

PIPE SORTING SYSTEM – FROM DESIGN TO IMPLEMENTATION

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ABSTRACT

This paper presents the design, development, and validation of an automated pipe sorting system built as a small-scale prototype integrating mechanical structures, infrared sensing, and Arduino-based control. The project follows the complete engineering workflow, beginning with concept generation and functional decomposition, continuing with iterative prototyping, subsystem testing, and final integration. The system performs pipe transportation, length measurement through timed sensor interruption, and robotic sorting using a 6-DOF arm. Emphasis is placed on experimental calibration, modular programming, and problem-solving strategies that address challenges such as sensor sensitivity, mechanical alignment, and communication constraints. Results show that the prototype achieves consistent classification for four pipe lengths, demonstrating that low-cost components and systematic testing can yield a reliable model of industrial automation. The project can also be expanded diversifying the types of pipes that can be sorted, increasing measurement accuracy, as well as using AI techniques in decision-making mechanism. The study highlights the educational value and scalability potential of modular, resource-efficient automation design.

Keywords: automated sorting, pipe classification, mechanical design, prototyping, experimental validation.

INTRODUCTION

Engineering projects often begin with uncertainty, especially for individuals with limited prior experience in specific technical domains. This study was initiated under similar circumstances, as the first author had minimal exposure to programming and integrating Arduino Uno-based assemblies prior to the commencement of this work. Although earlier academic exercises provided some foundational knowledge, the current project presented a significantly higher level of complexity and integration [2,3].

This paper documents the conception, design, and realization of a pipe sorting system developed using Arduino-based control [4]. It details the complete process - from brainstorming and conceptual design to testing and refinement - while addressing the challenges encountered and the strategies employed to overcome them [11,20]. The objective is not only to present a functional technical solution but also to emphasize the importance of experimentation, resilience, and creative problem-solving throughout the development process.

MATERIALS AND METHODS

This section describes the design methodology, materials, and components used in the development of the pipe sorting system. The design was based on modular principles, focusing on simplicity, cost-effectiveness, and adaptability to educational and small-scale prototyping environments [13,15].

System Overview and Design Concept

To develop the system, the primary functional process was divided into three core actions: **transportation**, **measurement**, and **sorting**. Breaking down the workflow into smaller, well-defined routines facilitated a clearer design approach and more manageable implementation. While industrial systems typically have rigid design constraints, this project benefited from greater flexibility in experimentation and iteration [7,8].

Based on the review of the relevant technical literature, of interest to the topic of the paper is the automated solution developed by JR Automation [13]. In that system, conveyor belts are used to transfer pipes from a loading area to a measurement and packing zone. The measurement mechanism employs an array of optical sensors that detect the pipe's length by timing the interruption of a light beam as the pipe passes. The pipe length can be determined using the formula:

$$L = t \times v \quad (1)$$

where L is the pipe length, t is the time during which the sensor beam is blocked, and v is the conveyor's transport speed [2,5]. Measurement accuracy depends largely on sensor precision and conveyor speed stability [1]. Sorting in such systems is typically performed using robotic arms, which offer high flexibility but at the cost of increased complexity. This industrial system served as the conceptual foundation for the present work [16,18].



Figure 1. System overview [13]

Reference Systems and Use of Artificial Intelligence Tools

Due to limited access to detailed industrial data—most of which is proprietary—research into existing systems was supplemented using **Large Language Models (LLMs)** such as ChatGPT [21]. Although these tools are sometimes criticized for generating inaccurate information, they proved valuable in identifying potential sources, technical documentation, and relevant design references when used with proper verification. Cross-referencing AI-generated suggestions with credible sources enhanced the research efficiency, compensating for the limitations of traditional search engines [16,9].

- for the start button, one terminal was connected to GND, while the second terminal was connected to digital pin D2;
- for the conveyor end-limit switch, one terminal was connected to GND and the other to digital input D3;
- the 5V power supply was soldered directly to the terminals of the Arduino's power connector;
- the 24V power supply was wired with the negative conductor connected to the conveyor's negative terminal, while the positive conductor was routed through the relay and connected via the common and normally open contacts to the conveyor's positive terminal.

The sorting subsystem exhibits greater complexity compared to the conveyor control module. It includes an infrared emitter–receiver pair, four LEDs equipped with current-limiting resistors, and is directly interfaced with the robotic arm control unit through four dedicated wires connected to digital input addresses.

For this subsystem the connections are made as follows:

- for the LEDs, the cathodes share a common connection to the most accessible GND point on the Arduino board, while the anodes are individually connected to digital pins D3, D4, D5, and D6, each branch including its own current-limiting resistor;
- for the IR receiver, the VCC pin is connected to the Arduino's 5V supply, the GND pin is routed to a convenient ground point on the board, and the DATA pin is connected to digital pin D2;
- the IR emitter is powered similarly to the IR receiver, with its DATA pin connected to digital pin D9;
- digital pins D7, D8, D10, and D11 are used to transmit a HIGH signal—corresponding to the sorting result—to the Arduino controlling the robotic arm subsystem.

The robotic arm control system consists of an Arduino microcontroller, a PWM driver module, and six servo motors. Digital pins D2, D3, D4, and D5 are assigned to receive HIGH signals from the sorting system, depending on the detected pipe category. The connections were implemented as follows:

- the PWM driver module uses the SDA line connected to analog input A4 and the SCL line connected to analog input A5. Logical power is supplied via the Arduino's VCC and GND pins (5V and GND). Servo motors are powered separately through the dedicated connector and an external power supply;
- the servo motors are connected to the designated output channels on the PWM control module.

A set of clarifications is necessary before proceeding. The circuit diagrams used in this paper were created using the Cirkuit Designer platform, which also enables virtual testing of the designed circuits together with the implemented programs. In the physical system, however, the power connections of the Arduino modules are arranged as shown in the final figure, with all three modules connected in parallel to the same power supply.

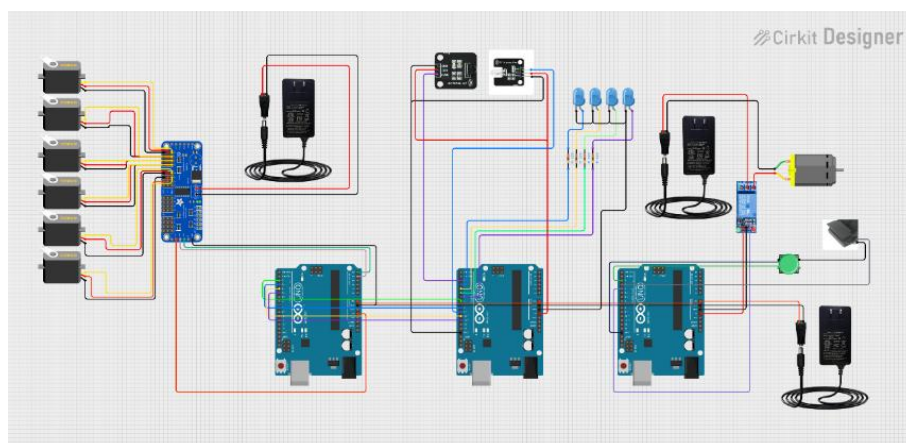


Figure 3. Wiring diagram of the complete pipe-sorting system

Assembly and Wiring Challenges

The physical assembly presented several challenges. Wiring was particularly time-intensive, as the robotic arm alone required 18 wires (three per motor) in addition to power and signal lines. A transition ramp, made from reshaped plastic, was installed between the conveyor and sorting zones to ensure consistent pipe positioning for robotic gripping. Adjustments were made to the ramp's angle and surface to improve stability and alignment [24].

Additional refinements were necessary after system assembly. The optical sensors required several mounting adjustments to achieve consistent readings. A time-delay routine was introduced in the sorting control program to compensate for pipe travel time between the measurement and sorting areas. Furthermore, IR sensor performance was optimized by pulsing the signal at fixed intervals instead of continuous transmission, which prevented signal dropouts [6, 12].

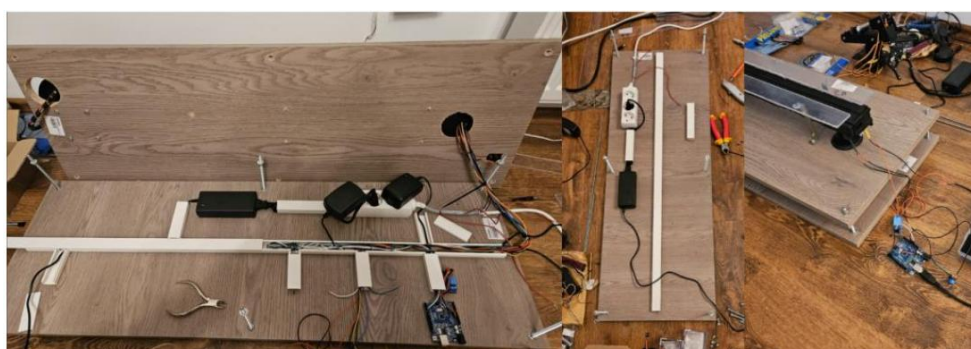


Figure 4. Pipe sorting system assembly steps

Calibration and Speed Measurement

Accurate conveyor speed determination was crucial for reliable measurement. Constant-speed operation was preferred; however, empirical testing was conducted for validation. Four pipe lengths (4 cm, 8 cm, 12 cm, and 16 cm) were used as test samples. Each pipe was passed through the system five times, and the average sensor blocking time was recorded for each length.

Using the recorded values, the conveyor speed was calculated as:

$$v = \frac{L}{t} \quad (2)$$

where L represents the known pipe length and t the average blocking time. The resulting average conveyor speed (see Table 1) was found to be approximately **2.26 cm/s**, confirming a stable and consistent transport rate. This verification also provided reference timing values for the sorting algorithm, ensuring dependable classification. For higher-precision systems, this formula can be extended with real-time feedback to improve sorting accuracy.

Table 1. Conveyor Speed Calculation

Pipe Length (cm)	Average Time (s)	Calculated Speed: $v = \frac{L}{t}$ (cm/s)
4	1.77	2.26
8	3.53	2.27
12	5.32	2.26
16	7.07	2.26
Average	—	2.26

RESULTS AND DISCUSSION

The fully assembled pipe sorting system was evaluated to determine its operational reliability, accuracy, and overall effectiveness. Experiments were conducted using pipe samples of four distinct lengths (4 cm, 8 cm, 12 cm, and 16 cm), with multiple runs performed for each length to assess repeatability and measurement precision. The results are presented in the Table 2.

Table 2. Calibration data

Pipe Length (cm)	Run 1 (s)	Run 2 (s)	Run 3 (s)	Run 4 (s)	Run 5 (s)	Average (s)
4	1.77	1.78	1.76	1.79	1.77	1.77
8	3.54	3.52	3.55	3.51	3.53	3.53
12	5.32	5.30	5.33	5.31	5.34	5.32
16	7.08	7.05	7.07	7.06	7.09	7.07

System Functionality and Performance

The system successfully executed the three core functions: transportation, measurement, and sorting. The conveyor consistently transported pipes from the loading zone to the measurement and sorting areas, and the infrared sensor array reliably detected pipe presence and length. The Arduino-based control architecture, combined with the simple digital signalling protocol between measurement and sorting modules, ensured timely execution of servo routines in the robotic arm.

The sorting system demonstrated accurate classification for all four pipe lengths. The calibration of sensor blocking times allowed the Arduino controller to correctly trigger the corresponding sorting routine, resulting in successful placement of pipes into designated categories.

Measurement Accuracy and Conveyor Speed Verification

Empirical testing confirmed the conveyor operated at a relatively stable speed of 2.26 cm/s. Minor variations in sensor readings were observed due to slight differences in pipe dimensions and placement, but these deviations did not significantly impact sorting accuracy. The repeated measurements indicated that the time-based length detection method was robust for the intended prototype scale, achieving 100% correct classification in all tests runs for the four length categories.

Challenges and Limitations

Several challenges were identified during testing:

- **Mechanical alignment:** Fine-tuning the ramp and conveyor-to-sorting transition was necessary to ensure consistent pipe positioning for the robotic arm.
- **Sensor sensitivity:** Infrared sensors required periodic signal pulsing and mounting adjustments to avoid misreadings.
- **Control delays:** Timing buffers were implemented in the sorting program to account for minor delays in pipe travel between the measurement and sorting zones.
- **Limited sorting categories:** Due to the Arduino Uno's limited I/O and communication simplicity, the system was restricted to sorting four pipe lengths. Expanding the system would require more complex communication protocols or additional hardware.

Despite these limitations, the modular design allowed for easy adjustments, and the system provided a reliable demonstration of automated sorting principles for educational and prototyping purposes.

Significance and Practical Implications

The results indicate that even with a simple conveyor, infrared sensors, and an educational robotic arm, a functional and accurate pipe sorting system can be developed. The project highlights the importance of:

- **Iterative testing:** Continuous adjustment of mechanical components and sensor calibration is crucial for reliable operation.
- **Modular control:** Dividing the control system into multiple microcontrollers simplified programming and reduced debugging complexity.
- **Experimental validation:** Empirical testing of conveyor speed and sensor timing provided reliable data for system design and coding.

This study demonstrates that low-cost components and accessible control platforms can be effectively used to model industrial sorting processes, providing valuable insights for both educational projects and preliminary system prototyping.

The present work leads to the following remarks and contributions:

- **Modular design approach:** Dividing the system into transportation, measurement, and sorting modules simplified both mechanical construction and programming.

- **Iterative testing and calibration:** Fine-tuning the conveyor, sensors, and robotic arm ensured consistent pipe positioning and accurate length detection, highlighting the importance of hands-on experimentation.
- **Effective use of low-cost components:** Infrared sensors, an educational 6-DOF robotic arm, and Arduino Uno microcontrollers were sufficient to build a prototype demonstrating industrial sorting principles.
- **Practical insights for prototyping:** The study emphasizes the importance of modularity, simple communication protocols, and systematic testing when developing automated systems with limited resources.

Overall, this project shows that even with constrained resources, it is possible to design, implement, and validate a functioning pipe sorting system. The methodology and insights presented may serve as a reference for educational projects, small-scale prototyping, or preliminary industrial automation studies.

CONCLUSIONS

This paper presented the design, development, and implementation of a small-scale automated pipe sorting system using Arduino Uno controllers, infrared sensors, a conveyor belt, and a 6DOF robotic arm. The project demonstrates that functional automation systems can be created with off-the-shelf components by applying systematic design, iterative testing, and troubleshooting.

The main conclusions of this paper are presented below:

- **System Reliability:** by carefully calibrating the conveyor speed and sensor timings, the system achieved consistent and repeatable sorting for four predetermined pipe lengths;
- **Modular Design Benefits:** dividing the system control across three Arduino Uno modules simplified programming, reduced resource constraints, and facilitated easier debugging;
- **Practical Problem-Solving:** many challenges, such as sensor sensitivity, robotic arm positioning, and transport alignment, required iterative adjustments, highlighting the importance of hands-on experimentation;
- **Scalability and Flexibility:** while the current system sorts only four pipe lengths, the approach can be extended to more complex setups using additional sensors, robotic degrees of freedom, and improved control algorithms;
- **Educational Value:** the project provides a practical learning experience in mechatronics, automation, and robotics, demonstrating how theoretical principles can be translated into a functioning prototype.

Future work could focus on improving measurement accuracy, expanding sorting categories, and integrating AI-assisted decision-making for more advanced automation.

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