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Prototype of an IoT-Based Height Sorting Conveyor using ESP32, HC-SR04, and IR Sensors

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Abstract: Industrial sorting on small-scale production lines is often still performed manually, which can reduce throughput consistency, increase human error, and limit real-time traceability. **Objective:** design, implement, and evaluate an ESP32-based conveyor prototype that automatically sorts items by height while providing local and IoT-based monitoring. **Methodology:** engineering experimental approach (prototype development and verification testing). Data were collected from embedded sensor readings (HC-SR04 ultrasonic and IR sensors), actuator response observations, LCD outputs, IoT dashboard records, and manual reference measurements for validation. Data were analyzed by assessing measurement accuracy, detection reliability, actuator responsiveness, and overall sorting success rate. **Findings:** HC-SR04 estimated item height with good accuracy (average deviation approximately ±0.1 cm), supported by interrupt-based handling and data averaging to improve stability. IR sensors reliably detected item presence and position, while pull-up configuration and debounce logic prevented duplicate triggering. MG90S 180° servo actuator performed smooth category-based diversion using non-blocking and soft-open control without disrupting other system processes. Sorting success rate exceeded 95%, and operation remained stable in both offline and online modes, with IoT integration enabling real-time monitoring without becoming a dependency for control. **Implications:** proposed architecture can function as a low-cost learning platform and a basis for small-scale industrial automation requiring reliable sorting and operational visibility. **Originality/value:** integration of baseline-calibrated ultrasonic height measurement, IR-based position gating, non-blocking servo control, local 20×4 I2C LCD feedback, and IoT monitoring into a single workflow that remains functional during network disruptions.

Keywords: Automatic Sorting; ESP32; Height-Based Classification; HC-SR04; Infrared Sensor; Iot Monitoring.

INTRODUCTION

Industrial automation is a central lever for improving efficiency, throughput, and output consistency in production and internal logistics, particularly within the broader transition toward cyber-physical manufacturing associated with Industry 4.0 (Lasi et al., 2014; Bi et al., 2014). In practice, however, many small-scale production lines, teaching laboratories, and prototype-oriented workshops still rely on manual sorting when items move along a conveyor and must be routed immediately into categories. Manual decisions in a continuous-flow setting tend to be labor intensive and vulnerable to variability—where minor delays or inconsistent judgments can propagate into misroutes, rework, and reduced process stability. These constraints become more pronounced when sorting rules depend on physical attributes (e.g., height tiers), because classification must occur while the object is in motion and the actuator must be triggered at the correct position on the conveyor.

Beyond productivity, modern operations increasingly require real-time visibility of shop-floor activity—such as item counts per category, process status, and event logs—to support faster corrective actions and basic traceability (Gubbi et al., 2013; Bi et al., 2014). IoT-enabled automation is often positioned as a practical pathway to connect embedded processes with lightweight monitoring dashboards, especially when budgets and integration resources are limited. Low-cost Wi-Fi microcontrollers (e.g., ESP32-class devices) enable a single embedded node to handle sensing, decision logic, actuation, and connectivity, thereby supporting both local operation and remote supervision. Empirical IoT prototype implementations also highlight that usability improves when monitoring is paired with simple remote controls (e.g., conveyor ON/OFF) and when the system remains functional even if the network becomes intermittent.

From the literature on conveyor-based automation prototypes, a common approach to small-scale sorting is to combine a distance/sensing stage, a rule-based classifier (often threshold-based), and a mechanical diverter (e.g., servo-driven gate) (Restuasih et al., 2022; Supriyadi et al., 2022). For instance, ultrasonic-sensor-based designs demonstrate that object presence can trigger a measurement cycle and the resulting distance value can be converted into a routing decision for automated sorting (Restuasih et al., 2022). Related applied prototypes in Indonesian contexts also show that microcontroller-based sorting systems can be implemented with simple sensors and actuators and evaluated through functional testing and basic accuracy metrics (Anggreani et al., 2023). Nevertheless, across these prototypes, implementation details vary substantially in how sensors are sequenced, how timing is enforced while the conveyor is moving, and how classification decisions are synchronized with actuator commands.

A second stream of evidence emphasizes that ultrasonic distance measurement accuracy is not purely a function of sensor hardware, but is influenced by target material characteristics and measurement conditions (Rihmi et al., 2024). Experimental results indicate that certain materials yield very accurate readings, whereas others can generate larger deviations relative to manual reference measurements, implying a non-trivial risk of misclassification near threshold boundaries if the signal is noisy or biased (Rihmi et al., 2024). Consequently, height-based sorting should explicitly manage (i) baseline calibration—such as establishing the reference distance between sensor and conveyor surface—and (ii) noise mitigation through structured sampling or averaging before applying classification thresholds. In conveyor settings, where objects pass under the sensor briefly, these steps are essential to maintain consistent decisions without inflating latency or missing items.

A third stream concerns IoT dashboards and mobile monitoring/control for embedded systems. Practical implementations demonstrate that the Blynk ecosystem can be used to display real-time variables and to provide remote control functions that enhance operational flexibility for IoT prototypes (Akbar et al., 2025). However, prototype literature often under-specifies two reliability-critical aspects for conveyor sorting: fail-safe behavior during network loss (so the sorter continues operating locally) and non-blocking control design (so actuation does not halt sensor sampling, classification, or reporting). These issues are especially important when multiple sensing events (IR triggers and ultrasonic readings) must be coordinated with servo actuation at precise conveyor positions, because blocking delays can increase decision latency and reduce sorting accuracy under continuous flow.

Therefore, this study aims to design, implement, and evaluate a conveyor-based automatic sorting prototype that classifies items by height using an ultrasonic sensor for measurement and infrared sensors for presence/position triggering, controlled by an ESP32 microcontroller. The system employs a servo-based diverter for routing, a 20×4 I2C LCD for local visualization (height value, category, and counts), and IoT-based monitoring to display sorting counts and categories in real time through a mobile dashboard. The evaluation focuses on (i) measurement accuracy and stability, (ii) correct sorting rate across height categories, (iii) responsiveness under continuous item flow, and (iv) operational continuity in offline conditions when network connectivity is disrupted.

The main argument of this work is that a height-based sorting system can achieve stable and reliable performance when: (i) the measurement pipeline applies baseline calibration and smoothing to reduce ultrasonic noise and material-dependent bias, (ii) the sorting decision and servo actuation are gated by IR-based detection to align timing with conveyor motion, and (iii) the embedded logic is implemented in a non-blocking, state-machine-oriented manner so sensing, decision-making, actuation, LCD updates, and IoT reporting can execute concurrently without sacrificing responsiveness. This argument frames the system architecture and testing design, positioning the prototype not only as a functional sorter but also as a reproducible reference for small-scale industrial automation and learning-oriented IoT conveyor systems.

RESEARCH METHOD

To clarify the operational logic and the interaction among system modules, a flowchart is used to represent the complete workflow of the ESP32-based automatic goods sorting prototype. The flowchart summarizes how the system transitions from initialization and table-height calibration to item detection, height measurement, category classification, position verification, and servo-based sorting. This representation is important because the prototype is designed to run in a coordinated non-blocking manner, where sensing (IR and ultrasonic), decision-making, actuation, LCD updates, and IoT transmission must be executed without interrupting the main control loop. In addition, the flowchart explicitly includes the system's offline–online behavior, illustrating that the core sorting process continues locally when network connectivity is unavailable, while data transmission and dashboard updates resume once the connection is restored. The complete operational flow of the system is presented in Figure 1.

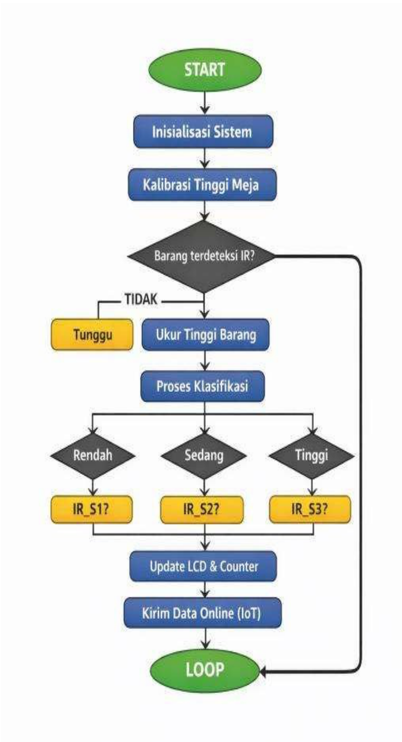


Figure 1. Flowchart

The unit of analysis in this study is an ESP32-based conveyor prototype for automatic height-based sorting, treated as an integrated engineered system consisting of (i) input sensors, (ii) embedded processing, (iii) output actuators, (iv) local display, and (v) IoT-based online monitoring. The system architecture is defined in the block diagram (Figure 2), while the physical realization is shown in the prototype layout Figure 3 and the output interface is represented by the LCD module Figure 4. System behavior is analyzed based on the end-to-end workflow described in the operational flowchart (Figure 1), with the primary outputs being the measured item height, the assigned height category, the actuator response, and the recorded item counts per category.

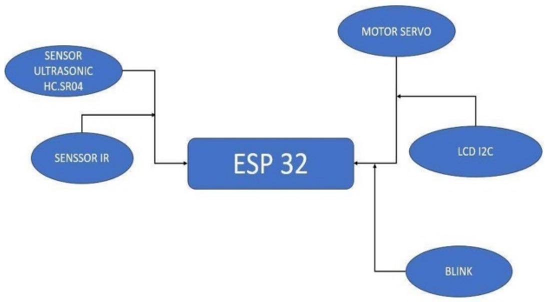


Figure 2. Block Diagram

This research uses an engineering experimental design (prototype development and verification testing) because the objective is to design, implement, and evaluate a working sorting mechanism rather than to study human subjects. A prototype-based approach is appropriate to demonstrate technical feasibility and to measure performance under controlled operational conditions on a moving conveyor. The system is intentionally implemented using a non-blocking control strategy to ensure time-critical tasks—object detection, height sampling, category decision, servo actuation, LCD update, and IoT transmission—can run in a coordinated manner without halting the main control loop. This design choice supports responsiveness when items pass continuously and actuator timing must align with object position on the conveyor (as represented in Figure 3).

Data are obtained from three main sources. First, embedded system outputs produced by the ESP32 include ultrasonic distance readings, calculated item height values, category labels (low/medium/high), IR event states (main IR trigger and line IR sensors IR_S1–IR_S3), servo actuation events, and LCD-displayed information (Figure 4). Second, manual reference measurements of item height (ground truth) are collected using a measuring tool (e.g., ruler/caliper) to validate ultrasonic-derived heights. Third, IoT monitoring records (online platform dashboard) provide remote data logs for item counts and categories, enabling cross-checking between local counts (LCD/system variables) and transmitted counts. The hardware configuration follows the defined components: ESP32 DevKit V1 microcontroller, HC-SR04 ultrasonic sensor, multiple IR sensors, MG90S servo motor (180°), 20×4 I2C LCD, 5V power supply, and stabilizing capacitors for servo voltage stability.

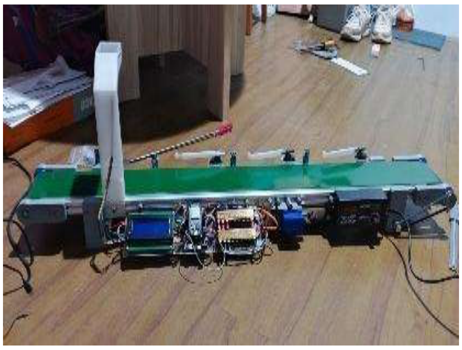


Figure 3. Physical prototype of the conveyor-based sorting system and sensor/actuator placement.

Data collection follows the operational workflow in the system flowchart Figure 5. After power-up, the ESP32 performs initialization and executes table-height calibration by sampling the ultrasonic sensor to obtain the baseline distance between the sensor and conveyor surface (stored as D_table). During operation, the main IR sensor detects a passing item and triggers the measurement routine. The ultrasonic sensor then reads the instantaneous distance from sensor to item surface (D_item), and item height is computed using H_item = D_table − D_item. The system classifies the item by comparing H_item against predetermined threshold values (e.g., low/medium/high boundaries: [T_low] and [T_high] cm). Next, the line IR sensors (IR_S1–IR_S3) determine whether the item has reached the correct sorting position for its assigned category; when the position condition is satisfied, the servo motor is actuated to route the item. After each sorting event, the system updates the LCD with height, category, and counters Figure 3 and transmits the updated totals to the IoT platform via ESP32 Wi-Fi. Additional collection scenarios include offline testing, where Wi-Fi is intentionally disconnected to verify that sorting continues locally while IoT transmission pauses and resumes automatically upon reconnection.

Figure 4. 20×4 I2C LCD interface displaying height, category, and item count

Data analysis focuses on accuracy, reliability, and responsiveness. Ultrasonic measurement accuracy is evaluated by comparing calculated heights (H_item) to manual reference heights across repeated trials, using error metrics such as absolute error and mean error, and reporting variability across repeated samples [N trials per height level]. IR sensor reliability is analyzed by observing stable detection of presence/position events and verifying that debounce handling prevents duplicate triggers during conveyor motion. Servo performance is assessed by confirming that the servo reaches the target angle for each category and that actuation timing matches the position gating logic from IR_S1–IR_S3 without disrupting concurrent processes (non-blocking responsiveness). Sorting performance is quantified as the sorting success rate, defined as the proportion of items correctly routed into the intended category, reported overall and per category (low/medium/high). IoT performance is evaluated by verifying consistency between local counters and dashboard counters and by documenting behavior under online/offline transitions to ensure telemetry does not degrade the core sorting loop.

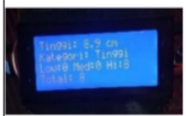
RESULTS AND DISCUSSION

Ultrasonic Sensor Testing (HC-SR04)

The ultrasonic sensor test was conducted to evaluate the capability of the HC-SR04 in measuring item height accurately for classification purposes. The measurement procedure followed the flowchart logic, starting from table-height calibration (baseline distance between the sensor and conveyor surface), followed by distance measurement to the object surface. The item height was calculated as the difference between the baseline distance and the measured distance when an item passed under the sensor.

The results indicate that the HC-SR04 is able to measure item height with good accuracy. The average difference between sensor readings and manual reference measurements was reported to be approximately ±0.1 cm. This error level suggests that the ultrasonic sensor is suitable as the primary height-measurement device for a height-based sorting prototype. The stability of readings was improved by applying averaging and interrupt-based measurement handling, which reduces noise and improves repeatability during conveyor operation.

Table 1. Ultrasonic Sensor Testing presents the comparison between manual height and sensor-derived height (including the measured difference).

No	Tinggi Aktual (cm)	Tinggi Terbaca (cm)	Selisih (cm)
1.	4,4 cm	4,3 cm 	0,1 cm
2.	6,4 cm	6,3 cm 	0,1 cm
3.	9,0 cm	8,9 cm 	0,1 cm

Infrared Sensor Testing

Infrared (IR) sensor testing was performed to verify that the IR sensors can reliably detect item presence and support position-based triggering on the conveyor line. The IR sensor functions as a trigger to start the height measurement routine (main IR sensor) and as a position confirmation mechanism (line IR sensors) to ensure the item reaches the correct lane before the servo actuator is activated.

The test results show that the IR sensors detected items quickly and stably within the defined working distance. No detection errors were observed at normal conveyor speed, and the debounce mechanism successfully prevented duplicate triggering when an item passed the sensor boundary. In addition, the use of the INPUT_PULLUP configuration contributed to a more stable input signal, reducing noise-related false transitions.

Figure 5. Infrared Sensor is used to illustrate the IR sensor implementation on the conveyor prototype.

Servo Motor Testing (MG90S 180° as Sorting Actuator)

Servo motor testing was conducted to confirm that the MG90S servo motor can actuate the sorting mechanism at predetermined angles for each height category (e.g., low/medium/high). The servo control was implemented using a non-blocking approach to prevent actuator motion from interrupting other processes such as sensing, LCD updates, and IoT data transmission.

The results indicate that the servo motor consistently moved to the designated angles for each category. The "soft-open" (smooth actuation) approach produced smoother motion, helping reduce mechanical shock and improving stability during repeated cycles. Importantly, no system disruption was observed while the servo was active, indicating that the non-blocking servo routine maintained system responsiveness.

Table 2. Servo Testing

No.	Sensor Status	Servo Response	Conveyor Speed	Total Test Time (minutes)
1	Not Detected	Not Moving	0.335	4
2	Detected	Moving	0.335	4

Servo Testing should summarize servo performance, including at minimum the target angle per category, observed response behavior, and whether the sorting action was successful for each trial.

Blynk Application Integration Testing (IoT Monitoring and Remote Control)

IoT integration testing was performed by connecting the ESP32 to the Blynk application via Wi-Fi. The objective of this test was to validate that the system can transmit sorting data to the IoT platform in real time and enable remote control functions (e.g., conveyor ON/OFF) without affecting the core sorting operation.

During the test, the data displayed on the Blynk dashboard (item counts and category totals) were cross-checked with local system outputs (LCD display and manual counting) to verify consistency. The interface supports real-time monitoring of the number of objects successfully sorted by height category and provides a power switch for controlling conveyor operation. This function improves usability by enabling operators to supervise system performance remotely while still maintaining local operation.

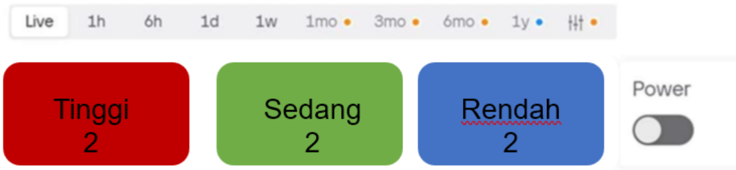


Figure 6. Application Integration Testing shows the monitoring interface used in the experiment.

Overall System Performance (Sorting Accuracy and Reliability)

Overall system testing confirms that the prototype can sort items into low, medium, and high categories effectively. The reported sorting success rate reached more than 95%, indicating that the combined design of (i) ultrasonic height measurement, (ii) IR-based triggering and position detection, and (iii) servo actuation logic can produce reliable category-based routing on the conveyor.

In addition, IoT integration provides added value in the form of real-time monitoring without degrading the system's core performance. The system is also designed to remain operational in offline mode: when the network connection is lost, the sorting process and local display continue functioning, while data transmission resumes once the Wi-Fi connection is restored. These results demonstrate that the prototype operates stably and responsively in both offline and online conditions, making it suitable as a learning platform and as a baseline for small-scale automation development.

DISCUSSION

The results indicate that the proposed ESP32-based conveyor sorter can perform height-based classification reliably in a small-scale automated handling scenario. The ultrasonic measurement test (Table 1) shows a small average deviation from manual readings (±0.1 cm), suggesting that the distance-to-height conversion (via reference/table calibration) is sufficiently stable for threshold-based categorization. In parallel, the IR sensing subsystem (Picture 5) provides consistent event triggering and position confirmation, which is essential for synchronizing measurement and actuation when items move continuously on the conveyor. The servo actuator test (Table 2) further shows that category-dependent mechanical diversion can be executed smoothly without interrupting other tasks, and the end-to-end evaluation demonstrates that items are sorted into low, medium, and high classes with an overall success rate above 95%, while local status information remains visible via the LCD and online monitoring remains functional when connectivity is available.

These outcomes can be explained by how the system handles the two most error-prone stages of low-cost sorting: sensing stability and timing alignment. Ultrasonic sensors are known to exhibit measurement dispersion due to factors such as object surface reflectivity, geometry, sensor placement angle, and ambient conditions; therefore, using structured sampling (e.g., averaging) and a clearly defined baseline distance (table height reference) directly reduces noise-induced variability near decision thresholds. In practice, the calibration step that records the conveyor reference distance becomes crucial because the system's "height" is derived from a difference calculation; any drift in the reference will propagate into classification error. The observed stability in this study is consistent with prior experimental discussions on characterizing low-cost ultrasonic sensing and the need to treat sensor behavior as an empirical component requiring calibration rather than an ideal measurement source.

A second reason the system performs well is the use of IR sensing as a gating mechanism for measurement and actuation. Instead of continuously sampling and classifying "free-running" distance values, the system uses IR detection to confirm item presence and, critically, item position before actuating the servo. This approach reduces false triggering and mitigates double counting, especially when combined with pull-up configuration and debounce logic, because the measurement is taken at a meaningful event boundary (item present under the sensor) and the diverter is activated only when the item reaches the correct lane position. Conceptually, this aligns with practical Industry 4.0 automation requirements where stable throughput is not only a function of sensor accuracy but also of deterministic coordination between sensing, decision logic, and actuation under continuous flow conditions (Lasi et al., 2014; Bi et al., 2014).

When compared with prior prototype-oriented sorting studies, the results are directionally consistent but show a more explicit emphasis on real-time coordination and monitoring. For example, other microcontroller-based sorting systems have successfully separated objects using simple decision rules and servo-based mechanical routing, even when the classification basis differs (e.g., color and weight sorting) (Anggreani et al., 2023). Similarly, many IoT prototypes demonstrate that low-cost embedded devices can combine sensing and actuation with remote monitoring for operational visibility (Adams & Giap, 2024). The novelty here is not the use of a single sensor or actuator, but the integrated architecture that couples (i) height computation anchored by a table-reference calibration step, (ii) multi-point IR triggering for timing alignment along the conveyor path, and (iii) a non-blocking control strategy so that measurement, classification, actuation, LCD refresh, and IoT reporting can operate concurrently without introducing decision latency that would otherwise reduce sorting accuracy at higher conveyor speeds.

The IoT component adds interpretive value beyond "automation for automation's sake." In industrial and lab logistics settings, traceability and rapid intervention depend on visibility: operators need to see counts, category distributions, and abnormal patterns without stopping the line. The system's ability to publish sorting results to an online dashboard while maintaining local operation reflects a typical IoT design principle: connecting edge processes to lightweight monitoring layers for supervision, auditability, and faster corrective actions (Gubbi et al., 2013; Bi et al., 2014). This direction is also reflected in applied IoT implementations that combine ESP32-class devices with app-based dashboards for real-time control and observation, demonstrating usability benefits for monitoring live variables remotely. Importantly, the offline-continuation behavior described in this prototype addresses a common deployment concern: network connectivity should enhance observability but should not become a single point of failure for core control functions.

From a reflection and action perspective, the findings imply that the prototype is suitable as a learning platform and as a baseline for small-scale industrial adaptation, but several engineering refinements are advisable before broader deployment. First, classification reliability near threshold boundaries should be stress-tested using objects with challenging acoustic properties (matte vs. glossy surfaces, angled tops, porous materials) and varying conveyor speeds; this is important because low-cost sensor error distributions can widen under different operating conditions.

Second, mechanical repeatability can be improved by documenting servo timing margins and diverter geometry (e.g., ensuring consistent deflection under load), because even small actuation delays can translate into misrouting at higher throughput. Third, a formal acceptance protocol can be added: periodic table-height recalibration, automatic drift checks, and logging of "borderline" height values for diagnosis. As a practical policy/action recommendation for implementers, the next iteration should include (i) a standardized calibration and verification procedure at shift start, (ii) minimum network-resilience requirements (offline-safe operation as default), and (iii) traceable test reporting (confusion matrix per category, error types, and conditions) so performance claims remain auditable and comparable across environments.

CONCLUSIONS

This study shows that the ESP32-based automatic goods sorting prototype was successfully designed, implemented, and tested according to the intended objectives. The main takeaway is that a low-cost embedded system can perform automatic height-based sorting on a conveyor without direct manual intervention when sensing, decision logic, and actuation are integrated in a coordinated control loop. In the prototype, the HC-SR04 ultrasonic sensor was effective for height measurement with good accuracy, and the use of interrupt-based measurement handling and data averaging improved reading stability. The infrared (IR) sensors also worked reliably to detect the presence and position of items on the conveyor line, providing appropriate triggers to ensure that the measurement and sorting actions occurred at the correct time. The 180° servo motor (MG90S) functioned well as the sorting actuator, and the non-blocking, soft-open control approach produced smooth movements without disrupting other system processes.

In terms of scientific contribution, this research contributes an integrated and reproducible system architecture for small-scale conveyor sorting that combines (i) ultrasonic height estimation supported by baseline calibration and signal stabilization, (ii) IR-based event gating for presence and position confirmation, (iii) non-blocking actuator control for maintaining responsiveness, (iv) local visualization via a 20×4 I2C LCD for real-time monitoring of height, category, and sorted-item counts, and (v) IoT connectivity for online, real-time monitoring. Importantly, the system design treats IoT as an added-value monitoring layer rather than a dependency for control, since the sorter can continue operating normally in offline mode when network connectivity is disrupted. Overall, the prototype operates stably, responsively, and efficiently in both offline and online conditions, making it suitable as a learning tool and as a baseline for developing small-scale industrial automation systems.

This study also has limitations. First, the performance outcomes are bounded by the tested conditions, including the selected object set, the chosen height thresholds, the conveyor speed, and the sensor mounting configuration; different materials, object geometries, or higher throughput may affect ultrasonic measurement behavior and the timing margin for servo actuation. Second, the current evaluation has not yet established a complete operating envelope (e.g., systematic testing across multiple speeds, object spacing, and near-threshold cases) and does not include long-duration durability testing of the servo diverter mechanism under extended cycles. Future work should therefore expand validation across more diverse object materials and shapes, evaluate robustness under varying conveyor speeds and distances, implement hysteresis-based thresholds to reduce borderline misclassification, and include longer-term reliability testing to support potential adaptation for practical industrial automation applications.

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