and Materials, 2014, Vol. 441, pp 875-878.
[5] Shaofei Wu, Study on an Improved Algorithm for Optimization of PID Parameters, International Journal of Online Engineering, Vol 12, No 02 (2016).
[7] M. Aabid, PID Parameters Optimization Using Ant-colony Algorithm for Human Heart Control, proceedings of the 23rd International Conference on Automation & Computing, University of Huddersfield, UK, 2017.