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Fully Automated Dispensing System Based on Machine Vision

Xiang Liu, Bo Huang

College of Mechanical Engineering, Sichuan University of Science & Engineering, Zigong 643000, China

ABSTRACT

The manual dispensing and semi-automatic dispensing process in small and medium-sized electronic enterprises has the problems of low productivity and large dispensing positioning errors. This study takes RJDNEL-type PCB boards as the research object, proposes a fully automatic dispensing method based on machine vision, and plans the dispensing path. The method is based on vision imaging technology, and the optimized minimum outer rectangle algorithm is used to complete the extraction of dispensing positioning information; combined with the proposed path planning method based on a simulated annealing algorithm, the operational efficiency of the dispensing system is improved. The experimental results show that: the dispensing efficiency of the proposed path planning method is improved by 20%~30% compared with the traditional method; the positioning accuracy error of the system is less than 0.02mm; the matching accuracy is more than 99%, and the matching point positioning accuracy error is less than 0.02mm, which effectively improves the dispensing accuracy and dispensing efficiency while satisfying the dispensing quality.

KEYWORDS

Machine Vision; Dispensing Machine; Localization Information Extraction; Simulated Annealing Algorithm; Path Planning

1. INTRODUCTION

Automated machines instead of traditional manual manufacturing, can be called the product of cross-generation thinking, the birth and popularization of the application of machine vision technology is the practice of this cross-generation thinking. Machine vision system unlike the manual vision system has the advantages of high precision, speed, efficiency, reliability, and better performance[1]. The small circuit board dispensing system is no longer a simple dispensing module, but the machine vision module, host computer processing module automatic control module, and other functional modules fusion integration, because of its unique features and advantages have been developed and expanded, but also become the leading technology for electronic product dispensing positioning and packaging. Dispensing products based on the vision system application object 40% to 50% concentrated in the field of electronic processing and semiconductor industry, mainly concentrated in the United States, Switzerland, Japan, and other image processing technology more developed countries and regions[4], integrated fully automated dispensing equipment is the production of dispensing machine system of a mainstream direction[5]. However, in the field of small, microelectronic product packaging, given the diversity of dispensing packaging product types and models, packaging precision requirements, complex application environment, etc., the development of its dispensing packaging technology and equipment system independent development speed is relatively slow. Domestic large and medium-sized dispensing equipment systems mainly rely on foreign technology and products to achieve high precision and automation, while small and medium-sized enterprises, limited by cost and other reasons, or choose to use a lower degree of automation of semi-automatic dispensing equipment or even manual operation to complete the production, to a greater extent, restricting the formation of China's independent industrial chain of electronic products and supply.

2. WORKING PRINCIPLE OF THE DISPENSING SYSTEM

2.1. Positioning method

Through the human-computer interaction platform for automatic dispensing position detection, the process is mainly divided into image acquisition, image processing, position coordinate extraction, and output. First of all, install and configure image equipment and acquire image acquisition equipment, create video input objects, preview the acquisition of real-time images, and then create an image acquisition object in the settings of the camera can be pre-set exposure, gain, and other pre-settings, the acquisition of PCB board images. A series of image processing is performed on the captured image, using the Sobel algorithm to extract the edges of the dispensing area and using the Hilditch algorithm and edge refinement. By finding out the minimum external rectangle of the dispensing area, the length, and width of the minimum external rectangle to approximate the maximum length and width of the equivalent dispensing area, and the use of Matlab image processing techniques in the regionprops function[6] extracted the dispensing area of the area value through the extraction of the dispensing area of the width to length ratio, the minimum external rectangle of the four vertices of the coordinates of the known, the dispensing area of the center of the point, and then the dispensing area of the center coordinates of the point. The area of the center of the coordinates of the point, and then through signal transmission will coordinate information transmitted to the motion controller compilation, dispensing needle movement to the correct dispensing position. The technical route is shown in Figure 1.

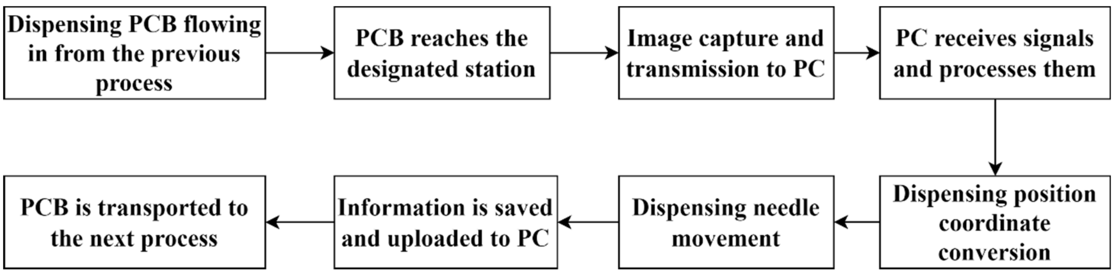


Figure 1 Schematic diagram of the technical route

2.2. Vision dispensing camera calibration and path optimization

In the dispensing process, because the object information parameters collected by the camera can not be directly applied to the robot dispensing, the dispensing vision system camera needs to be calibrated by eye to hand, in machine vision, the purpose of eye-to-hand calibration is to obtain the relationship between the coordinate system of the robotic arm and the coordinate system of the camera, and ultimately, the results of the image acquisition and recognition is transformed into the end of the robotic arm coordinate system[7]. This paper adopts Eye to hand calibration method for calibration, after the positioning information of the dispensing object is extracted, if the identified point coordinates are directly sent to the motion control, the dispensing will be carried out by the order of sending, which can not ensure that the dispensing path is optimal, which requires the introduction of the path optimization algorithm, and then send to the control system through the corresponding optimization algorithm after the optimization of the dispensing path is good, which can effectively improve the dispensing efficiency. This can effectively improve the dispensing efficiency. Before the conversion of coordinate points, it is necessary to extract multiple pixel coordinates and the corresponding array of dispensing needle mechanical coordinates, substituting into the coordinate conversion formula with set camera parameters (dispensing camera internal reference, external reference, and aberration parameter, etc.), and then carry out transposition and other processing, and finally output the actual dispensing coordinate points. Coordinate point conversion in the host computer software, the conversion process is shown in Figure 2.

In the process of automatic continuous dispensing by the dispensing system, to optimize the path traveled by the dispensing needle in the dispensing system, path planning is used to realize the shortening of the dispensing path and to improve the working efficiency of the dispensing system. Initially, two dispensing path methods are analyzed. Figure 3 (2) shows the order of dispensing after the optimization of the dispensing path, the dispensing needle from the origin, running to point 1 for dispensing, dispensing is completed without returning to the origin, directly to the target points such as No. 2, No. 3, the final dispensing is completed to return to the origin, compared to the traditional dispensing path such as Figure 3 (1) each time the completion of the dispensing to return to the origin, the entire dispensing path is clear, the efficiency of the dispensing can be greatly improved, and after that, can carry out the The coordinate error can be revised to meet the accuracy requirements.

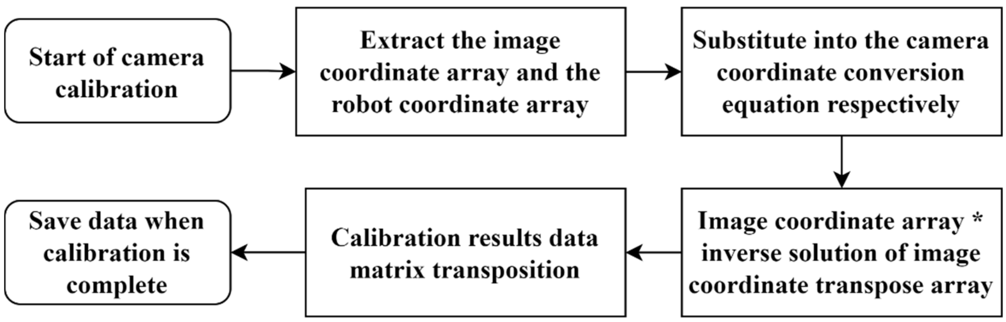
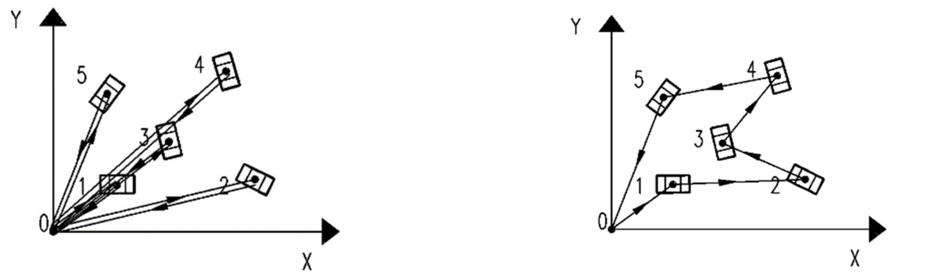


Figure 2 Coordinate conversion process



(1) Traditional dispensing path (2) Improved dispensing path

Figure 3 Multi-target dispensing position path analysis

For multiple dispensing position path problem can be resolved as the dispensing head from the origin, without repeating through each dispensing center point location, and ultimately return to the origin of the process, which belongs to the traveler[9] problem. Combined with the characteristics of the dispensing system and the dispensing object in this paper, the simulated annealing algorithm is selected to plan and solve the dispensing path, and the simulated annealing algorithm flow chart is shown in Figure 4.

Based on the simulated annealing algorithm process, the algorithm is analyzed: assuming that the N_{ij} (i=1,2,…,M; j=1,2,…P) matrix is the set of nodes in the dispensing path, and thus the total demand T_j (j=1,2,…,P) in the j-direction can be calculated for the path in the M-direction, which can be found as $T_j = n_{j1}r_1 + n_{j2}r_2 + \cdots + n_{jM}r_M$ as shown in equation (2-1):

$$T_j = \begin{bmatrix} N_{11} & N_{12} & \cdots & N_{1M} \\ N_{21} & N_{22} & \cdots & N_{2M} \\ \cdots & \cdots & \cdots & \cdots \\ N_{p1} & N_{p2} & \cdots & N_{pM} \end{bmatrix} \cdot \begin{bmatrix} r_1 \\ r_2 \\ \cdots \\ r_M \end{bmatrix} = \sum_{i=1}^{M} n_{ji} r_i \quad (2\text{-}1)$$

The ideal demand in direction j can be calculated by the above equation, and by the same token, the demand in direction j can be calculated for S positions as shown in equation (2-2):

$$C_{js} = N_{j1} \cdot x_{1s} + N_{j2} \cdot x_{2s} + \cdots + N_{jM} \cdot x_{Ms} = \begin{bmatrix} N_{11} & N_{12} & \cdots & N_{1M} \\ N_{21} & N_{22} & \cdots & N_{2M} \\ \cdots & \cdots & \cdots & \cdots \\ N_{p1} & N_{p2} & \cdots & N_{pM} \end{bmatrix} \cdot \begin{bmatrix} x_{1s} \\ x_{2s} \\ \cdots \\ x_{Ms} \end{bmatrix} = \sum_{i=1}^{M} n_{ji} \cdot x_{is} \quad (2\text{-}2)$$

Since the direction of the path from a dispensing point is random, the direction of the dispensing path must be compared, and only through comparison can the path be better optimized:

$$E = Min(|C_{1js}(t) - C_{2js}(t)|) \quad (2\text{-}3)$$

By using equation (2-3), we can derive the first S(S=1,2,3,...,P) positions of the direction j(1,2,3,...,P) in the total path planning in the total dispensing path direction, and then by using the squared sum of the deviation of the ideal usage and the actual usage, we can derive the objective function of the optimized direction consumption rate as equation (2-4):

$$F = \min \sum_{r=1}^{R} \sum_{j=1}^{P} (S \cdot \frac{\sum_{i=1}^{M} n_{ji} \cdot r_i}{\sum_{i=1}^{M} r_i} - \sum_{i=1}^{M} N_{ji} \cdot x_{is})^2 = \min \sum_{i=1}^{R} \sum_{j=1}^{P} (S \cdot d_j - C_{js})^2 \quad (2\text{-}4)$$

The constraints in the equation include:

$$\sum_{i=1}^{M} x_{is} = s, i = 1,2,\cdots,M; s = 1,2,\cdots,R \quad (2\text{-}5)$$

$$x_{is} - x_{i,s-1} \le 1, i = 1,2,\cdots,M; s = 1,2,\cdots,R \quad (2\text{-}6)$$

$$x_{is} - x_{i,s-1} \ge 0, i = 1,2,\cdots,M; s = 1,2,\cdots,R \quad (2\text{-}7)$$

$$0 < x_{is} < r_i, i = 1,2,\cdots,M; s = 1,2,\cdots,R \quad (2\text{-}8)$$

Thus, the optimal path space solution is finally determined: $N_{ij} = [K_{p1}, T_{i1}, T_{d1}; K_{p2}, T_{i2}, T_{d2}]$.

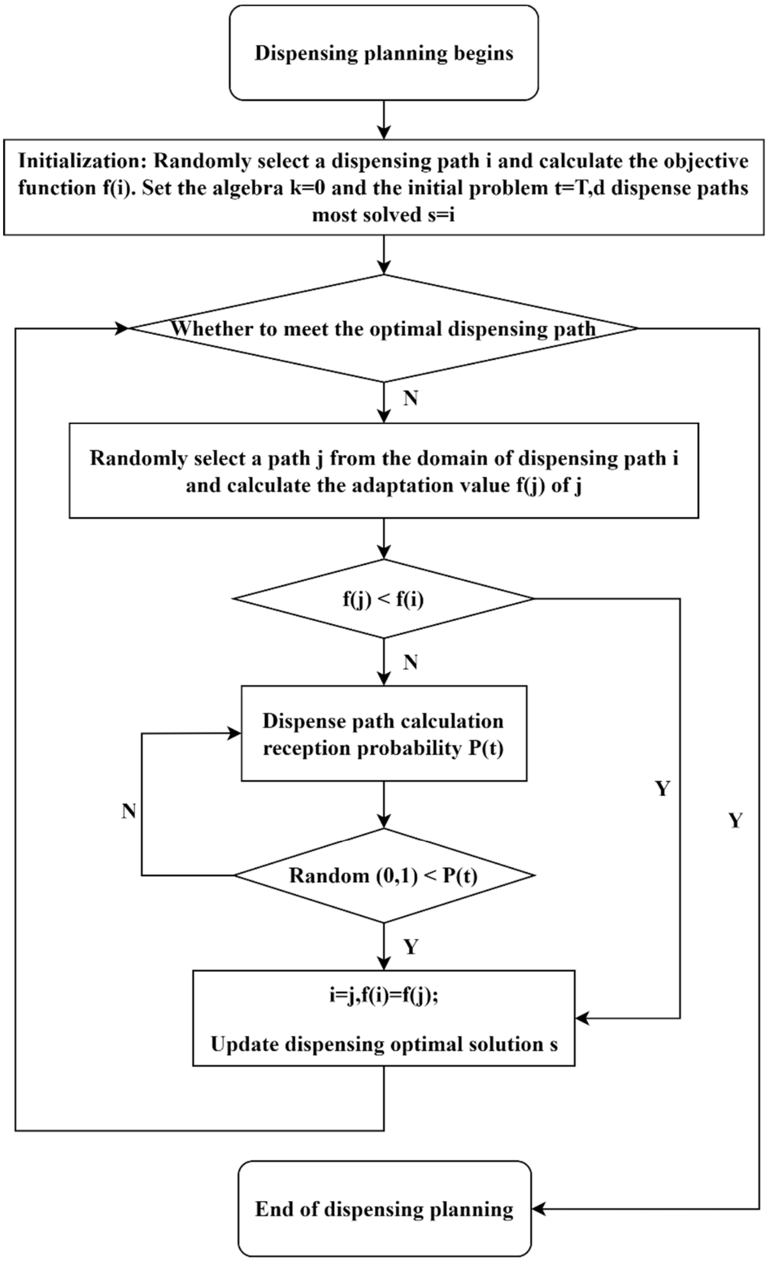


Figure 4 Simulated annealing algorithm flow chart

3. VISUAL DISPENSING SYSTEM REALIZATION

3.1. Overall Mechanical Structure Analysis

The entire dispensing platform is mainly composed of three modules: mechanical structure module, machine vision system module, and control communication module. The system needs to meet the PCB board movement on the conveyor mechanism, which can realize both camera acquisition and dispensing. The mechanical structure of the entire dispensing machine is mainly composed of the following parts: frame, conveyor, code plate, dispensing head, three-axis mechanical parts, and vision acquisition system, the overall structural design dimensions for the length, width, and height were 1000 mm, 500 mm, 870 mm, design layout and design dimensions reflecting the integration and miniaturization features, and each part of the division of labor is clear and coordinated. The design of the dispensing platform is shown in Figure 5.

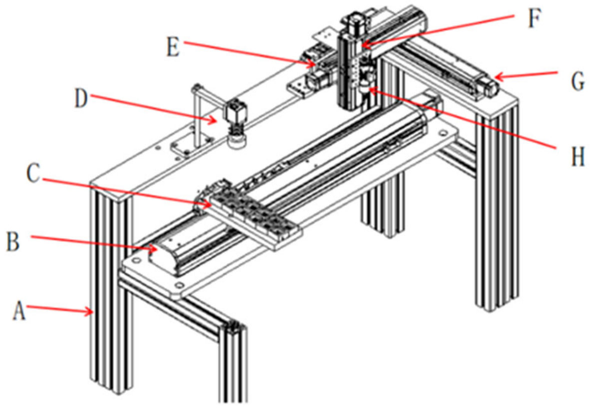


Figure 5 Dispensing platform design diagram

Note: A-frame; B-conveyor mechanism; C-code plate and PCB board; D-vision system; E-X-axis; F-Z-axis; G-Y-axis; H-dispensing mechanism

The specific steps of each part are: First, after initialization of the device, the PCB board is loaded, the conveying mechanism (B) is conveyed to the vision system (D), the position sensor is triggered and the industrial camera is in image acquisition; Second, the image processing and coordinate conversion are carried out by the upper computer to determine the dispensing coordinates, and then the coordinate information is transmitted to the motion controller for compilation through signal transmission; Third, the conveying mechanism conveys the code plate The X-axis (E) and Y-axis (G) make a plane movement, and the dispensing head (H) moves up and down through the Z-axis (F), thus realizing PCB dispensing, and after dispensing is completed, the conveyor (B) moves to the next process. The whole mechanical structure has the characteristics of small size, low cost, simple assembly and maintenance, and the three-axis mechanical structure is capable of linear interpolation motion.

3.2. Analysis of the vision dispensing system

The vision system is mainly composed of three hardware parts: camera, lens, and light source. In this paper, the key hardware equipment of the micro dispensing visual identification system is specified as follows: an industrial camera with a resolution of 2448×2048 pixels is used, and the light source is an R70-36-20 type LED ring light source; the hardware will be used to build the dispensing visual platform, as shown in Figure 6.

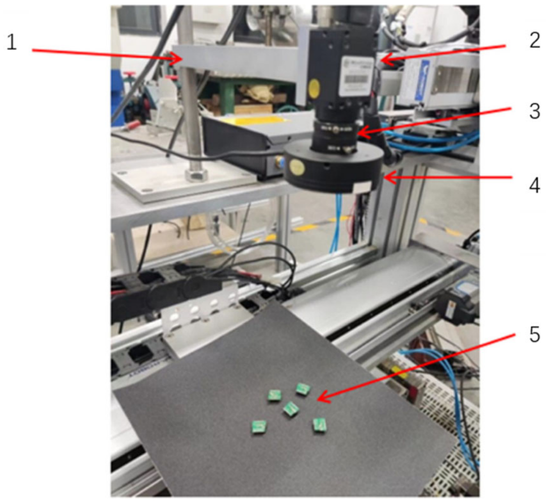


Figure 6 Dispensing vision system construction

Note:1-Vision Mount; 2-Camera; 3-Lens; 4-Toroidal light source; 5-Dispensing PCB

3.3. Overall control analysis

For subsequent software writing and hardware function upgrading, this paper uses an open control scheme with better compatibility, modularity, and secondary development[11]. In motion control, the motion control method that combines the motion control card and the PC side is used. The host computer, motion control card, servo driver, servo motor, I/O control module, and camera can be used as control system function modules to complete the control function.

This design uses an ECI1000 series motion control card (ECI1408 model), and PC is selected as the industrial control machine. The slot-type photoelectric sensor, light source controller, dispensing solenoid valve, X/Y/Z three axes mechanical axis limit module, emergency stop button, indicator light, buzzer, etc. are connected in a unified way mainly through the digital output and input of the motion control card, and the corresponding control signal is output after processing on the upper computer through the feedback signal of the sensor.

According to the above overall design plan, the complete dispensing experimental platform is built. The whole dispensing platform mainly consists of the frame part, transfer mechanism, code plate and PCB board, three-axis mechanical module, dispensing vision part, and dispensing head and dispenser. The code plate is fixed on the transfer mechanism, the three-axis mechanical part and the vision part are mounted on the frame, the dispensing head is mounted on the Z-axis, and the code plate and PCB board are fixed on the transfer mechanism as shown in Figure 7. After the whole dispensing platform is built, the overall mechanism runs smoothly and the sequence of motion logic is correct, and the overall actual operation flow is shown in Figure 8.

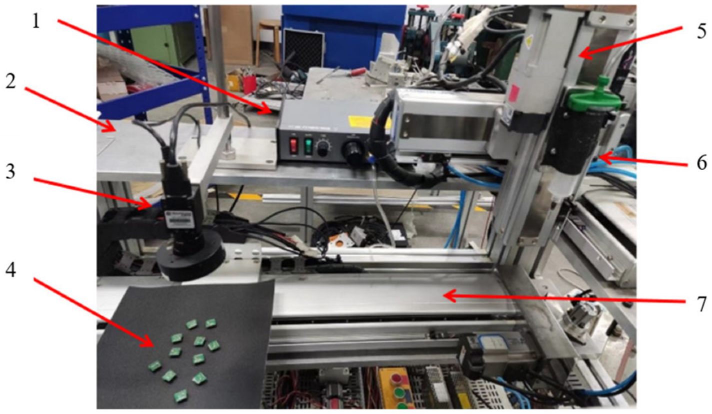


Figure 7 Automatic dispensing platform construction

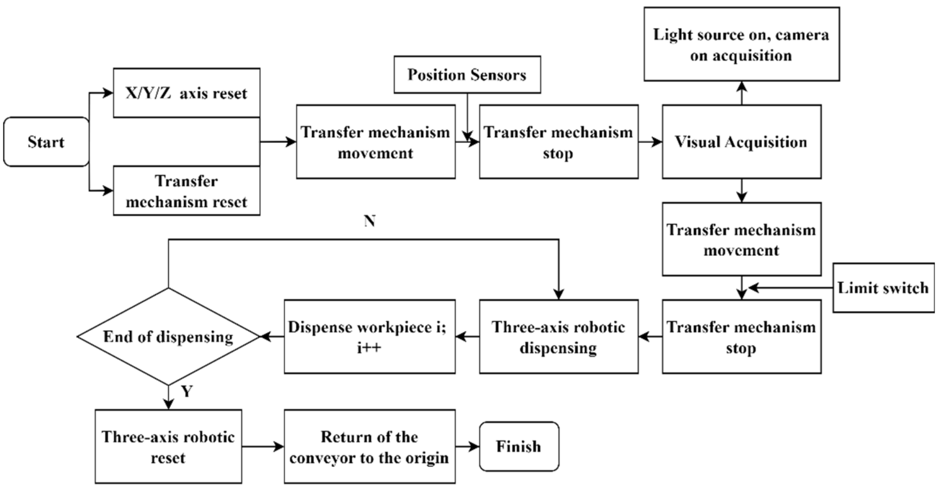


Figure 8 The overall movement flow of the fully automatic dispensing physical platform

4. ALGORITHM IMPLEMENTATION AND EXPERIMENTS

In the whole control system, the main thing is to dispense the capacitors on the PCB board and to meet the precision and efficiency of the dispensing. The entire dispensing platform can operate normally, but it is not a good explanation of the proposed design to improve the dispensing accuracy and dispensing efficiency, so the key functional modules are experimented with and verified to verify the key design content in the paper.

The dispensing object is small, and manual dispensing and traditional dispensing can not guarantee accuracy well, to improve the dispensing accuracy, the machine vision is used for image acquisition processing. To improve the dispensing accuracy, machine vision is used for the image acquisition process. For this purpose, the image acquisition experiment is done on the physical dispensing platform, where the PCB board is placed in the code tray for image acquisition, and the upper computer is compiled to display the number of the dispensing PCB board in the code tray in real-time. Among them, image acquisition, image processing, image template matching, and other operations can be completed in the human-computer interaction interface of the upper computer, and the XY pixel coordinates and angle values of the center point of the dispensing area can be displayed in the data display area.

4.1. Localization information extraction experiment

The experiment selected 120 RJDNEL-type PCB boards, divided into 5 groups for the positioning information extraction test, the recognition results are shown in Table 1. Through the analysis of the extraction test results, it can be concluded that 600 PCB boards correctly extracted 599 pieces, matching the correct rate above 99%. After repeated analysis of the test, one of the unsuccessful matchings is due to the presence of edge-breaking missing PCB boards, not a defect in the extraction algorithm.

Table 1 Positioning information extraction rate

Experiment serial number	Total number of PCB boards/block	Number of correct extractions/block	Withdrawal time /ms	Correct extraction rate
1	120	120	815	100%
2	120	120	820	100%
3	120	120	765	100%
4	120	119	910	99.2%
5	120	120	620	100%

4.2. Image recognition coordinate position accuracy error analysis

In image acquisition, if the positioning coordinate points identified from each image differ greatly, it will lead to inaccurate dispensing in the subsequent actual dispensing process, which requires repeated identification and positioning test analysis for a certain position.

When doing the repeatability test, the standard deviation of the set of measured values represents the accuracy of the measured values[12], and this experimental theory uses the standard deviation as a quantitative criterion for the accuracy of repeatedly extracting the positioning coordinate points, and the experimental steps are as follows:

1) The experiment randomly selects 2 PCBs into groups A and B.
2) Repeatedly collecting the coordinates of the center point of the extracted dispensing area on the PCB board in group A 10 times, and reading the extracted coordinates (X_1, Y_1) respectively.

3) Repeat the experimental steps in group B in group A to obtain(X_2, Y_2).

4) Calculate $u(p)X_1, u(p)Y_1, u(p)X_2, u(p)Y_2$ respectively by repeating the experimental standard deviation.

The analysis of the obtained repeat extraction coordinates. The details are shown in Table 2. To calculate the duplicate position error, the duplicate experimental standard deviation can be calculated according to the formula of (4-1).

$$\begin{cases} \bar{p} = \frac{1}{n}\sum_{i=1}^{n} p_i \\ u(p) = \sqrt{\sum_{i=1}^{n} (p_i - p)^2 / n} \end{cases} \tag{4-1}$$

Where, p_i - data of the ith test; $u(p)$- repeatability test error.

Through the image recognition positioning accuracy error analysis test, the coordinate position of the center of the PCB board is derived as the alignment point, and the coordinates of the center point position of the dispensing area are extracted through the camera acquisition and processing image. According to multiple sets of repeated experiments, such as formula (4-1) with the data in the table can be calculated: $u(p)X_1$=0.014 mm; $u(p)Y_1$=0.011 mm; $u(p)X_2$=0.012 mm; $u(p)Y_2$=0.013 mm. according to the repeated test calculation analysis can be concluded that the image repeatedly extracted coordinates error does not exceed 0.02 mm, to meet the design requirements.

Table 1 Image acquisition to locate coordinate points

Location	X_1	Y_1	X_2	Y_2
1	236.32	658.49	845.69	759.15
2	236.35	658.30	845.33	759.58
3	236.58	658.98	845.85	759.37
4	236.40	658.11	845.08	759.88
5	236.38	658.67	845.92	759.02
6	236.60	658.32	845.51	759.88
7	236.51	658.88	845.67	759.63
8	236.60	658.04	845.96	759.56
9	236.47	658.25	845.10	759.37
10	236.52	658.59	845.94	759.69

4.3. Path planning experiment and Verification

The experiment uses 20 pieces of dispensing PCB boards for experiments, randomly placed in the code plate for dispensing, the physical diagram is shown in Figure 9, and in the diagram marked with dispensing needle movement trajectory, at the same time, through the compilation of the upper computer, respectively, to complete the dispensing path optimization before and after the path planning time, total travel and path real-time display of dispensing.

Table 1 Path optimization experimental predicate parameter setting

Category	Dispensing operation speed（mm/s）	Gum spitting volume（ml/s）	Number of dispensing at a time	Number of groups
Parameters	1	1	20	5

In the path optimization above, a theoretical efficiency study was done before and after the dispensing path optimization, and here a comparative experiment is used to verify the dispensing time comparison before and after the dispensing path optimization, with the parameters set as shown in Table 3.

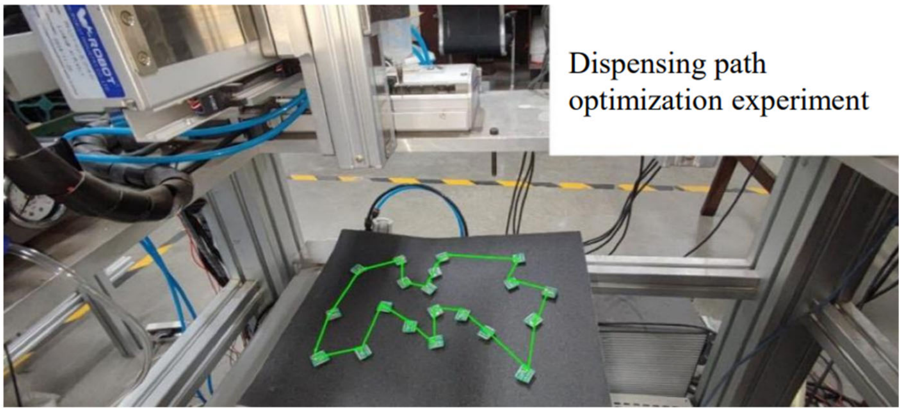


Figure 9 Dispensing path planning experiment

Table 2 Movement timetable before and after dispensing path optimization

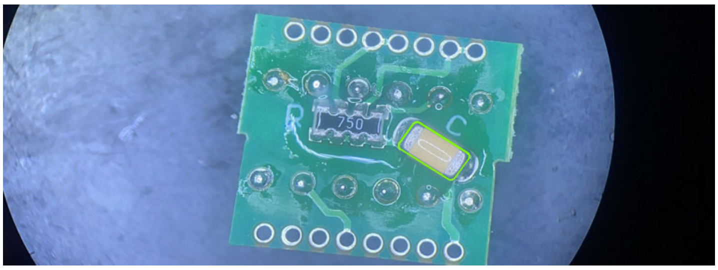
Group	Number of Dispensing	Traditional dispensing is time-consuming / s	Optimized dispensing time / s	Efficiency Improvement Percentage
1	20	429.4	297.6	30.7%
2	20	420.3	298	29.1%
3	20	397.6	295.1	25.8%
4	20	374	293.6	21.5%
5	20	396.4	298.1	24.8%

Specific experimental methods are as follows:

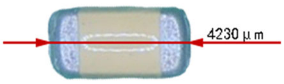
(1)Set up five groups, each group chooses 20 PCB boards randomly placed, and the position of the PCB boards placed between different groups can not be the same;(2)Start timing from dispensing, the last PCB board dispensing finished the end timing. (3)The dispensing before and after the optimization of the path is carried out respectively, and the time is counted. The final experiment can be derived from the dispensing time of different groups, as shown in Table 4. According to the above table, it can be concluded that the traditional dispensing path has a long dispensing time, and after the path optimization, the dispensing efficiency has been improved by 20%~30%.

4.4. Dispensing object dispensing quality testing experiment

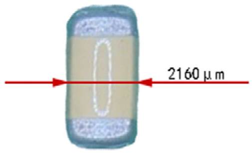
The construction of the entire dispensing platform in kind is to carry out the dispensing, and whether the final dispensing out of the dispensing area meets the requirements (according to the quality inspection requirements of an electronics factory, the dispensing package accuracy of ±0.5 mm) is crucial. This experiment is the final dispensing quality verification experiment, the same selection of 20 PCB board irregular placement, strictly by the process requirements for dispensing, using the path based on the simulated annealing algorithm to optimize the dispensing path. Among them, the visual recognition system carries out image acquisition processing and dispensing coordinate point extraction and transformation after 217.6 ms, and the identified 20 points are shown in Table 5 before and after the transformation position information. The conveyor mechanism takes 7 s in motion from entering the dispensing platform to resetting after dispensing is completed.



(1) Single PCB board dispensing effect



(2) Dispensing area length test



(3) Dispensing area width test

Figure 10 PCB board dispensing quality inspection experiment

The dispensing quality experiment uses a simulated annealing algorithm based on path planning, after 0.61 s to complete the entire path planning, determined the robot dispensing path, as shown in Figure 9, and then the planned dispensing path information is transmitted to the control system of dispensing, after 109 s to complete the dispensing of 20 PCB boards, of which the average dispensing time of each PCB board is 4 s, while the dispensing platform is derived in 20 Detailed enlargements of a PCB board dispensing quality results are shown in Figure 10, after testing, the general shape of the dispensing area is rectangular, the longest side is about 4400μm, the shortest is about 4100μm; the widest side is about 2300μm, the narrowest is about 2100μm, all meet the dispensing accuracy requirements. The overall dispensing quality of the PCB board is good.

The information on the 20 dispensing positions is extracted from Figure 10 and the converted coordinates are shown in Table 5.

Table 1: Extraction of information on the location to be dispensed

Number	Image acquisition dispensing coordinates	Angle	Actual dispensing coordinates	Dispensing area /pixel
1	（629.28，713.64）	135.6	（27.6，31.3）	2236
2	（1999.52，1128.5）	165.2	（87.7，49.5）	2245
3	（1108.04，1598.28）	36.2	（48.6，70.1）	2231
4	（264.48，1550.5）	64.8	（11.6，68）	2229
5	（2186.52，579.12）	95.6	（95.9，25.4）	2236
6	（1374.84，1903.8）	308.9	（60.3，83.5）	2227
7	（2031.04，2197.92）	225.8	（88.8，96.4）	2239
8	（642.96，2008.68）	294.3	（28.2，88.1）	2236
9	（948.48，2058.84）	10.8	（41.6，90.3）	2234
10	（2243.52，2496.6）	302.2	（98.4，109.5）	2225
11	（1051.08，2421.36）	260.5	（46.1，106.2）	2226
12	（836.76，446.88）	159.7	（36.7，19.6）	2227
13	（1942.56，2118.13）	122.3	（85.2，92.9）	2236
14	（978.12，1459.2）	231.9	（42.9，64.1）	2234
15	（585.96，1146.84）	56.2	（25.7，50.3）	2238
16	（565.44，937.08）	78.3	（24.8，41.1）	2229
17	（2268.6，884.64）	170.8	（99.5，38.8）	2237

18	（563.16，1422.72）	264.9	（24.762.4）	2231
19	（2154.6，1561.9）	320.5	（94.5，68.5）	2228
20	（886.92，1694.06）	83.7	（38.9，74.3）	2233

5. CONCLUSION

The dispensing region in the PCB board is extracted by grayscale processing and threshold segmentation (binarization), the edge extraction of the dispensing region is carried out by using Sobel edge detection operator, the extracted edge is optimized by using the Hilditch algorithm, and finally, the information such as the center coordinate point, angle and area of the dispensing region is extracted by the minimum outer rectangle algorithm, and the experimental results of the 600 pieces of PCB boards are Correctly extracted 599 pieces, matching the correct rate of more than 99%. Based on the simulated annealing algorithm to optimize the dispensing path, compared with the traditional dispensing path, the optimized dispensing efficiency is improved by 20%~30%. Through the dispensing platform vision system construction, 20 PCB boards are used to carry out the complete dispensing process, and in the upper computer, the image acquisition processing and coordinate conversion takes a total of 217.6 ms, and the dispensing area detection is carried out on the PCB boards with completed dispensing, and the accuracy of the dispensing package is within ± 0.5 mm. In summary, the designed fully automatic dispensing system meets the practical requirements in terms of accuracy, efficiency, automation, and integration of the platform.

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