Research on Intelligent Control and Integration Technology for Visual Inspection of TEC Components

Zhishan Cai 1,2*, Jiangwei Chen 2, Shaobin Yan 2, Shizhan Li 2 and Tingdi Liao 1,2

1 School of Physics and Information Engineering, Quanzhou Normal University, Quanzhou 362000, Fujian, China.
2 Photonic Technology Research Center of Quanzhou Normal University, Quanzhou 362000, Fujian, China.

Email: 561390880@qq.com.

Abstract. Technical schemes such as uniform TEC component feeding, posture adjustment, multi-station positioning, and communication between upper and lower machines were designed. The opto-electromechanical integration mechanism was integrated by software to realize the detection of TEC component surface defects, and qualified TEC components were separated from unqualified TEC components by blow sieving. Adopt ARM MCU for real-time control; Image recognition adopts the machine vision deep learning platform based on Linux to learn and recognize the TEC components, and sends the results to the lower computer for sieving. The accuracy of triggering the camera to take pictures is 99.9%, which provides a guarantee for capturing and processing images accurately. The accuracy of blow sieving is over 99.9%, which can meet the sieving requirements. The electrical control system of the whole machine can meet the motion control requirements of detection.

Keywords. TEC components, STM32F407 MCU, Intelligent control, Integration technology, uC/OS-iii operating system.

1. Introduction
Thermoelectric cooler consists of several pairs of P-type and N-type TEC components, which are combined together through the series connection of circuits and the parallel connection of heat. A certain current is applied to the two electrodes of the device to dissipate the heat at the hot end, and the cold end can be cooled continuously. In the production process, various semiconductor materials are smelted, crystal pulled, sliced, electroplated and granulated, and finally TEC components are obtained.

In the process of slicing and granulating, due to the limitation of the existing technology, it is easy to cause defects in shape and size such as crystal crack, corner collapse, edge missing, etc. The existence of these surface defects will lead to the virtual welding and life reduction of TEC components, which will affect the performance of products. Therefore, it is necessary to strictly sieve the TEC components after granulating. At present, the methods of manual visual inspection and manual selection are widely used in TEC component sieving in the industry. However, this method has some shortcomings, such as strong subjectivity, low efficiency, easy to make mistakes, high labor cost, etc., which limits the further improvement of the performance, quality and output of semiconductor refrigeration devices, and has been unable to meet the high-speed and high-precision index requirements of modern industry, and has become one of the main bottlenecks restricting the development of enterprises. However, the automation equipment of machine vision [1-3] can not only overcome the above shortcomings and work for a long time instead of manpower, but also meet the product precision requirements [4-7]
which are difficult to achieve by artificial vision.

2. Electrical Control Scheme Design
According to the technical requirements of TEC component detection accuracy of 90%, detection speed of 8 TEC components/second and length detection accuracy of ±0.02 mm, a set of opto-electromechanical integration control scheme based on visual inspection was designed.

TEC components are generally rectangular in shape, which can be divided into N-type TEC components and P-type TEC components. The number of N-type TEC components and P-type TEC components contained in cooling plates with different cooling powers and the sizes of TEC components are different. The TEC component size detected by this system is 1.32×1.32×2.1 mm³, so it is necessary to detect four rectangular sides and the length of each side of the TEC component.

2.1. Overall Scheme
The main content of electrical control consists of four parts, namely: TEC component feeding and posture shaping; Image trigger photographing and sieve blowing control; Machine action control; Communication between upper and lower computers and debugging data processing; Image processing and recognition. The first four technologies are the research contents of this paper, and image processing is not the research scope of this paper.

TEC component feeding requires uniform delivery of TEC components to the glass turntable. Because the arrangement and orientation of the TEC components are not completely consistent when they are delivered to the turntable, which cannot meet the requirements of image processing, it is necessary for the shaping mechanism to adjust the posture when the TEC components enter the turntable and arrive at each station. The purpose of station detection and control is to trigger and take pictures of three camera stations and control the sieve blowing of two sieve blowing stations. The starting, running, speed adjustment, pause/emergency stop and servo motor control of the machine are all controlled by the lower computer. The upper computer needs to communicate frequently with the lower computer for image collection and processing results distribution, and various statistical data in the debugging process also need the lower computer to communicate frequently with the debugging interface.

The upper computer is only responsible for image storage, recognition and result distribution, and other functions are undertaken by the lower computer. The selection of the lower computer needs to consider: calculation speed, number of communication interfaces (serial ports), number of I/O ports, data storage capacity, etc. Considering comprehensively, select hard stone STM32F407 board, which is a motion control board based on industrial control design and can undertake: (1) closed-loop control of AC servo motor; (2) TEC component detection and station positioning; (3) Light control and trigger photographing; (4) receiving the image recognition result of the upper computer and carrying out sieving; (5) Function buttons such as power on and off, pause and emergency stop of the machine; (6) Communication with debugging assistant. As shown in figure 1.
2.2. Uniform Feeding and Avoiding Material Jamming Control

The feeding mechanism should enable the TEC components to be fed to the glass turntable with adjustable speed, uniform speed, equal spacing and lying position. Due to the different sizes and special shapes of TEC components, it is easy to jam in the feeding process, and measures should be taken to avoid jamming as much as possible. The feeding control process is as follows: (1) After the TEC components enter the direct vibration from the circular vibration plate, the standing TEC components are first blown back to the circular vibration plate through a height-limiting blowing port, and the height of the blowing port should be between the width and length of the TEC components; (2) The TEC components enter the transverse width-limiting groove section. The distance (groove width) between the lateral limit block in the figure and the edge of the feeding trough is adjustable. If the TEC component passes through this groove section horizontally, it will fall back to circular vibration because the center of gravity of the TEC component exceeds the edge of the feeding trough, thus avoiding material jamming. Groove width is usually slightly larger than half of TEC component width and far smaller than half of TEC component length, so as to achieve good filtration effect. (3) Two pairs of negative pressure suction holes are opened in the rear section of the discharge port, which aims to control the discharge speed of TEC components and make them be fed into the turntable at a uniform speed and at equal intervals. The center distance between the two suction ports is slightly longer than the TEC component length. When the TEC component passes through the suction port 1, it will be sucked twice by negative pressure. As long as the intensity and frequency of negative pressure are controlled, the speed of the TEC component can be controlled. When the TEC component passes through two pairs of suction ports successively, it can basically achieve the effect of uniform delivery of the TEC component to the turntable. (4) Install a laser sensor at a suitable position between the width-limited groove section and the air inlet 1 to control the feeding speed of the circular vibration. Generally, the feeding speed of circular vibration is greater than the discharging speed of direct vibration. In the feeding process, due to the speed adjustment of air inlet 1, it will lead to TEC component accumulation and material jam. The laser sensor can detect whether there is material accumulation at the sensor position, so as to control the start/stop of the circular vibration. The schematic diagram of the direct vibration feeding mechanism is shown in figure 2, and the physical diagram is shown in figure 3.

![Overall control scheme diagram.](image)

**Figure 1.** Overall control scheme diagram.
2.3. **TEC Component Posture Adjustment Mechanism**

When the TEC component passes through three camera stations successively, it is required to move along the same circular track and in the same direction, so that the TEC component pictures taken by the camera can be easily identified and processed. Therefore, when the TEC components enter the turntable at a uniform speed close to equal spacing, attitude adjustment is required. The shaping wheels are shown as the B and C wheels in figure 4. The debugging process shows that runners B and C need to rotate in opposite directions, the arc length of shaping contact between runner B and TEC components is about one quarter of that of runner, and runner C adjusts TEC components to the tangential direction by the position of tangent point. Rotating speed of runner B is slightly faster than that of turntable, while rotating speed of runner C is slightly slower than that of turntable. At first, the turntable is used to drive the A wheel to drive B and C, and the results need to be improved in the test. Later, the speed of the B and C wheels is controlled by MCU through a DC motor, which improves the shaping effect.

2.4. **Single Sensor Multi-Station Control Principle**

The MCU of the main control board drives the servo motor with a certain frequency signal, and the servo motor encoder returns the position information (pulse) in real time to realize accurate position control. The main frequency of MCU is about 15,000 pulses/second.

Is a sensor installed at each position of camera station and blowing sieve station to detect TEC components, or is only one position sensor used for positioning at all stations? After comparing hardware and installation, software debugging and other aspects, only one sensor is selected to locate five stations. The method is that the sensor is installed at an appropriate position between the outlet of the direct vibration feeding port and the camera 1 as the coordinate (pulse) zero point. After the installation position of each station is fixed, it can be debugged manually, and the pulse positions (pulse numbers) between the three cameras, two sieves and the coordinate zero point can be determined. The starting position of each circle is the coordinate zero point (origin of coordinates).
When the TEC components pass through the position sensor in sequence, the MCU can record the real-time position of each TEC component away from the zero point. After the TEC components pass through the blowing sieve port, the coordinates of the TEC components will return to zero.

2.5. Communication between Upper and Lower Computers
The upper computer needs to constantly send the TEC component picture recognition results to the lower computer for storage and processing. The lower computer needs to send the real-time feeding speed, total feeding amount, qualified/unqualified number and the detection number of each camera station to the debugging interface, so as to facilitate integrated debugging and testing. These data are sent and received through the same serial port.

3. Control Software Design and Debugging

3.1. Software Design
The lower computer control software is designed based on uC/OS-iii real-time operating system. UCOSIII is a multi-task, clipping and priority-based real-time kernel. The tasks involved here are: servo motor control, camera trigger photographing, TEC component position recording, blowing sieve control, feeding control, shaping control, etc. In particular, the communication between the upper and lower machines is frequent and the real-time requirements are strict, so the operation system is adopted [8-10].

Main program flow: system initialization includes resetting peripherals, initializing flash interface and system tick timer; uC/OS-iii real-time operating system enables multitasking environment, including initializing uC/OS-iii kernel, creating tasks, starting tasks, and finally handing over control rights to uC/OS-iii.

Servo motor control task includes acceleration and deceleration processing; The key processing tasks include the control of machine table, turntable, camera trigger and sieve blowing. The task is suspended after execution, and is not released until the system receives the control command, so as to reduce the CPU occupancy.

The task of real-time TEC component location processing is the key and difficult point in all tasks, which mainly includes the following functional modules: pulse recording of TEC component entering the starting position, TEC component numbering, obtaining encoder pulse signal, TEC component position judgment processing, and TEC component photographing result processing. The main flow chart and sub-function flow chart of this task are shown in figure 5 and figure 6.

![Figure 5. Main program flow.](image5)

![Figure 6. Flow chart of TEC component real-time positioning processing task.](image6)
The processing function of TEC component position detection is to realize accurate camera shooting and TEC component sieving. uC/OS-iii adopts preemptive task priority scheduling, and the tasks with high priority can preempt the tasks with low priority for optimal execution. We make the task with the lowest priority for TEC component position judgment, but the CPU occupancy rate is the highest, so as to ensure that the TEC component position can be judged in time.

The focus of the lower computer program control is real-time processing. On the one hand, the motor pulse drive uses the advanced timer to output PWM waveform, and then uses the encoder function of the timer to count the feedback pulses. This process will no longer occupy CPU resources as long as it is initialized, so that the camera can be triggered accurately after the TEC component obtains the real-time position, so as to ensure that the TEC component can be in the middle of the field of view after each trigger. On the other hand, in the case of fast TEC component processing speed, the communication between the lower computer and the upper computer is frequent, so the lower computer should reduce the execution time in the interrupt service program, and the serial port can cooperate with DMA function to reduce the interrupt frequency.

3.2. Debugging Method
During debugging, it is necessary to observe multiple data parameters and real-time images. For image photographing and debugging, the software of industrial camera can be used. For data observation, it is necessary to rely on debugging assistant as a dialogue window between engineers and machines. The functions realized by the debugging assistant include: (1) motion control of sieving machine, trigger control of camera and light source; (2) position initialization setting of each station; (3) Statistical data of recognition results of TEC components by upper computer; (4) image processing timeout information.

4. Data Analysis

4.1. TEC Component Posture Adjustment
Measurement method: (1) Calibrate the flatness of glass disc turntable. Measured with a dial indicator is ±0.2mm, which meets the requirements; (2) simulating vibrating plate feeding, and placing TEC components on the glass plate; (3) after passing through the shaping wheel, the TEC components are sent to the required field of view of the camera by the glass turntable; (4) adding a new whole-angle mechanism; (5) Take pictures of all passing TEC components by the camera at the first station; (6) Import the pictures into CAD software to measure the angle of each TEC component. The measurement pictures and statistical data show that 94.47% of the TEC components deviate from the inspection benchmark analysis within 4° when they arrive at the camera station, which meets the requirements of length precision measurement.

4.2. Camera Shooting Accuracy and Joint Adjustment of Upper and Lower Machine Functions
Test conditions: (1) TEC component speed is 8 TEC components/second. (2) Field of view parameters. The field of view should be within 4mm*6mm, so an industrial camera with 2 million pixels is selected with a lens with a magnification of 1.5. The pixel size of the camera is 4.5nm. After calculation, the actual size of the field of view is 3.6 mm * 5.76 mm.

4.2.1. Verification of Camera Shooting Accuracy. When the TEC component passes through each camera station, it should be able to trigger and take pictures accurately, without missing inspection or triggering. During the test, the number of triggered photos at the three stations was counted by the camera's own software, and the statistics were carried out by Matlab. As long as the TEC components did not exceed the center point of the field of view by 0.7mm, the processing requirements of pictures could be met. In particular, the parameters of "return clearance" of the reducer have a direct impact on whether the camera can take pictures accurately. The smaller the "return clearance", the more accurate the pictures will be. The "return clearance" of the reducer used in this study is divided into five arcs.
The data is shown in figure 7.

**Figure 7.** photographing accuracy data of three camera stations

4.2.2. Function Coordination and Detection of Upper Computer and Lower Computer. In order to adjust the logic of TEC component identification process of sieving machine properly, a camera is used for debugging first, that is, the upper computer program is only processed according to the situation of one camera, and the lower computer program is only controlled according to the situation of one camera. There are 160 TEC components per disc, and the data of making the TEC components pass through the camera completely for 16 times is shown in table 1.

**Table 1.** Verification that the lower computer receives the processing results of the upper computer under the condition of a single camera.

| Measure serial number | Limit time (ms) for sending results to the next machine. | Statistical Data | NG number (pieces) | OK number (pieces) | Timeout times (times) |
|-----------------------|--------------------------------------------------------|-----------------|-------------------|-------------------|---------------------|
|                       | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting |
| 1                     | 120                      | 2560            | 2560              | 582               |                     |
| 2                     | 200                      | 2560            | 2560              | 0                 |                     |

From the time when the upper computer receives the camera trigger photo signal → taking pictures → image recognition processing → processing results to the lower computer, the shorter the time, the faster the upper computer processes the TEC components. In the table above, "the limit time (ms) for sending results to the lower computer" means that if the lower computer does not receive the processing results sent by the upper computer within this time, it will output "timeout" to indicate that the processing of a certain TEC component has timed out. If calculated at the speed of 8 TEC components/second, the longest average processing time of each TEC component is 125ms. The limit time (ms) for sending results to the lower computer can be set by the debugging assistant of the lower computer.

It can be seen from table 1 that the TEC component statistics function and communication function of the upper and lower computers are normal; The number of "timeout" increases because of the long
time of image processing in the upper computer.

4.2.3. Test of Image Processing Time of Upper Computer. It can be seen from table 2 that the TEC component statistics function and communication function of the upper and lower computers are normal; in the case of a single camera, the process time of processing pictures by the upper computer will hardly exceed 170 ms. If this time is too long, the image recognition program needs to be optimized.

| Measure serial number | Limit time (ms) for sending results to the next machine | Statistical data | NG number (pieces) | OK number (pieces) | Timeout times (times) |
|-----------------------|--------------------------------------------------------|------------------|-------------------|-------------------|----------------------|
|                       |                                                        | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting | Lower computer counting |
| 1                     | 150                                                    | 160              | 160               | 79                | 79                   | 81                    | 81                    | 21                    |
| 2                     | 160                                                    | 160              | 160               | 76                | 76                   | 84                    | 84                    | 4                     |
| 3                     | 170                                                    | 160              | 160               | 80                | 80                   | 80                    | 80                    | 1                     |

4.2.4. Communication Test of Upper Computer and Lower Computer in Multi-Camera Situation. Based on the results in table 2, the image processing time of the upper computer with a single camera is generally not more than 170ms, and the logic of communication and cooperation between the upper computer and the lower computer in processing of TEC components is normal. Change the number of cameras processed by upper and lower computer software to the normal situation of 3 cameras for testing. The data are shown in table 3.

| Measure serial number | Limit time (ms) for sending results to the next machine | Camera position | Statistical data | NG number (pieces) | OK number (pieces) | Timeout times (times) |
|-----------------------|--------------------------------------------------------|----------------|------------------|-------------------|-------------------|----------------------|
|                       |                                                        | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting | Upper computer counting | Lower computer counting | Lower computer counting |
| 1                     | 170                                                    | Pos1            | 160              | 160               | 160               | 0                     | 0                     | 3                     |
|                       |                                                        | Pos2            | 137              | 137               | 137               | 0                     | 0                     | 4                     |
|                       |                                                        | Pos3            | 119              | 119               | 119               | 0                     | 0                     | 2                     |
|                       |                                                        | Pos1            | 160              | 160               | 160               | 0                     | 0                     | 1                     |
| 2                     | 200                                                    | Pos2            | 136              | 136               | 136               | 0                     | 0                     | 2                     |
|                       |                                                        | Pos3            | 119              | 119               | 119               | 0                     | 0                     | 1                     |
|                       |                                                        | Pos1            | 480              | 480               | 480               | 0                     | 0                     | 0                     |
| 3                     | 210                                                    | Pos2            | 457              | 457               | 457               | 0                     | 0                     | 0                     |
|                       |                                                        | Pos3            | 440              | 440               | 440               | 0                     | 0                     | 0                     |

It can be seen from table 3 that the TEC component statistics function and communication function of the upper and lower computers are normal; The accumulated timeout time of the three cameras in the process of processing images has been greatly increased. In this case, it is almost impossible to complete the speed index of 8 TEC components/second, so the image processing software needs to be
optimized.

5. Conclusion
The whole machine integration technology of sieving machine focuses on the real-time and accuracy of photographing and the real-time and accuracy of data communication between upper and lower computers. Through the test, the camera and communication functions of the machine meet the technical requirements, and the data index (excluding image recognition) meets the task requirements. A large number of tests show that the main functions are stable and reliable, which provides a guarantee for accurate sieve blowing.

Acknowledgments
Fund Project: Major Science and Technology Project of Fujian Province (2019Hz 020010); Guiding Project of Fujian Science and Technology Department (2021H0052).

References
[1] Tao X, Hou W and Xu D 2021 A survey of surface defect detection methods based on deep learning Acta Automatica Sinica 47(5) 1017–34 doi: 10.16383/j.aas.c190811
[2] Huang Y B, Qiu C Y, Wang X N, et al. 2020 A Compact Convolutional Neural Network for Surface Defect Inspection 20(7)
[3] Lv X M, Duan F J, Jiang J J, Fu X and Gan L 2020 Deep active learning for surface defect detection J. Sensors (Basel, Switzerland) 20(6)
[4] Kang Y X, Chen G H, Zhang S B, Chen X Y and Sun Y B 2017 Chip resistance direction detection system based on Halcon Packaging Engineerin 38(023) 116-120.
[5] Zhao L 2013 Research and Application of Defect Detection Method Based on Image Processing (Nanjing: Nanjing university of post and telecommunication).
[6] Zu S L and Xiao S H 2020 Research on location detection method of SOP patch element based on machine vision Machine Tool & Hydraulics 48(7) 29-33, 46.
[7] Li Q C 2006 Research on machine-vision-based smd location and inspection technology of mounter system (Xi'an: Xi'an University of Technology).
[8] Zhang J and Zhang K 2004 Research and implementation of porting Rtos uC/OS-II to ARM7 J. Computer Engineering and Application (04) 100-102+153.
[9] Li Q, Liu S, Liu M S, Liang Y 2020 The design of BMS software based on embedded operating system uC/OS-II J. Electrical Application 39(02) 85-90.
[10] Sha D P and Peng G 2018 Construction of an embedded system based on uC/OS J. Automation and Instrumentation 33(04) 91-94+108.