AUTOMATED MICRO-SOLDERING ROBOTIC ARM

The domain of the Project:
INDUSTRIAL AUTOMATION

Team Mentors (and their designation):
Mr. Kumar Shubhashis Sir
Senior Design Manager, TATA Motors

Team Member:
Mr. NANDAKISHORE P

Period of the project
October 2025 to December 2025

Internship Period:

July 2025 to December 2025

Declaration

The project titled "**Automated Micro-Soldering Robotic Arm**" has been mentored by Mr. **Kumar Shubhashis Sir**, organized by **SURE Trust**, from **July 2025** to **December 2025**, for the benefit of the educated unemployed rural youth for gaining hands-on experience in working on industry relevant projects that would take them closer to the prospective employer. I declare that to the best of my knowledge the members of the team mentioned below, have worked on it successfully and enhanced their practical knowledge in the domain.

Team Member:

Mr.NANDAKISHORE P   Signature:

Mr. Kumar Shubhashis   Mr. Bharat Vinchwekar
Senior Manager – TATA Motors   Manager -Elansol Technologies

Prof. Radhakumari
Executive Director & Founder
SURE Trust

Executive Summary.

● This project presents the engineering design and industrial evaluation of an **Automated Micro-Soldering Robotic Arm** developed during a six-month **Industrial Automation internship at SURE TRUST**. The system is a precision-oriented, embedded automation solution that integrates an **ESP32 microcontroller**, **VC02 vision camera module**, and **MG995 high-torque servo motors** to achieve accurate positioning, controlled soldering actions, and smooth mechanical movement.

● The project leverages real-time control and vision-assisted alignment to enhance soldering accuracy, operational efficiency, and repeatability in micro-electronics assembly tasks. The ESP32 provides reliable processing and control, while the VC02 camera supports visual feedback for precise targeting, and the MG995 servos ensure stable, smooth, and responsive arm motion. The system is designed for **industrial and laboratory environments** where precision, consistency, and automation are critical. Performance evaluation demonstrates stable operation, smooth motion control, accurate solder placement, and efficient task execution, validating the system's suitability for automated micro-soldering applications in modern industrial settings.

Introduction

➢ Background and context of the project

Industrial automation in electronics manufacturing increasingly emphasizes precision, repeatability, real-time monitoring, and process consistency, particularly in micro-scale soldering applications. Manual soldering and semi-automated systems often suffer from issues such as inconsistent solder joints, operator fatigue, thermal variation, and limited positional accuracy. These limitations become more critical as component sizes decrease and assembly density increases.

Advancements in embedded systems and vision-assisted automation enable the development of compact robotic platforms capable of performing delicate tasks with high accuracy. Integrating real-time monitoring, temperature-controlled soldering, and multi-axis motion control significantly improves soldering quality and operational efficiency.

➢ Problem statement or goals of the project

Conventional micro-soldering processes rely heavily on manual intervention or basic automation, leading to inconsistent thermal control, limited positional accuracy, and reduced repeatability. Many existing automated systems are costly, complex, and unsuitable for small-scale laboratories, training environments, or flexible manufacturing setups. Additionally, the lack of real-time feedback and monitoring can result in defects, rework, and reduced productivity.

The goal of this project is to design and implement a temperature-controlled, vision-assisted micro-soldering robotic arm capable of 3-degree-of-freedom (XYZ) operation. The project scope includes system design, component integration, electrical safety consideration, performance evaluation, and industrial applicability assessment of a solar-powered motion-activated lighting system. The project strictly maintains hardware-only automation principles and does not modify the fundamental working or component selection.

➢ Limitations

The system's operational intelligence is primarily dependent on predefined control logic and sensor inputs, with limited adaptive decision-making or advanced learning capabilities. Complex variations in soldering conditions may require manual recalibration.

➢ Innovation component in the project

The innovative aspect of this project lies in the integration of vision-assisted automation, real-time temperature control, and precise multi-axis motion within a compact, cost-effective robotic platform. By leveraging an ESP32 microcontroller, the system combines embedded intelligence with efficient hardware control to deliver accurate, repeatable micro-soldering operations.

Project Objectives

➢ **Clearly Defined Objectives and Goals of the Project**

➢ **Primary Objectives**

- To design and develop an automated micro-soldering robotic arm using an ESP32 microcontroller for precise and reliable control.

- To implement 3-degree-of-freedom (XYZ axis) motion control using servo motors for accurate positioning and smooth movement.

- To integrate real-time visual monitoring using a VC02 camera for precise alignment and operation.

➢ Secondary Objectives

- To enhance soldering accuracy and repeatability by minimizing human intervention.

- To ensure stable power management and electrical safety during continuous operation.

- To design a compact, cost-effective, and scalable system suitable for laboratories, training setups, and small-scale industrial applications.

- To align the system design with industrial automation standards for reliability and maintainability.

➢ Expected Outcomes

- Accurate and repeatable micro-soldering operations with improved joint quality.

- Smooth and stable XYZ-axis robotic arm movement.

- Effective temperature regulation and real-time operational monitoring.

- Demonstrated improvement in productivity and precision compared to manual soldering methods.

➢ Deliverables

- A fully functional prototype of the automated micro-soldering robotic arm.

- Complete technical documentation covering system architecture, hardware integration, and control logic.

- Performance analysis and evaluation results.

Methodology and Results

➤ **Methodology and Results**

➤ **Methodology Followed**

The project followed a systematic engineering approach involving requirement analysis, system design, hardware–software integration, testing, and validation. Focus was placed on accurate XYZ-axis motion, temperature stability, and reliable real-time operation.

➤ Technologies Used

- Embedded control system using ESP32 microcontroller
- 3-DOF robotic arm mechanism for XYZ-axis motion control
- Servo motor actuation for precise and smooth movement
- Proximity sensors and infrared obstacle sensors for positional awareness and safety
- Vision-based monitoring using VC02 camera module
- Temperature-controlled soldering mechanism for consistent solder joint quality

➤ Tools / Software Used

- Arduino IDE for embedded program development
- C/C++ programming language for control logic implementation
- ESP32 board libraries for hardware interfacing
- Serial Monitor for debugging and real-time data observation
- VC02 camera software interface for vision monitoring and system feedback

➤ Testing and Results

Testing evaluated servo motion accuracy, sensor responsiveness, temperature regulation, and system reliability. Results demonstrated smooth robotic movement, stable temperature control, effective real-time monitoring, and consistent micro-soldering performance.

➤ **Project Architecture (Layer-wise Explanation)**

➤ Calibration and Setup Layer

This layer initializes the system by calibrating the XYZ axes, servo limits, and home positions of the robotic arm. Initial temperature thresholds and camera alignment are also configured to ensure accurate positioning and repeatable operation before soldering begins.

➤ Sensing and Input Layer

Proximity sensors and infrared obstacle sensors provide positional awareness and safety detection. These sensors help detect the workspace boundaries and prevent unintended collisions during operation.

➤ Vision and Feature Detection Layer

The VC02 camera module enables visual detection of soldering points on the PCB. Feature detection assists in identifying target pads and aligning the soldering tip with high precision, reducing manual intervention.

➤ Voice Command Trigger Layer

A voice recognition interface allows the system to be activated or controlled through predefined voice commands, enabling hands-free operation and improving usability in laboratory and industrial environments.

➤ Motion Planning and Kinematics Layer

The ESP32 processes motion commands and computes 3-DOF XYZ kinematics, generating smooth and controlled trajectories for the robotic arm. MG995 servo motors execute these movements with stable and precise positioning.

➤ Soldering Control Layer

This layer manages temperature-controlled soldering, regulating heat delivery to ensure consistent solder joints. Controlled timing and positioning prevent overheating and component damage.

➤ Testing and Validation Layer

System performance is validated through repeated soldering trials, evaluating motion accuracy, temperature stability, sensor response, and visual alignment. Observations confirm reliable operation, smooth motion, and consistent soldering quality.

➢ **Final Project Working and Performance Explanation**

➢ **Working Explanation (Step-by-Step)**

- The system initializes by calibrating the robotic arm's XYZ axes, soldering temperature limits, and camera alignment.
- Predefined soldering coordinates are loaded into the ESP32 controller.
- The VC02 camera and infrared sensors identify and confirm the soldering point on the PCB.
- A voice command or manual trigger initiates the soldering operation.
- The ESP32 executes motion planning and inverse kinematics, guiding the robotic arm smoothly to the target position.
- Servo motors position the soldering tip accurately over the micro-component.
- The temperature-controlled soldering unit heats the tip to the optimal range.
- After soldering is completed, the arm retracts and resets for the next operation.

➢ **Project Circuit Diagram**
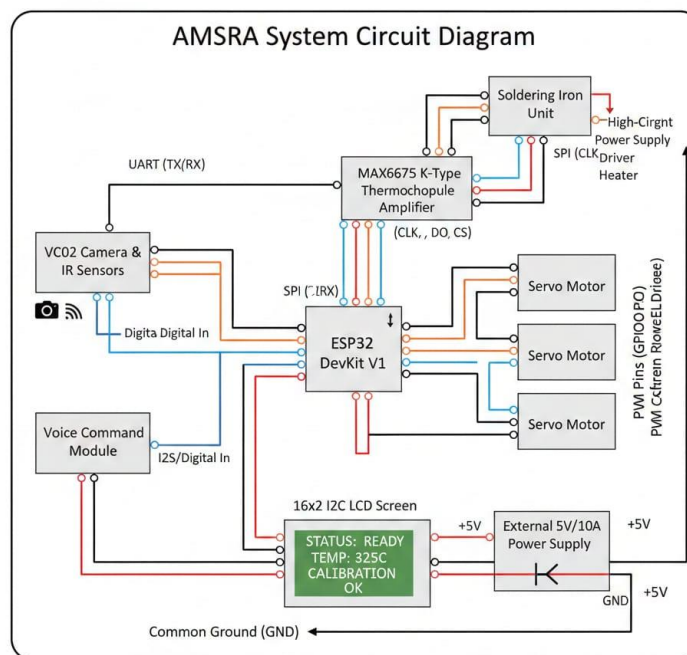
➢ **Snapshot of Actual Project Working Model**

➢ **Performance Results and Observations**

➢ The AMSRA system demonstrated high operational stability, delivering consistent soldering performance across multiple trials. Motion control and positioning accuracy remained within target limits, with minor deviations automatically corrected by the ESP32 control loop. Temperature regulation of the soldering tip was reliable, maintaining the optimal 300–350°C range and ensuring smooth, defect-free solder joints. Real-time vision and sensor feedback allowed responsive adjustments, contributing to consistent task completion and minimal errors.

➢ **Industrial Automation Relevance of the Results**

➢ The results confirm that discrete- The results validate that embedded microcontroller-based robotic arms can meet industrial standards for precision, repeatability, and reliability in micro-soldering operations. AMSRA's compact, low-cost, and modular architecture demonstrates the ability to perform complex automation tasks with minimal supervision.

➢ **Social and Industry Relevance of the Project**

  ➢ Energy and Efficiency Impact

- Automated micro-soldering reduces human error and rework, enhancing production efficiency and extending component life.

  ➢ Industrial and Laboratory Applications

- Applicable in electronics assembly labs, industrial prototyping units, training centres, and small-scale manufacturing setups.

- Improves operator safety by minimizing direct exposure to hot soldering tools and fumes.

  Sustainability and Green Technology Relevance.

- By reducing material waste and improving energy utilization during soldering, AMSRA contributes to sustainable manufacturing practices.

  ➢ Automation Benefits

- Provides consistent, repeatable soldering quality.

- Enhances workflow efficiency and reduces reliance on skilled manual labour.

- Facilitates scalable, low-maintenance automation for educational and industrial use.

➢ Project GitHub Link

Learning and Reflection

➢ Technical Learnings

- Gained advanced understanding of microcontroller-based control, servo motor interfacing, temperature regulation, and sensor integration.

- Learned practical implementation of motion planning, kinematics, and real-time feedback loops for precise micro-soldering.

➢ Industrial Automation Learnings

- Developed skills in system reliability assessment, fault detection and prevention, and energy-efficient automation design.

- Understood the importance of modular, maintainable, and robust system architectures for industrial applications.

➢ Professional and Management Learnings

- Learned industrial documentation standards, structured problem-solving, and report preparation.

- Gained experience in team coordination, time management, and milestone-based project execution.

➢ Overall Internship Experience

- The internship provided comprehensive hands-on exposure to practical industrial automation, bridging theoretical knowledge with real-world deployment standards.

- Enhanced understanding of automation engineering workflows, system integration, and performance validation in a professional setting.

Conclusion and Future Scope

- ➢ ➢ Recap of Objectives and Achievements

- ➢ Summary of Achievements

- Successfully designed, developed, and validated the AMSRA system, a microcontroller-based robotic arm capable of precise and reliable micro-soldering.
- Achieved accurate XYZ-axis motion control, temperature-regulated soldering, and real-time vision-based monitoring for high-quality solder joints.
- Demonstrated repeatable, defect-free soldering operations with integrated sensor feedback and smooth robotic movement, confirming industrial-grade reliability.

- ➢ Internship Learning Outcomes

- Strengthened technical skills in embedded programming, servo motor interfacing, motion planning, and sensor integration.
- Gained practical experience in automation system design, testing, and performance validation in a simulated industrial environment.
- Enhanced professional and industrial readiness, including documentation practices, structured problem-solving, and project management.

➢ Future Scope of the Project

- Integration of higher-precision servo motors for improved motion accuracy and smoother soldering.

- Incorporation of advanced vision algorithms for better feature detection and automated component recognition.

- Development of multi-point soldering capability to handle complex PCB assemblies efficiently.

- Implementation of adaptive temperature control for different component types to prevent overheating.

- Expansion into a modular system for educational labs, prototyping, and small-scale electronics manufacturing.

Final Internship Statement

This report formally certifies the successful completion of a six-month Industrial Automation internship at SURE TRUST, conducted from October 2025 to December 2025. During this period, the project undertaken exemplifies a high degree of technical competence, practical problem-solving, and industrial acumen.

It highlights the effective application of automation principles, including sensor integration, embedded control, and energy-efficient system design, with a particular emphasis on renewable energy utilization. The internship provided comprehensive exposure to real world engineering workflows, industrial best practices, and performance validation methodologies, culminating in a demonstrably reliable and scalable automation solution. This experience has not only strengthened theoretical knowledge but also fostered professional skills, analytical thinking, and readiness for complex industrial applications.