INTISARI

Pembuatan PCB (*Printed Circuit Board*) merupakan tahapan penting dalam perancangan rangkaian elektronik karena berpengaruh terhadap presisi dan keandalan sistem. Metode pembuatan PCB konvensional seperti *chemical etching* memiliki beberapa kelemahan, antara lain penggunaan bahan kimia berbahaya, menghasilkan limbah, membutuhkan waktu lebih lama, serta berpotensi menimbulkan ketidaktepatan jalur akibat proses manual. Oleh karena itu, penelitian ini mengembangkan alat pembuat PCB otomatis berbasis CNC mini yang mampu melakukan proses *engraving* secara cepat, presisi, serta dapat dipantau secara real-time tanpa proses kimia.

Metode penelitian meliputi perancangan dan implementasi sistem menggunakan Arduino Mega 2560, RAMPS 1.6 *Shield*, driver TB6600, motor stepper sumbu X/Y/Z, serta sistem monitoring berbasis ESP32 dan ESP32-CAM melalui WiFi lokal. Proses pembuatan PCB dilakukan dengan mengonversi desain layout menjadi G-code yang dieksekusi oleh *firmware* GRBL. Pada tahap pengembangan dilakukan beberapa pembaruan komponen, yaitu penggantian RAMPS 1.4 menjadi RAMPS 1.6 untuk meningkatkan stabilitas daya, penghapusan modul relay, penggantian monitoring Blynk menjadi web server lokal agar tidak bergantung pada internet, serta penambahan modul powerbank untuk menjaga kestabilan suplai daya ESP32-CAM selama proses streaming.

Hasil pengujian menunjukkan sistem mampu menghasilkan proses *engraving* dengan akurasi jalur sebesar 0.10–0.13 mm, kestabilan streaming ESP32-CAM sebesar 78–91%, waktu respons sistem WiFi lokal sebesar 125–140 ms, dan waktu pengerjaan *engraving* 84–102 detik. Data sekunder menunjukkan error posisi motor stepper 0.00–0.02 mm, respons *limit switch* 18–23 ms, serta kestabilan pembaruan status mesin pada UGS sebesar 97–99%. Berdasarkan pengujian *short test* pada enam sampel PCB, tingkat keberhasilan isolasi jalur berdekatan mencapai 67,9% (57 titik uji berhasil dari total 84 pengujian), sehingga alat dinyatakan mampu bekerja dan menghasilkan PCB prototipe secara otomatis, meskipun masih diperlukan optimasi parameter *engraving* untuk meningkatkan konsistensi hasil.

Kata Kunci: PCB otomatis, CNC mini, GRBL, RAMPS 1.6, TB6600, ESP32-CAM, *engraving*, prototipe elektronik, akurasi jalur, sistem monitoring.

ABSTRACT

PCB (Printed Circuit Board) fabrication is an essential stage in electronic circuit development because it determines the quality, precision, and reliability of the overall system. Common PCB manufacturing methods such as chemical etching have several drawbacks, including the use of hazardous chemicals, waste generation, relatively long processing time, and potential inaccuracies caused by manual procedures. Therefore, this research proposes a mini CNC-based automatic PCB engraving system as an alternative solution that enables faster, safer, and more consistent PCB production without chemical processes, while also allowing real-time monitoring.

The proposed system was designed and implemented using an Arduino Mega 2560, a RAMPS 1.6 Shield, TB6600 stepper drivers, and stepper motors for the X, Y, and Z axes. Monitoring and control were supported by an ESP32 and an ESP32-CAM operating on a local WiFi web server. The PCB fabrication workflow was performed by converting the PCB layout design into G-code, which was executed by GRBL firmware. Several hardware and software improvements were applied during development, including upgrading RAMPS 1.4 to RAMPS 1.6 for better power stability, removing the relay module as it was no longer required, replacing the Blynk-based monitoring platform with a local WiFi web server to eliminate internet dependency, and adding a powerbank module to stabilize the ESP32-CAM power supply during video streaming.

Experimental results show that the system achieved a trace engraving accuracy of 0.10–0.13 mm, ESP32-CAM streaming stability of 78–91%, local WiFi response time of 125–140 ms, and engraving completion time of 84–102 seconds. Secondary data indicate a stepper motor position error of 0.00–0.02 mm, limit switch response time of 18–23 ms, and UGS machine status update stability of 97–99%. Based on short-circuit testing across six PCB samples, the success rate of adjacent-trace isolation reached 67.9% (57 successful tests out of 84 total tests). Overall, the developed system is capable of producing prototype PCBs automatically with acceptable performance, although further optimization of engraving parameters is required to improve consistency.

Keywords: Automatic PCB Maker, CNC Mini, GRBL Control, RAMPS 1.6, TB6600 Driver, ESP32-CAM, PCB Engraving, Real-Time Monitoring, Stepper Motor, Prototype Electronics.