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Design of a Fully Automatic Circuit Board Pick-and-Place Robot

Longfei Qi, Yijin Shi, Chuanshai Zhu, Jinhe Luo and Yuebao Liu *

College of Information and Cyber Security, Xinjiang University of Political Science and Law, Tumxuk, China

* **Corresponding author**

Abstract: To resolve manual soldering difficulties encountered by university students, electronics enthusiasts, and small-batch customized users in circuit board assembly, this paper presents the design and implementation of a multifunctional fully automatic circuit board pick-and-place robot. The system employs an Arduino2560 or a self-developed mainboard as the control core, integrating Surface Mount Technology (SMT), modular mechanical structures, and OpenPnP software control to achieve automatic picking, inspection, and placement of electronic components. For surface-mount device handling, the system utilizes a servo positioning mechanism and an intelligent placement head for efficient circuit board assembly. Furthermore, the system supports 3D-printed feeder expansion and can integrate laser cutting and solder paste dispensing functions. Experimental results indicate that the placement relative error for miniature components is within 3%, significantly enhancing small-batch assembly efficiency. With advantages including low cost, ease of DIY customization, and simplified maintenance, the proposed solution demonstrates feasibility and practicality, offering a low-cost and highly flexible intelligent approach for electronic product assembly.

Keywords: Automatic pick-and-place robot; Surface mount technology; OpenPnP; Modular design; Small-batch assembly.

1. Introduction

According to market research data, surface-mount devices (SMDs) currently account for over 90% of components used in the global electronics assembly market [1]. In Chinas electronic manufacturing industry, small and medium-sized enterprises (SMEs) and small-batch production sectors are particularly affected by the challenges of manual soldering, which suffers from low efficiency and poor precision. Relevant reports indicate that the community of electronics enthusiasts and university students in China numbers approximately 5 million, representing 2.5% of all electronics enthusiasts. This demographic is experiencing rapid growth, with an estimated 500,000 new users requiring manual soldering services annually—equivalent to one new electronics assembly demand generated every minute. Supported by national policies, Chinas capacity for research, development, and deployment of electronic assembly equipment has strengthened considerably. Concurrently, the infrastructure for intelligent manufacturing environments and support policies for small-batch users have progressively improved. However, despite these advancements, individual users and small enterprises continue to face significant challenges in independent assembly due to the high cost, large footprint, and complex maintenance requirements of commercial pick-and-place machines [2].

The evolution of electronic assembly technologies has been predominantly shaped by the demands of high-volume manufacturing, with surface mount technology (SMT) becoming the industry standard, accounting for over 90% of component placements globally [3]. Commercial pick-and-place machines have achieved remarkable speed and precision; however, their high capital costs, substantial footprint, and operational complexity render them inaccessible for low-volume production environments and individual users [4]. This accessibility gap has spurred research into alternative, low-cost automation solutions. Recent studies have explored the integration of open-source hardware platforms, such as Arduino, with software like OpenPnP to democratize SMT assembly [5]. Furthermore, modular design approaches have been investigated to enhance system flexibility and maintainability, allowing for customization and expansion with technologies such as 3D-printed feeders and integrated solder paste dispensing [6]. Despite these advancements, challenges remain in achieving placement accuracy for increasingly miniaturized components while maintaining affordability, highlighting the need for continued innovation in this domain to effectively serve the growing community of small-batch producers, electronics enthusiasts, and educational institutions.

This paper presents the design and implementation of a fully automatic circuit board pick-and-place robot that integrates multiple functional modules including servo positioning, feeders, and placement heads, all coordinated through an Arduino-based mainboard and OpenPnP software control. By leveraging modular hardware architecture and software, the proposed system aims to realize a low-cost yet highly reliable pick-and-place platform. The research validates the feasibility and effectiveness of this technical approach in advancing the intelligence level of electronic assembly equipment, demonstrating its potential to bridge the gap between commercial-grade systems and the accessibility requirements of small-batch production environments.

2. Overall system design

The overall framework of the fully automatic circuit board pick-and-place robot designed in this paper is illustrated in Figure 1. The system is primarily composed of five modules: the main control module, mechanical main body module, feeder module, placement module, and software control module. The main control module serves as the system core, responsible for configuring and driving each functional module, coordinating task scheduling, and managing signal

transmission. The feeder module and placement module jointly constitute the core execution layer, with complementary functions: the former handles component supply (such as resistors, capacitors, ICs, etc.), while the latter provides high-precision picking and placement information. Their synergistic operation provides reliable data support for circuit board assembly. The software control module issues instructions during component processing to precisely control mechanical movements. Additionally, the system supports modular expansion, enabling users to integrate 3D-printed feeders or laser cutting functions based on specific requirements.

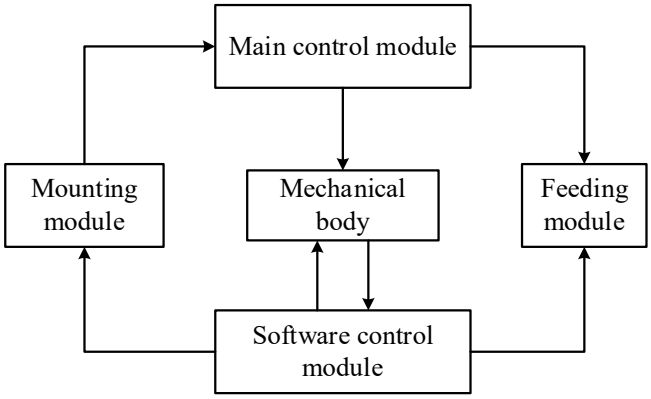


Figure 1. Framework of the Fully Automatic Circuit Board Pick-and-Place Robot

3. Hardware design

3.1. Main control module

The main control module is built around an Arduino2560 or a self-developed motherboard as its core component. Utilizing the ATMega2560 processor with a maximum operating frequency of 16 MHz, it delivers robust computational capabilities for rapid processing of complex logic and algorithms. Its low-power characteristics effectively extend operational duration in portable devices. Notably, the module features rich peripheral interfaces including USART, I2C, and SPI, enabling seamless communication with diverse heterogeneous peripherals such as servo motors and cameras simultaneously. Ample GPIO and timer resources provide hardware support for parallel multi-task processing. In this implementation, the complete main control module hardware circuit is realized using an Arduino2560 minimum system board. Beyond the main chip, this minimum system board integrates essential circuits including clock, power supply, reset, and programming interface, enabling rapid construction of the control module while meeting application requirements.

3.2. Feeder module

This paper adopts a 3D-printed feeder to construct the feeder module. The feeder supports customized component tapes, including resistors, capacitors, and IC trays. It integrates internal vibratory or mechanical actuators to ensure stable component feeding. Crucially, its open-source design and mature 3D printing toolchain significantly simplify the development process for integrating and debugging feeders on desktop platforms. The feeder module is equipped with multiple component slots, vibration motors, and various commonly used peripheral interfaces such as I2C and UART. By utilizing 3D-printed feeders, rapid deployment of component feeding is achieved, enabling the system to deliver real-time supply functionality for components of various specifications as required.

3.3. Placement module

The placement module is implemented based on an intelligent placement head, featuring a placement range of 10 cm × 10 cm (expandable) and achieving 0.1 mm accuracy, which satisfies the requirements of small-batch production. Additional characteristics of the module include 5V low-voltage operation, low power consumption, fast response, and millisecond-level placement speed.

The main controller initiates placement by sending pulses through its control pins, subsequently detecting position information via the feedback pin. Based on servo feedback, the position is calculated using the following formula:

$$position = (servo_angle \times scale)/2$$

3.4. Mechanical main body module

The mechanical main body module adopts a gantry-type structure, integrating a steel frame with smooth guide rods and belts, offering high flexibility, durability, and ease of fabrication. The module communicates with servo motors via timing belts, receiving commands from the main controller to execute precise movements. When the main control module determines that component placement is required based on inspection data, it transmits movement instructions and coordinate references. Upon receiving these commands, the mechanical module drives the Z-axis pneumatic and servo motors to perform actions such as component picking.

3.5. Servo positioning module

The core components of the servo positioning module are servo motors and guide rails. The servo motors feature a measurement range of 0° to 180° with an accuracy of 1°. A feedback processor is integrated within the module to perform fusion and filtering of position data . After completing coordinate calculation, the module transmits information to the main controller via the I2C interface.

Upon receiving the servo output position data, the main controller applies dual thresholds for angle and speed to ensure placement accuracy and stability. This mechanism filters out transient fluctuations caused by mechanical vibrations or electrical noise. When the measured values consistently exceed both thresholds for two consecutive measurement cycles, the system confirms successful placement completion, minimizing false triggers and enhancing control reliability.

3.6. PCB conveyor module

The PCB conveyor module utilizes a transmission belt and support cylinder. It operates on a 5V low-power supply and communicates with the main control module via a USART serial interface, transmitting conveyor data in accordance with a custom protocol. The main controller receives and stores the board position information. Once components are detected to be in place, this information is integrated into control commands, enabling conveyance through the mechanical module.

4. Software program design

The system software adopts a heterogeneous programming model. The low-level control and component data processing programs are developed in C language within the Arduino IDE environment and executed on the main control board.

Meanwhile, the upper-layer vision inspection tasks are developed using OpenPnP on the Raspberry Pi operating system and deployed on an extended processor. These two layers achieve efficient command and data interaction through UART serial communication.

4.1. Main program design

The main program flow of the system is illustrated in Figure 2. Upon power-up, the system first enters the main controller initialization phase, completing the initialization settings for on-chip peripherals including GPIO ports, serial communication interfaces, timers, and external interrupts. Subsequently, it initializes functional modules such as the feeder, placement head, mechanical main body, and expansion modules, while sending a startup command to the software control module.

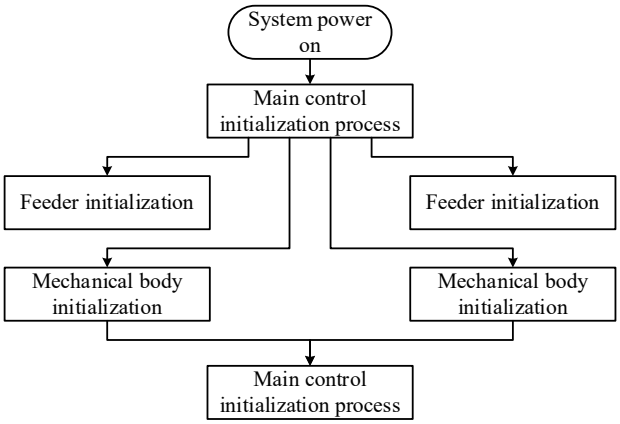


Figure 2. Main Program Flow of the System

After completing the initialization steps, the system enters operational status. When the feeder module detects components in position or identifies placement requirements ahead, it sends a signal to the main controller. The main controller then triggers the placement module to execute pick-up actions promptly. Simultaneously, the main controller activates the servo positioning module for real-time measurement of coordinates and angles. When measurement accuracy falls below the threshold, it initiates the mechanical main body module to issue notifications, facilitating the completion of assembly actions.

Beyond basic placement functions, the system incorporates expansion detection capabilities. The main controller performs real-time monitoring of component data. If values exceed the normal range, it determines that an error has occurred. The system then acquires position information, activates debugging functions, and transmits the information to the user interface. Concurrently, the system triggers the control panel to issue alerts, prompting user intervention for adjustments.

4.2. Software control program design

Upon power-up, the software control module initializes its subsystem, including loading the OpenPnP vision model, initializing the camera for component detection, and configuring the UART serial interface to establish communication with the main controller. After receiving the startup command from the main controller, the program enters real-time control operation mode. In this state, the system continuously acquires component information through the module interface and feeds the data to the vision model for processing. When a component requiring placement is identified, the program generates and transmits corresponding control signals to the main controller via the serial interface, triggering subsequent pick-and-place actions. This closed-loop mechanism ensures timely and accurate coordination between visual recognition and physical actuation throughout the assembly process.

5. System testing

5.1. Component detection function test

To verify the component detection functionality, tests were conducted under various indoor scenarios. As shown in Figure 3, the system successfully identifies, picks up, and classifies common components such as resistors and capacitors. Under normal conditions, the detection latency for typical targets is less than 500 ms, meeting real-time requirements. These results preliminarily validate the effectiveness of the OpenPnP model within the proposed system.

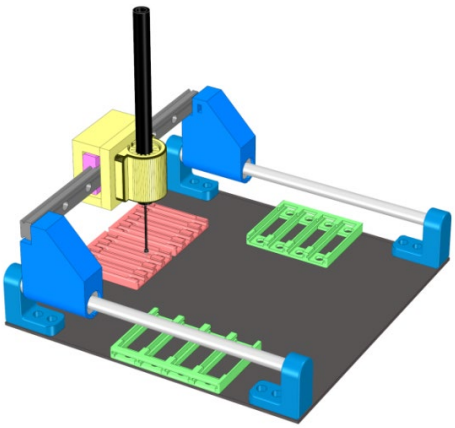


Figure 3. Component Detection

5.2. Placement accuracy test

As shown in the table 1, the relative error between the measured placement coordinates and the actual coordinates remains within 3% across multiple test cycles. These results demonstrate that the proposed placement module achieves high precision and is capable of reliably positioning components during the assembly process. The consistency of the error distribution, particularly in the mid-range coordinates, further validates the stability and repeatability of the control and actuation system. Even at the maximum tested displacement of 3000 mm, the relative error is maintained at 2.7%, confirming the systems suitability for small-batch production tasks requiring accurate component placement.

Table 1. Placement Accuracy Test Results

Actual Coordinates /mm	Placement Measurement Coordinates /mm	Coordinate Error /mm	Relative Error /%
250	252	2	0.8
500	495	5	1.0
750	738	12	1.6
1000	988	12	1.2
1500	1512	12	0.8
2000	1985	15	0.8
2500	2475	25	1.0
3000	2920	80	2.7

5.3. Expansion and stability test

This paper validates the functionality of the expansion modules and system program by simulating multifunctional expansion operations, assessing whether the system can reliably detect expansion events while simultaneously controlling laser cutting or solder paste dispensing via software. The monitoring algorithm synchronously tracks position and velocity to accurately capture the distinctive composite of expansion actions—specifically characterized by "angle variation coupled with velocity surge." This mechanism effectively filters out interference from non-expansion motions, substantially reducing both false positives and missed detections. The algorithm is characterized by its simplicity and excellent real-time performance, rendering it particularly suitable for desktop-grade equipment applications.

Upon detection of an expansion event, the control panel promptly displays preset notification messages to provide intuitive user feedback. Concurrently, the software module accurately retrieves current component information and transmits commands incorporating expansion details and positional data to the main controller through the OpenPnP framework.

6. Conclusion

This paper successfully presents the design and implementation of a fully automatic circuit board pick-and-place robot that integrates surface mount technology, modular expansion capabilities, and software control. Through coordinated hardware integration and software co-design, the proposed system achieves effective picking and placement of miniature components and integrated circuits, while featuring essential DIY customization and multifunctional expandability. Experimental results validate the functionality of individual modules and confirm the feasibility of the overall system architecture.

Future research directions may include: (1) optimizing the software architecture by adopting lightweight frameworks to reduce power consumption and extend operational duration; (2) incorporating data fusion algorithms to achieve deeper integration of inspection results with servo positioning data, thereby enhancing system robustness under complex circuit conditions; and (3) conducting long-term user trials with real-world applications to gather feedback, enabling further refinement of human-machine interaction and functional practicality.

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