# ANALISIS KOMPARATIF IMPLEMENTASI ROBOT LINE FOLLOWER: STUDI LITERATUR PERBANDINGAN SISTEM BERBASIS MIKROKONTROLER ARDUINO DAN SISTEM ANALOG TANPA MIKROKONTROLER

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## *COMPARATIVE ANALYSIS OF LINE FOLLOWER ROBOT IMPLEMENTATION: A COMPARATIVE LITERATURE STUDY OF ARDUINO MICROCONTROLLER-BASED SYSTEMS AND ANALOG SYSTEMS WITHOUT MICROCONTROLLERS*

**Abstract:** *This study aims to compare the implementation of line follower robots using two system approaches, namely Arduino microcontroller-based and analog systems without microcontrollers. The study was conducted through a literature review using a qualitative descriptive approach, utilizing various reputable scientific publications published between 2018 and 2025. The analysis focused on technical aspects, including sensor configuration, control algorithm implementation—particularly PID—power usage efficiency, as well as the flexibility and operational stability of each system. The results show that Arduino-based systems have advantages in programming flexibility, dual sensor integration capabilities, and ease of algorithm modification. However, these systems are relatively more energy-intensive and have higher processing latency. Conversely, analog systems excel in response speed and power consumption efficiency, but are less adaptive to dynamic environmental changes. Thus, this study provides a conceptual framework for selecting a line follower robot system approach according to application needs, whether for industrial, educational, or research purposes. The implications of these findings are expected to serve as a strategic reference in the development of precise, efficient, and contextual robotics systems.*
**Keywords:** *Line Follower Robot, Arduino Microcontroller, Analog System*

**Abstrak:** *Penelitian ini bertujuan untuk membandingkan implementasi robot line follower dengan dua pendekatan sistem, yakni berbasis mikrokontroler Arduino dan sistem analog tanpa mikrokontroler. Kajian dilakukan melalui studi literatur dengan pendekatan deskriptif kualitatif, menggunakan berbagai publikasi ilmiah bereputasi yang terbit antara tahun 2018 hingga 2025. Analisis difokuskan pada aspek teknis, meliputi konfigurasi sensor, penerapan algoritma kontrol—khususnya PID—efisiensi penggunaan daya, serta fleksibilitas dan stabilitas operasional dari masing-masing sistem. Hasil telaah memperlihatkan bahwa sistem berbasis Arduino memiliki keunggulan pada fleksibilitas pemrograman, kemampuan integrasi sensor ganda, serta kemudahan dalam memodifikasi algoritma. Kendati demikian, sistem ini relatif lebih boros energi dan memiliki latensi pemrosesan yang lebih tinggi. Sebaliknya, sistem analog menonjol dalam kecepatan respons dan efisiensi konsumsi daya, tetapi kurang adaptif terhadap perubahan kondisi lingkungan yang dinamis. Dengan demikian, penelitian ini memberikan kerangka konseptual bagi pemilihan pendekatan sistem robot line follower sesuai kebutuhan aplikasi, baik untuk kepentingan industri, pendidikan, maupun penelitian. Implikasi temuan diharapkan dapat menjadi rujukan strategis dalam pengembangan sistem robotika yang presisi, efisien, dan kontekstual.*
**Kata Kunci:** *Robot Line Follower, Mikrokontroler Arduino, Sistem Analog*

## INTRODUCTION

In the era of Industry 4.0, robotics technology is advancing rapidly. One manifestation of this transformation can be seen in the development of automatic navigation systems, which serve as the foundation for various applications in the modern industrial sector (Dharma Setyawan et al., n.d.). Line follower robots represent one of the fundamental concepts in robotics that is highly relevant to the development of automatic transportation systems, integrated manufacturing, and smart logistics (Gusti Made Andi & Setiyono dan Enda Wista Sinuraya, 2020).

Precision in path tracking is one of the important capabilities that robots must have, especially in industrial applications such as automatic conveyors and small autonomous vehicles that depend on navigation accuracy. At the implementation level, the development of line follower robots generally refers to two main approaches, namely microcontroller-based systems and traditional analog systems. Arduino microcontroller-based systems have been widely adopted in the research and industrial communities due to the flexibility of programming they offer, enabling the implementation of complex algorithms such as PID controllers and machine learning for navigation performance optimization (Taupiq et al., 2024). In contrast, analog systems without microcontrollers are alternatives that rely on purely electronic circuits. This approach offers a number of advantages, including high energy efficiency, relatively short response times, and simpler system complexity (Nurrahmadi et al., 2018).

The two approaches have fundamental differences that need to be critically compared. Arduino, for example, offers high flexibility because the software configuration can be tailored to the needs of the environment. However, this system is not without its drawbacks, namely relatively high power consumption and processing latency (Syahrizal, 2023). Although analog implementations can provide excellent response speeds and high operational stability, these systems face serious limitations in terms of flexibility of modification and adaptation to changing operational conditions (Syafitri et al., 2025).

Comparative analysis is increasingly important in determining the appropriate technology for a particular application, as each approach brings different trade-offs in terms of implementation costs, development complexity, and operational performance. A number of previous studies have even shown that errors in system selection can lead to operational inefficiencies of up to 40% and a significant increase in maintenance costs (Tohir et al., 2023). Therefore, a deep understanding of the characteristics, advantages, and limitations of each system is a fundamental aspect of technological decision-making. A comprehensive literature review is needed to explore implementation patterns, development trends, and performance evaluations of both line follower robot approaches. Through systematic analysis of the latest scientific publications, this study attempts to develop an evidence-based technology selection framework that can be used as a reference in robotics project development. Thus, this study is expected to fill the knowledge gap regarding the comparison between Arduino-based and analog systems, while offering practical recommendations for optimal implementation according to specific application needs (Prasetiyanto & Hadisusila, 2023).

## RESEARCH RESULTS

This study uses a library research approach as the main methodology to analyze and compare the implementation of Arduino microcontroller-based line follower robots with analog systems without microcontrollers. This method was chosen based on its ability to collect comprehensive secondary data from published scientific literature.

Data collection was conducted through in-depth searches of a number of international academic databases, such as IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar, to obtain journal articles, conference proceedings, and relevant publications published between 2018 and 2025. The search strategy utilized a combination of specific keywords—including “Arduino line follower robot,” “analog line tracking system,” “microcontroller vs analog robot,” and “comparative analysis mobile robot”—with Boolean operators to improve the relevance of the results.

Inclusion criteria include publications in English and Indonesian that discuss the implementation, design, or performance evaluation of line followers with a focus on the two systems studied. Literature selection was conducted in stages through screening of titles and abstracts, followed by full-text analysis to ensure suitability with the research objectives. From each source, the data extracted included technical characteristics, operational performance, advantages, limitations, and test results. All findings were then analyzed comparatively to produce a comprehensive overview of the differences between the two approaches (Septaria et al., 2024).

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**RESULTS**

Based on the results of the literature review, various characteristics, advantages, and forms of application of the Arduino microcontroller-based line follower system were found. A summary of the findings from nine studies relevant to the focus of this study is shown in the following table.

**Table 1. Summary of Arduino-Based Line Follower System Analysis Results**

| No | Research & Year | Control System | Main Sensor | Key Advantages | Specific | Result |
|---|---|---|---|---|---|---|
| 1 | Adkine et al., 2025 | Arduino UNO + PID | IR Sensor | Cost-effective, simple, adaptive | Commercial, industrial, medical, education | Precise and smooth movement |
| 2 | Arifin et al., 2021 | Arduino Nano + PID/Fuzzy | Line Sensor | Power optimization, navigation stability | Advanced control systems | Optimal performance at 7.2V |
| 3 | Baballe, 2023 | Arduino UNO | IR Sensor | Simple frame, easily obtainable components | Basic robotics learning | Effective black/white line detection |
| 4 | Riyanto et al., 2021 | PID Control System | Multy-sensor | Precision tuning, adaptive control | Advanced robotics | High path accuracy, optimal stability |
| 5 | Riyanto et al., 2021 | Arduino Mega 2560 + PID | Line, ultrasonic, sensor Colour | Accurate position control, multi-object detection | Industrial forklift robots | Stable PID (100,0,1) |
| 6 | Yudhistira et al., 2025 | Arduino Nano | Sensor & actuator Integrated | Low cost, project-based | STEM education | Improves motivation & skills |

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|---|---|---|---|---|---|---|
| 7 | Sahu et al., 2021 | Arduino UNO + PID | IR Sensor | Autonomous navigation, error minimization | Autonomous navigation systems | High precision motor control |
| 8 | Tambunan & Simanjuntak, 2024 | Arduino UNO R3 | IR & ultrasonic | Integrated manipulator arm, multifunctional | Object manipulation industry | High accuracy with manipulation capabilities |

## DISCUSSION

### Characteristics of the Implementation of an Arduino-Based Line Follower Robot Control System

The implementation of Arduino microcontroller-based line follower robot control systems shows considerable variation, both in the selection of control algorithms and sensor configurations. From the literature review, the Proportional-Integral-Derivative (PID) algorithm appears to dominate, with its application in eight studies. This dominance demonstrates the effectiveness of PID in producing stable and optimal control responses (Adkine et al., 2025; Riyanto et al., 2021; Sahu et al., 2021). The application of the PID algorithm on line follower robots enables the minimization of position errors through the calculation of the difference between the actual position and the reference path. (Riyanto et al., 2021) The use of PID constant parameters with values of Kp = 100, Ki = 0, and Kd = 1 has been proven to produce stable position control during robot navigation toward colored target objects (Riyanto et al., 2021). The advantage of Arduino-based systems lies in their responsive characteristics, which enable the application of more complex control algorithms than conventional analog systems. This is supported by the ability to process sensor data in real time and adapt to changes in operating conditions.

In addition, the diversification of sensor configurations on line follower robots demonstrates the high level of adaptability of Arduino-based systems to various specific application needs. Infrared sensors remain a key component in the majority of implementations, given their effectiveness in consistently detecting the contrast between black lines and white surfaces (Baballe, 2023). (Tambunan & Simanjuntak, 2024) It can be concluded that the use of ultrasonic sensors as distance meters and color sensors to detect objects shows that the line follower system has evolved from a simple function to a multifunctional platform with higher complexity. (Riyanto et al., 2021) Implementing a combination of line sensors, ultrasonic sensors, and color sensors to develop a forklift robot capable of detecting colored objects at a distance of 5 cm. The flexibility of the Arduino platform allows for multi-sensor integration without significantly increasing hardware complexity, providing advantages in the development of robotic systems that are adaptive and responsive to variations in operational environmental conditions.

**Power Supply System Performance Analysis and Optimization**

Power supply optimization in Arduino-based line follower robots is directly related to the quality of navigation and operational stability of the system. (Arifin et al., 2021) found that voltage variations between 8.44V and 6V produced the best performance at 7.2V, indicating an optimum point for achieving maximum navigation speed. Battery voltage fluctuations significantly affect DC motor characteristics: high voltage causes excessive speed, while low voltage causes slow response and unstable movement. This finding emphasizes the importance of implementing effective power management to maintain consistent robot performance.

Battery voltage degradation has a significant impact on the navigation system of line follower robots, not only reducing motor speed but also triggering zigzag movement patterns that decrease path tracking accuracy. This condition demonstrates the dependence of Arduino-based systems on power supply stability to maintain control algorithm performance. Several studies emphasize the importance of implementing voltage monitoring and adaptive compensation systems to maintain performance in long-term operations. Power management strategies, such as the use of voltage regulators and voltage feedback, can be solutions to overcome the inherent limitations of battery-based systems while improving the reliability and operational consistency of robots.

**Applications and Functional Diversification of Line Follower Robots**

The diversification of Arduino-based line follower robot applications shows the evolution of technology from simple path tracking to multifunctional implementation in various industrial sectors. (Riyanto et al., 2021) developing a forklift robot with line following capabilities that not only follows a path, but also integrates object manipulation functions based on color identification. The system uses a position control algorithm that is able to keep the robot on the guide line while performing the task of picking up and moving objects to a specific location. Similar developments by (Tambunan & Simanjuntak, 2024) through a manipulator robot with an integrated arm, which expands the line follower's functions into a more advanced industrial robotics system, with the ability to pick up, lift, and move objects as required for operational needs.

The implementation of line follower robots in education demonstrates the significant role of technology as a medium for learning Science, Technology, Engineering, and Mathematics (STEM). (Yudhistira et al., 2025) developing an Arduino Nano-based prototype designed to support project-based learning at the secondary school level. The robot uses components that are easily obtainable at an affordable cost, making it potentially widely adoptable in the Indonesian education system. The results of the study show that the use of robots in project-based learning can improve STEM skills while motivating students. In line with the research (Adkine et al., 2025) The characteristics of cost-effectiveness, simplicity, and adaptability are key factors that make the Arduino platform relevant not only in education, but also in commercial, industrial, and medical applications.

**Evaluation of the Advantages and Limitations of the Arduino System in the Implementation of Line Follower Robots**

An evaluation of the implementation of an Arduino-based line follower robot reveals a number of fundamental advantages, particularly in terms of programming flexibility, relatively low cost, and ease of assembly, making it the dominant platform in modern robotics development. Arduino's ability to accommodate complex control algorithms, such as PID controllers, has proven effective in improving the precision and smoothness of movement (Adkine et al., 2025). The open-source nature and wide availability of components contribute to an ecosystem that supports rapid prototyping and iterative development. In addition, software configuration allows for the adjustment of operational parameters without the need for significant hardware modifications, as demonstrated by (Baballe, 2023) that Arduino-based robot construction can be done with simple and easily obtainable components, thereby lowering the barriers to adopting robotics technology.

On the other hand, the Arduino system has inherent limitations in power consumption and processing latency that can affect the operational performance of line follower robots. Dependence on power supply stability, as identified (Arifin et al., 2021) shows vulnerability to voltage fluctuations that can reduce navigation accuracy. High processing loads also have the potential to cause latency in responding to changes in route conditions. However, (Sahu et al., 2021) demonstrates that the application of PID algorithms with error minimization strategies can produce high-precision motor control, thereby overcoming some hardware limitations through software optimization.

Overall, despite a number of limitations, its flexibility, adaptability, and cost efficiency make Arduino a superior platform for implementing line follower robots in various application contexts with diverse requirements.

## CONCLUSION

Based on comprehensive analysis, the Arduino-based line follower system has proven to be superior in accommodating complex control algorithms and adapting to a variety of application needs. The implementation of the PID algorithm has consistently demonstrated its effectiveness in minimizing position errors in real time and improving navigation precision. Optimal performance is also achieved through power supply optimization at 7.2V and multi-sensor integration that expands the system's functionality. The fundamental advantages of Arduino—programming flexibility, cost efficiency, and ease of implementation—are key factors driving the evolution of modern robotics.

Despite limitations in power consumption and processing latency, Arduino's high adaptability gives it superior value for various application contexts. Therefore, this study recommends Arduino as the preferred platform for developing line follower robots, with the caveat that operational parameters need to be optimized according to specific application characteristics.

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