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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

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Analisis Komparatif Implementasi Robot Line Follower: Studi Literatur Perbandingan Sistem Berbasis Mikrokontroler Arduino dan Sistem Analog Tanpa Mikrokontrole

Abstrak: *Penelitian ini bertujuan untuk menganalisis secara komparatif implementasi robot line follower antara dua pendekatan sistem, yaitu berbasis mikrokontroler Arduino dan sistem analog tanpa mikrokontroler. Metode yang digunakan adalah studi literatur dengan pendekatan deskriptif kualitatif, memanfaatkan berbagai publikasi ilmiah dari database bereputasi antara tahun 2018 hingga 2025. Fokus analisis diarahkan pada aspek teknis seperti konfigurasi sensor, algoritma kontrol (terutama PID), efisiensi catu daya, serta fleksibilitas dan stabilitas operasional masing-masing sistem. Hasil analisis menunjukkan bahwa sistem berbasis Arduino unggul dalam fleksibilitas pemrograman, kemampuan integrasi multi-sensor, dan kemudahan modifikasi algoritma. Namun, sistem ini memiliki keterbatasan dalam konsumsi daya dan latensi pemrosesan. Sebaliknya, sistem analog menawarkan respon cepat dan efisiensi energi tinggi, namun kurang adaptif terhadap kondisi operasional yang dinamis. Studi ini memberikan landasan konseptual untuk pemilihan sistem robot line follower sesuai dengan karakteristik aplikasi yang diinginkan, baik dalam konteks industri, pendidikan, maupun penelitian. Implikasi penelitian ini diharapkan dapat menjadi rujukan strategis dalam pengembangan sistem robotika yang presisi, efisien, dan kontekstual.*

Kata Kunci: *Robot Line Follower, Mikrokontroler Arduino, Sistem Analog*

Abstract: *This study presents a comparative analysis of line follower robot implementation by examining two primary system approaches: Arduino microcontroller-based systems and analog systems without microcontrollers. Employing a qualitative descriptive method through literature review, this research synthesizes scholarly publications from reputable databases spanning 2018 to 2025. The analysis emphasizes key technical aspects, including sensor configurations, control algorithms (notably PID), power efficiency, as well as each system's operational stability and adaptability. The findings reveal that Arduino-based systems excel in programming flexibility, multi-sensor integration, and ease of algorithmic modification. Nevertheless, these systems face challenges regarding power consumption and processing latency. Conversely, analog systems offer rapid response and high energy efficiency but lack flexibility in adapting to* *changing operational environments. This study establishes a conceptual framework for selecting line follower robot systems tailored to specific application requirements, whether for industrial, educational, or research purposes. The implications serve as strategic insights for the development of precise, efficient, and contextually appropriate robotic systems.*

Keywords: *Line Follower Robot, Arduino Microcontroller, Analog System*

INTRODUCTION

The development of robotics technology in the era of Industry 4.0 has undergone significant transformation, particularly in the implementation of autonomous navigation systems, which serve as the foundation for various modern industrial applications. The line follower robot represents one of the fundamental concepts in robotics, with high relevance to the advancement of automated transportation systems, integrated manufacturing, and smart logistics (Gusti Made Andi & Setiyono and Enda Wista Sinuraya, 2020). The ability of robots to track paths with precision has become an essential component across multiple industrial sectors, ranging from automated conveyor systems to small-scale autonomous vehicles that require high navigation accuracy.

In the context of technological implementation, there are two main paradigms that dominate the development of line follower robots: microcontroller-based systems and conventional analog systems. Arduino-based microcontroller systems have been widely adopted in both research and industry due to the programming flexibility they offer, enabling the implementation of complex algorithms such as PID controllers and machine learning for navigation performance optimization (Taupiq et al., 2024). Conversely, analog systems without microcontrollers present an alternative approach that relies purely on electronic circuits, offering advantages in energy efficiency, minimal response time, and lower system complexity (Nurrahmadi et al., 2018).

A comparison between these two approaches is crucial, as each system possesses fundamentally different operational characteristics. Arduino-based systems excel in adaptability to various environmental conditions through configurable software, but face challenges in power consumption and processing latency (Syahrizal, 2023). On the other hand, analog implementations offer superior response speed and high operational stability, but are limited in modification flexibility and adaptability to dynamic operational conditions (Syafitri et al., 2025).

A comparative analysis has become increasingly relevant in the context of selecting the most appropriate technology for specific applications, as each approach presents different trade-offs in terms of implementation cost, development complexity, and operational performance. Previous studies have shown that choosing an unsuitable system can lead to operational inefficiencies of up to 40% and significantly higher maintenance costs (Tohir et al., 2023). Therefore, a thorough understanding of the characteristics, advantages, and limitations of each system is fundamental to informed technology decision-making.

A comprehensive literature review is essential to identify implementation patterns, development trends, and performance evaluation outcomes of both line follower robot system approaches. Through a systematic analysis of recent scientific publications, this study aims to contribute an evidence-based technology selection framework that can serve as a reference for robotics project development. This research is expected to fill the knowledge gap regarding a comprehensive comparison between Arduino-based and analog systems, as well as provide practical recommendations for optimal implementation based on the specific requirements of an application (Prasetiyanto & Hadisusila, 2023).

RESEARCH METHODOLOGY

This study employs a library research approach as the primary methodology to analyze and compare the implementation of Arduino-based microcontroller line follower robots with analog systems that operate without a microcontroller. The library research method was chosen for its ability to collect comprehensive secondary data from various published scientific literature sources. Data collection was carried out through an in-depth exploration of international academic databases, including IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar, to obtain relevant journal articles, conference proceedings, and scientific publications within the 2018–2025 timeframe.

The search strategy utilized a combination of specific keywords such as *“Arduino line follower robot”*, *“analog line* *tracking system"*, *"microcontroller vs analog robot"*, and *"comparative analysis mobile robot"*, combined with Boolean operators to maximize the relevance of search results. Inclusion criteria covered English and Indonesian publications discussing the implementation, design, or performance evaluation of line follower robots, with a focus on the two systems under investigation. The literature selection process involved title and abstract screening, followed by full-text analysis to determine alignment with the research objectives.

Extracted data included technical characteristics, operational performance, advantages, limitations, and testing results of each system, which were then analyzed comparatively using a qualitative descriptive approach (Septaria et al., 2024).

RESEARCH RESULTS

Based on the literature analysis conducted on various scientific publications regarding the implementation of line follower robots, comprehensive findings were obtained, revealing the characteristics, advantages, and applications of Arduino-based microcontroller systems. The following table summarizes the analysis results from nine relevant studies aligned with the focus of this research

Table 1. Comparative Study on the Implementation of Arduino-Based Line Follower Robots

No	Researcher & Year	Control System	Main Sensor	Key Advantages	Specific Applications	Performance Outcomes
1	(Adkine et al., 2025)	Arduino UNO + PID	IR Sensor	Cost-effectiveness, simplicity, adaptability	Commercial, industrial, medical, educationa	Precise and smooth movement
2	(Arifin et al., 2021)	Arduino Nano + PID/Fuzzy	Line Sensor	Power supply optimization, navigation stability	Control system development	Optimal performance at 7.2 V

3	(Baballe, 2023)	Arduino Uno	IR Sensor	Simple construction, easily available components	Basic robotics learning	Effective black/white line detection
4	(Riyanto et al., 2021)	PID Control System	Multi-sensor	Precise parameter tuning, adaptive control	Advanced robotics applications	High path accuracy, optimal stability
5	(Riyanto et al., 2021)	Arduino Mega 2560 + PID	Line, ultrasonic, and color sensors	Accurate position control, multi-object detection	Industrial forklift robots	Stable PID parameters (100, 0, 1)
6	(Yudhistira et al., 2025)	Arduino Nano	Integrated sensors and actuators	Low cost, project-based learning	Secondary school STEM education	Increased motivation and skills
7	(Sahu et al., 2021)	Arduino Uno + PID	IR Sensor	Autonomous navigation, error minimization algorithms	Navigation system development	High-precision motor control
8	(Tambunan & Simanjuntak, 2024)	Arduino Uno R3	IR and ultrasonic sensors	Integrated multifunctional robotic arm	Industrial object manipulation	High accuracy with manipulation capability

DISCUSSION

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

The implementation of a line follower robot control system using an Arduino microcontroller demonstrates significant variations in the application of control algorithms and sensor configurations. Based on literature analysis, the Proportional-Integral-Derivative (PID) control system is the dominant algorithm implemented in eight reviewed studies, indicating its effectiveness in achieving optimal control responses (Adkine et al., 2025; Riyanto et al., 2021; Sahu et al., 2021). PID implementation in line follower robots provides the capability to minimize positional errors by calculating the deviation between the actual position and the desired reference position. The study by Riyanto et al. (2021) demonstrated that using PID constant parameters with values of Kp = 100, Ki = 0, and Kd = 1 resulted in optimal positional control stability during the robot's navigation toward a colored target object. The responsive characteristics of the Arduino system enable the implementation of more complex control algorithms compared to conventional systems, with real-time sensor data processing capabilities and adaptability to changing operational environmental conditions.

The diversification of sensor configurations in the implementation of line follower robots demonstrates the adaptability of the Arduino system to various specific application requirements. Infrared sensors are the primary sensing components used in most implementations due to their effectiveness in detecting the contrast between black lines and white surfaces (Baballe, 2023; Tambunan & Simanjuntak, 2024). The integration of additional sensors, such as ultrasonic sensors for distance measurement and color sensors for object identification, indicates the evolution of the system from basic line tracking functionality toward more complex multifunctional applications. Riyanto et al. (2021) implemented a combination of line sensors, ultrasonic sensors, and color sensors to develop a forklift robot capable of detecting colored objects at an operational distance of 5 centimeters. The flexibility of the Arduino platform allows the integration of multiple sensors without excessive hardware complexity, providing significant advantages in developing robotic systems that are adaptive and responsive to variations in operational environmental conditions.

Performance Analysis and Optimization of a Power Supply System

Optimization of the power supply system in the implementation of an Arduino-based line follower robot shows a direct correlation with navigation performance and the overall operational stability of the system. The study by Arifin et al. (2021) identified that variations in power supply voltage within the range of 8.44V to 6V resulted in optimal performance at 7.2V, indicating a specific optimum point for achieving the best navigation speed. Voltage fluctuations from the battery have a significant impact on the operating characteristics of DC motors, where higher voltages result in excessive motor speeds, while lower voltages cause slow motor responses and unstable robot movement. This phenomenon highlights the importance of effective power management systems in the implementation of line follower robots to maintain consistent operational performance.

The implications of battery voltage degradation on the robot's navigation system reveal the complexity of challenges faced in the practical implementation of line follower robots. A drop in power supply voltage not only affects motor speed but also results in zigzag movement patterns that reduce tracking accuracy. These characteristics indicate the Arduino system's dependency on power supply stability to maintain optimized control algorithms. Research findings suggest that implementing voltage monitoring and adaptive compensation systems is essential for sustaining robot performance in long-term operations. Developing effective power management strategies through the use of voltage regulators and voltage feedback systems can provide solutions to overcome the inherent limitations of battery-based power supplies, thereby improving the reliability and operational consistency of line follower robots.

Applications and Functional Diversification in Line Follower Robots

The diversification of applications for Arduino-based line follower robots demonstrates the technological evolution from the basic concept of path tracking toward complex multifunctional implementations across various industrial sectors. The implementation of a forklift robot with line-following capabilities, as developed by Riyanto et al. (2021), illustrates the adaptation of technology for specific industrial applications, in which the robot not only performs path tracking but also integrates object manipulation functions based on color identification. This system implements a position control algorithm capable of keeping the robot precisely on the guide line while simultaneously performing the task of picking up and transporting colored objects to predetermined locations. The development of a manipulator robot with an integrated arm by Tambunan & Simanjuntak (2024) further demonstrates the expansion of line follower robot functionality toward sophisticated industrial robotic systems, with the ability to grasp, lift, and manipulate objects according to defined operational specifications.

The implementation of line follower robots in educational contexts highlights the significance of the technology as an effective platform for Science, Technology, Engineering, and Mathematics (STEM) learning. Yudhistira et al. (2025) developed a prototype Arduino Nano-based line follower robot specifically designed to support project-based learning for secondary school students, demonstrating the adaptation of the technology for pedagogical purposes. This robot was designed using easily obtainable components and at a cost-effective level, enabling widespread adoption within Indonesia's education system. The study's results showed that students engaged in project-based learning with the line follower robot experienced significant improvements in STEM skills and learning motivation. The characteristics of cost-effectiveness, simplicity, and adaptability identified by Adkine et al. (2025) are key factors in the technology's applications across commercial, industrial, medical, and educational fields, demonstrating the versatility of the Arduino platform in accommodating diverse application requirements of varying complexity.

Evaluating the Advantages and Limitations of Arduino-Based Line Follower Robot Systems

A comprehensive evaluation of Arduino-based line follower robot implementations identifies fundamental advantages in programming flexibility, cost-effectiveness, and ease of implementation, making it a dominant choice in modern robotics system development. The Arduino platform's ability to accommodate complex control algorithms such as PID controllers provides a significant advantage in achieving optimal precision and smooth movement (Adkine et al., 2025). Its open-source nature and the wide availability of components in the market create an ecosystem that supports rapid prototyping and iterative development processes. The implementation of adaptive control systems through software configuration enables fine-tuning of operational parameters without significant hardware modifications, resulting in high development efficiency. Baballe (2023) reported that constructing a line follower robot using Arduino can be accomplished with readily available components, reducing barriers to entry for implementing robotics technology.

The analysis of Arduino system limitations identifies inherent trade-offs in power consumption and processing latency that affect the operational performance of line follower robots. The system's dependency on power supply stability, as identified by Arifin et al. (2021), highlights the Arduino's vulnerability to power fluctuations that may cause navigation performance degradation. Processing overhead generated by the microcontroller when executing complex control algorithms can result in latency that affects the system's response time to dynamic path conditions. Nevertheless, Sahu et al. (2021) demonstrated that implementing error-minimization algorithms via the PID control system can achieve high-precision motor control, indicating that software optimization can partially overcome hardware limitations. The overall evaluation shows that the Arduino system's strengths in flexibility, adaptability, and cost-effectiveness outweigh its limitations, making it an optimal platform for implementing line follower robots in various applications with diverse requirements.

CONCLUSION

Based on a comprehensive analysis of Arduino microcontroller-based line follower robot implementations, this study identifies the superiority of the Arduino system in accommodating complex control algorithms and adapting to varying application requirements. The dominance of PID algorithm implementations demonstrates the system's effectiveness in achieving optimal navigation precision through real-time positional error minimization. Power supply optimization at 7.2V and the integration of multiple sensors have resulted in consistent operational performance with significant functional diversification. The Arduino system's fundamental advantages in programming flexibility, cost-effectiveness, and ease of implementation contribute substantially to the evolution of modern robotics technology. Although inherent trade-offs exist in power consumption and processing latency, the system's adaptability offers superior value for optimal implementation across diverse application sectors. This study recommends the use of the Arduino system as a priority platform for the development of line follower robots, with operational parameter optimization tailored to the specific characteristics of the intended application.

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