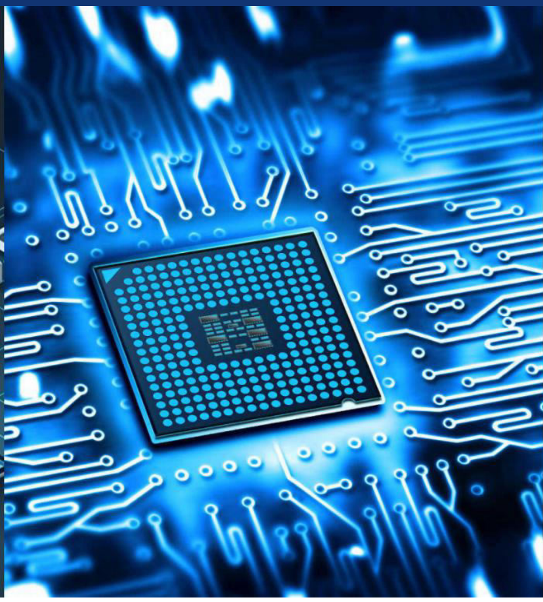
IJIRCCE

ISSN(O): 2320-9801

ISSN(P): 2320-9798



International Journal of Innovative Research in Computer and Communication Engineering

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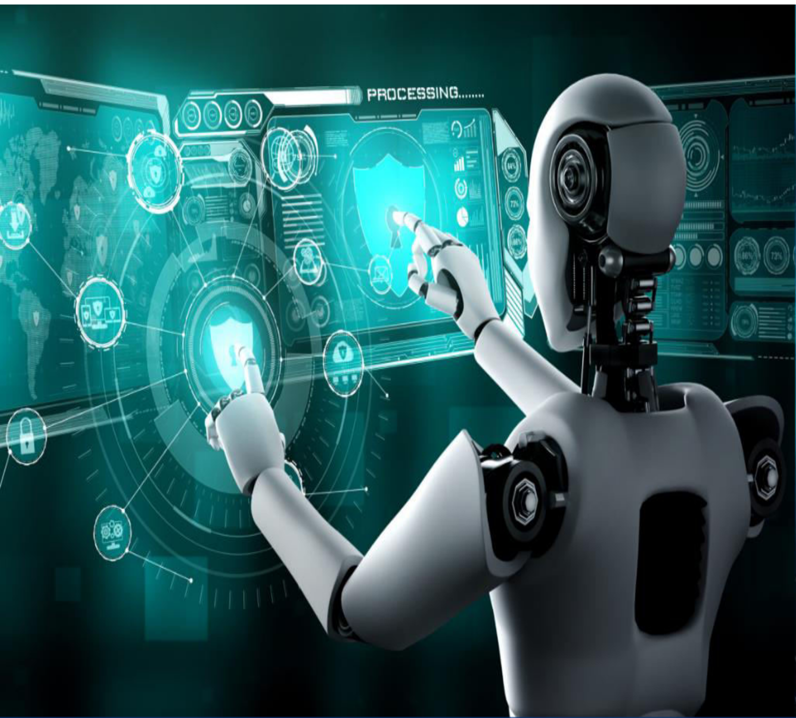

Impact Factor: 8.771

Volume 14, Issue 3, March 2026

© 2026 IJIRCCE | Volume 14, Issue 3, March 2026 DOI: 10.15680/IJIRCCE.2026.1403058

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(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Autofill Cap-Label System (AFCL)

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ABSTRACT: Manual bottle filling, capping, and labeling processes in small-scale industries are often labor-intensive, time-consuming, and prone to inconsistency, leading to reduced productivity and product quality. Although advanced industrial automation systems are available, their high cost makes them unsuitable for startups in dairy, juice, and bottled water sectors. This project presents the development of a low-cost automatic bottle filling, capping, and labeling system integrated with machine vision for quality monitoring. The system employs an STM32 microcontroller to control the filling, conveyor, and labeling mechanisms using stepper motors, servo motors, and relay modules. An ESP32-CAM module, interfaced with OpenCV, is used for visual inspection of bottles to detect filling level, cap presence, and labeling status. Image processing techniques implemented in OpenCV enable real-time analysis and decision-making, allowing the system to identify faulty bottles and trigger corrective actions. The proposed system is compact, efficient, and significantly reduces manual intervention. The total system cost is maintained under ₹15,000, offering an affordable and practical automation solution for small-scale manufacturers. The results demonstrate the feasibility of integrating low-cost machine vision with embedded control to improve productivity and quality assurance in bottling operations.

KEYWORDS: Automated bottle filling; Bottle capping; Bottle labeling; ESP32-CAM; OpenCV; Machine vision; STM32 microcontroller; Low-cost automation

I. INTRODUCTION

Automation has become a key component of modern industrial systems due to its ability to improve production speed, accuracy, consistency, and operational safety. Automated machines can perform repetitive tasks continuously without fatigue, thereby reducing human intervention and minimizing errors associated with manual operations. In bottling industries, processes such as filling, capping, and labelling are critical for maintaining product quality and throughput. However, when performed manually or using semi-automated setups, these operations often suffer from inconsistent fill levels, improper capping, increased spillage, and higher labor dependency, which ultimately raise production costs.

Although fully automated bottle filling and capping machines are widely used in large-scale industries, they are generally expensive, bulky, and complex to maintain. Such systems are often designed for high-volume production lines and are financially inaccessible to small-scale industries and startups, particularly in sectors such as dairy, juice, and bottled water manufacturing. As a result, there is a growing demand for compact and affordable automation solutions that can deliver reliable performance without the high cost associated with industrial-grade machinery.

To address these challenges, this project presents a low-cost automated prototype designed to integrate bottle filling, capping, and labelling operations into a single system. By combining these processes into one compact unit, this machine reduces production time, saves floor space, and lowers overall operational expenses. The system is controlled by an STM32 microcontroller, which serves as the central processing unit and manages motor control, timing, and operational sequencing to ensure smooth and synchronized operation.

In addition to mechanical automation, quality assurance is enhanced through the integration of an ESP32-CAM module for vision-based inspection. Using OpenCV-based image processing, this unit verifies proper cap placement before allowing bottles to proceed to the labeling stage. This vision-assisted feedback helps reduce defective output and improves overall process reliability. The proposed system integrates mechanical, electrical, and software components to provide an efficient, low-cost automation solution suitable for small-scale bottling applications.

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II. BACKGROUND

This project is designed with a user-centric approach to ensure simple operation, accessibility, and smooth interaction for operators with minimal technical expertise. The system provides an intuitive operational workflow in which bottles placed at the input section are automatically conveyed through filling, capping, and labelling stages without requiring manual intervention. The STM32 microcontroller manages all control logic, timing, and motor sequencing, thereby eliminating the need for complex user adjustments or parameter tuning.

Vision-based inspection using the ESP32-CAM module further enhances ease of operation by automatically verifying proper cap placement before bottles proceed to the labelling stage. This reduces dependence on manual quality checks and minimizes operator involvement. Clear process sequencing, minimal setup requirements, and automated handling of incorrect bottle conditions contribute to reduced operator workload and improved system reliability. Overall, this machine enables efficient production with minimal training, making it wellsuited for small-scale industrial environments.

III. LITERATURE SURVEY

Automation in bottling and packaging industries has advanced significantly in recent years with the integration of sensors, vision systems, and IoT-based monitoring. Modern automated systems aim to improve filling accuracy, reduce human intervention, and ensure consistent product quality. This section reviews five recent studies relevant to automated bottle filling, capping, and labeling systems.

In [7], the authors developed an in-line vision-based inspection system for detecting fill level, cap sealing, and label placement defects in bottled liquids. A CMOS camera mounted above a conveyor captured grayscale images, and Canny edge detection was used to identify liquid boundaries, while template matching verified label alignment and color thresholding detected cap presence. The system achieved an overall inspection accuracy of 95.6% with real-time processing capability. However, its performance was evaluated only on transparent amber bottles under controlled lighting, limiting its applicability in diverse industrial environments.

Similarly, [3] presented an IoT-enabled automated bottling plant capable of filling bottles of different heights using a PLC-controlled conveyor and ultrasonic sensors. Proportional valves adjusted liquid volumes, and operational data was transmitted via MQTT to an IoT dashboard for real-time monitoring. Experimental results showed improvements in throughput (35%) and reductions in downtime (20%) and waste (15%). Despite these benefits, the system focused on water-based applications and did not account for foaming or viscosity variations common in beverage industries.

The authors in [4] proposed an IoT-connected smart liquid dispensing system using a Raspberry Pi and computer vision techniques. OpenCV and YOLOv3 were used to detect containers, while an ultrasonic sensor controlled the filling level. The system achieved up to 97% dispensing accuracy under optimal lighting conditions but showed reduced detection performance for transparent or reflective vessels. This highlights the dependency of vision-based systems on environmental conditions.

In [5], an integrated PLC-based filling, capping, and labeling machine with an HMI interface was implemented. Timed pump filling, pneumatic capping, and stepper motor–driven labeling were used to automate the process. Although the system achieved high volumetric accuracy, labeling and capping reliability were limited due to mechanical inconsistencies, indicating the need for automated inspection and error handling.

A low-cost microcontroller-based dispensing system was presented in [6], achieving high volumetric accuracy using a solenoid valve and level sensor. While cost-effective, the system lacked integration with conveyor mechanisms, capping, labeling, and quality inspection, restricting its use in automated production lines.

Our Contribution

The proposed Smart Automated Bottle Filling, Capping, and Labelling System integrates bottle detection, controlled filling, vision-based inspection, automated capping, labeling, and error handling within a single compact architecture. A conveyor-mounted sensor detects empty bottles, a controlled filling unit dispenses a predefined volume, and a camera

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module verifies fill level and cap presence using image processing techniques. Bottles that fail inspection are automatically rerouted for re-filling or rejection. Real-time process status and fault information are displayed and logged through an IoT-enabled interface. Compared to existing solutions, the proposed system offers improved integration, reduced human intervention, and enhanced reliability, making it suitable for small- to medium-scale production environments.

IV. PROJECT CHALLENGES AND FUTURE PLANS

The primary challenges encountered in this project were related to the implementation of machine vision using OpenCV with Python. Reliable cap detection was sensitive to variations in lighting conditions, camera angle, and background noise, which affected detection accuracy. Transparent bottle surfaces and reflective caps further complicated image processing, requiring careful adjustment of thresholds and preprocessing parameters. Real-time image acquisition and processing also posed challenges due to limited computational resources, necessitating optimization of OpenCV routines to maintain acceptable response times.

Future work will focus on improving vision robustness by incorporating controlled illumination, adaptive thresholding, and advanced image processing techniques. The use of trained machine learning or deep learning models may enhance detection accuracy under varying environmental conditions. Additionally, optimizing the Python–OpenCV pipeline and exploring hardware acceleration can further improve real-time performance, making the system more reliable for industrial deployment.

V. PREPARATION OF PROJECT REPORT

Before applying formatting and styling, the complete content of this project report should be written and saved as a separate text file. All technical descriptions, explanations, and section organization must be finalized prior to formatting. Proofreading for spelling, grammar, and technical accuracy should be completed at this stage to ensure clarity and correctness.

Text content and graphical elements, such as figures, block diagrams, flowcharts, and tables, should be prepared separately and inserted only after the text has been properly formatted. Hard tabs should be avoided, and only a single line break should be used at the end of each paragraph. Page numbers must not be added manually, and section headings should not be numbered manually, as numbering will be handled automatically by the selected template.

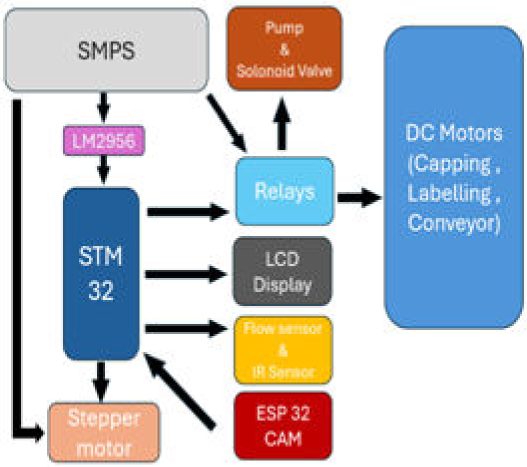

Fig 1:Block Diagraam

The above block diagram illustrates the working process of a Smart Automated Bottle Filling, Capping, and Labelling System for small to medium-scale production lines. The system uses sensors, actuators, and a vision module to automate the process with minimal human interaction.

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The process starts with the detection of an empty bottle by a sensor mounted along the conveyor belt. As soon as the bottle is detected, it is automatically transferred to the filling unit through a motorized conveyor system. After that, the filling process begins, where a predetermined amount of liquid is dispensed into the bottle.

There is a fill check process that ensures the bottle is filled to the desired level. If the bottle is not filled to the desired level, the system halts the filling process and proceeds to take a picture of the bottle. If the bottle is filled to the desired level, it moves on to the next step.

Then comes the capping stage, where the bottle is capped with a cap that is tightened automatically. After that, an image is taken through a camera module to check the status of the cap. The system checks for errors like loose caps, missing caps, or misplaced caps. If there is any problem, the bottle is sent to an error handling section for rejection or further checking.

If there is no problem and the status of the cap is okay, the system moves to the labelling stage, where a label is stuck to the bottle. Finally, the system shows the status of the process, whether the bottle is filled, capped, and labelled successfully or if there is an error.

In conclusion, this smart automation project enhances efficiency, accuracy, and reliability in the bottling process, as well as minimizing human labor and errors. The project integrates mechanical motion, controlled liquid flow, vision inspection, and real-time status reporting for a smooth production process.

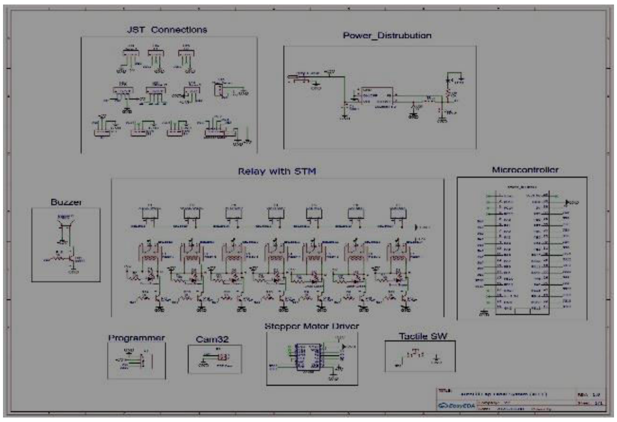

Fig. 2:Schematic of Atomiser

The schematic represents the functional design of the automated bottling system controller. The system is centered around the STM32F103C8T6 microcontroller, which manages the overall operation by interfacing with sensors, actuators, and peripheral modules. Inputs from devices such as the flow sensor and limit switches are processed by the microcontroller to monitor bottle position and liquid flow during the filling process. Driver circuits using BC547 transistors are implemented to control relays that switch high-power components like pumps, solenoid valves, and motors. Protective diodes are included across relay coils to prevent voltage spikes from damaging the control circuitry.

In addition, the system integrates a stepper motor driver, the A4988 Stepper Motor Driver, which controls the movement of the conveyor or bottle positioning mechanism. The schematic also includes interfaces for peripheral devices such as a buzzer, LCD display, servo motors, and camera module connectors. A dedicated power distribution section regulates and distributes the required voltages to the microcontroller, sensors, and actuators, ensuring stable and reliable operation of the entire system.

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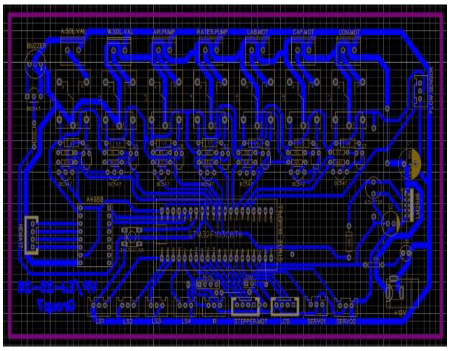
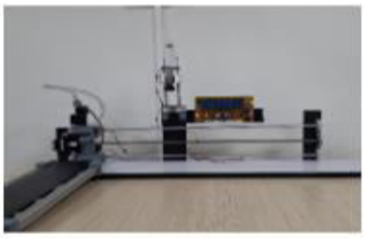


Fig. 3:PCB of LAYOUT

The PCB layout is the physical realization of the schematic, designed to organize and interconnect all components efficiently on a single board. The STM32F103C8T6 microcontroller is placed near the center of the board to reduce the length of signal traces connecting it to different modules. The relay driver circuits are arranged in a row to simplify routing and maintain a clear separation between control signals and high-current paths used for pumps and motors.

Power distribution traces are designed wider to handle higher currents safely, while signal traces are routed carefully to minimize interference and noise. Connectors for sensors, motors, servo modules, and external devices are positioned along the edges of the PCB to allow easy access during installation and maintenance. The layout also maintains proper spacing between components and traces, ensuring reliability, thermal stability, and ease of manufacturing for the automated bottling system control board.

VI. IMAGES OF PROJECT

VII. ADVANTAGES AND FEATURES,APPLICATIONS

Advantages:

1. Cost-Effective Solution

The system is designed using affordable components like STM32 and ESP32-CAM, making it suitable for small-scale industries and startups that cannot invest in expensive industrial machines.

2. Reduced Labor Requirement

Since filling, capping, and labeling are automated, the need for continuous manual supervision is reduced, lowering labor costs.

3. Improved Accuracy and Consistency

The automated control ensures uniform fill levels, proper cap placement, and consistent labeling, reducing human errors.

4. Compact and Space-Saving Design

All three operations are integrated into a single unit, reducing floor space usage compared to separate machines.

5. Quality Inspection with Vision System

The ESP32-CAM with OpenCV verifies proper cap placement before labeling, reducing defective products and improving quality control.

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6. Reduced Material Wastage
Accurate filling minimizes liquid spillage and product loss, saving raw materials.
7. Easy Maintenance and Scalability
The modular design allows easy troubleshooting and future upgrades according to production requirements.

Features:
1. Integrated Three-in-One Operation
Performs filling, capping, and labeling in a single compact unit.
2. STM32-Based Control System
Uses an STM32 microcontroller for precise motor control, timing, and synchronized operation.
3. Vision-Based Cap Inspection
Incorporates an ESP32-CAM with OpenCV for detecting proper cap placement before labeling.
4. Automatic Sequencing
Ensures smooth step-by-step operation without manual intervention.
5. Accurate Liquid Filling
Provides consistent and controlled fill levels to minimize wastage.
6. Modular and Compact Design
Easy to assemble, maintain, and upgrade; suitable for small workspaces.
7. Low-Cost Implementation
Built using affordable components, making it suitable for small-scale industries.
8. Reduced Human Error
Automation and camera-based inspection improve reliability and product quality.

Applications:
1. Dairy Industry
Used for filling and sealing milk, flavored milk, and other liquid dairy products.
2. Beverage Industry
Suitable for juice, soft drinks, mineral water, and energy drink bottling units.
3. Packaged Drinking Water Plants
Ensures accurate filling and proper capping for bottled water production.
4. Pharmaceutical Industry
Can be adapted for filling liquid medicines, syrups, and chemical solutions with high precision.
5. Cosmetic Industry
Used for filling products like lotions, shampoos, oils, and other liquid cosmetics.
6. Small-Scale Manufacturing Units
Ideal for startups and small businesses that require affordable automation solutions.
7. Food Processing Units
Can be used for edible oils, sauces, syrups, and other liquid food products.

VIII. RESULT

The developed automated bottle filling, capping, and labeling system successfully performed all three operations in a synchronized and sequential manner. The STM32 microcontroller effectively controlled motor movements and timing, ensuring accurate liquid filling and proper cap placement. The ESP32-CAM with OpenCV-based image processing was able to detect correct cap positioning before allowing the labeling process, thereby improving quality control.

The system demonstrated reduced manual intervention, minimized spillage, consistent output, and reliable operation within a compact setup. Overall, the prototype validated that a low-cost, integrated automation solution can efficiently meet the needs of small-scale bottling industries.

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IX. CONCLUSION AND FUTURE SCOPE

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Future work will focus on improving vision robustness by incorporating controlled illumination, adaptive thresholding, and advanced image processing techniques. The use of trained machine learning or deep learning models may enhance detection accuracy under varying environmental conditions. Additionally, optimizing the Python–OpenCV pipeline and exploring hardware acceleration can further improve real-time performance, making the system more reliable for industrial deployment.

This project demonstrates that effective industrial automation can be achieved through smart system integration rather than expensive hardware. By combining simple mechanical design, STM32-based embedded control, and OpenCV-supported vision inspection using ESP32-CAM, the system delivers reliable and affordable bottling automation for small-scale industries. The development process highlighted the importance of synchronizing mechanical operations with digital decision-making, especially in real-time vision-based feedback systems. It also showed that cost-effective, compact, and modular designs can successfully address practical constraints such as limited space, low investment capacity, and minimal technical resources, making it a valuable reference for low-budget smart manufacturing solutions.

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