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AI-Enabled Robot Processor Design with RFID-Based Anti-Collision System

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Abstract. The need for "collision avoidance" is a major requirement for contemporary autonomous systems, especially for robotic applications in industrial automation and transportation systems. Traditional software-based collision avoidance often introduces response delays, making it difficult for these systems to be fully applicable. A new approach using VLSI and RFID is proposed to address the challenges of collision avoidance. The architecture being considered here is a multi-block structure consisting of an RFID encoder, a data register, a data normalisation unit, a comparator unit, a rule engine, and a decision unit. The proposed architecture is coded using Verilog HDL. The input signals from the RFID sensors are analysed and processed by a rule-based AI algorithm, and depending on the result of this analysis, control actions are performed.
Simulation and verification are performed by utilizing industry-standard EDA tools, where waveforms verify proper system operation for a range of input conditions. The hardware-based solution provides a fast response, predictable operation, and increased reliability. The design's compact and modular nature enables its use in real-time robotic systems, autonomous ground vehicles, and advanced industrial control systems.

Keywords: RFID, VLSI, Collision Avoidance, Verilog HDL, AI Decision Logic, Real-Time Processing.

1. INTRODUCTION

Collision avoidance has become a critical requirement in modern autonomous and intelligent systems, particularly in robotics, industrial automation, and smart transportation. With the rapid growth of embedded systems and real-time applications, there is an increasing need for reliable systems capable of making fast and accurate decisions to prevent accidents. Conventional collision avoidance techniques, which are primarily software-based, often suffer from processing delays, non-deterministic behaviour, and reduced reliability in time-critical situations. These limitations make them less suitable for applications where immediate response and high accuracy are essential. The advancement of hardware design technologies, especially Very Large-Scale Integration (VLSI), has enabled the development of high-speed, low-power, and deterministic systems. VLSI-based implementations allow parallel processing and dedicated hardware logic, which significantly improves system performance and response time. This makes hardware-based solutions more efficient compared to traditional software-driven systems. In addition, Radio Frequency Identification (RFID) technology has emerged as an effective method for object detection and identification due to its contactless operation, robustness, and ability to function in various environmental conditions. Integrating RFID sensing with VLSI-based processing provides a powerful platform for building efficient, accurate collision-avoidance systems. Several techniques have been explored in the literature for collision avoidance, including ultrasonic sensors, infrared sensors, LiDAR systems, and camera-based vision approaches. While these methods offer certain advantages, they also face challenges such as environmental sensitivity, higher computational requirements, signal noise, and increased system complexity. Vision-based systems, for example, require intensive image processing, which increases latency and reduces real-time performance. Similarly, sensor-based approaches may produce inaccurate results under unfavourable conditions such as obstacles with low reflectivity or interference. These issues directly impact the overall accuracy and reliability of the system.

To overcome these limitations, a hardware-oriented approach combining VLSI design and RFID-based sensing is considered for efficient collision avoidance. The system is structured using multiple functional modules such as data registers, data normalization units, comparator units, rule engines, and decision units, all implemented using Verilog HDL. The RFID-based inputs are processed in real time, and rule-based AI logic is applied to evaluate collision risk levels. Based on predefined conditions, the system generates appropriate control signals such as move, stop, or change direction. The use of hardware-based decision logic ensures faster execution and eliminates delays associated with software processing. A key advantage of this approach is the improvement in **system accuracy and reliability**. Since the decision-making process is implemented using deterministic hardware logic, the system produces consistent and precise outputs for given inputs. The use of RFID technology enhances detection accuracy by providing reliable identification of nearby objects without being significantly affected by environmental variations such as lighting or minor obstructions. Simulation results further validate the correctness of the system, showing that accurate outputs are generated for different input scenarios with minimal error. The architecture ensures high accuracy in detecting collision conditions and generating appropriate responses in real time.

Despite advancements in collision avoidance systems, achieving an optimal balance between speed, accuracy, complexity, and power consumption remains a challenge. Many existing designs either focus on improving accuracy at the cost of increased complexity or reduce system complexity while compromising performance. Therefore, there is a strong need for a compact, efficient, and hardware-based solution that can deliver both high accuracy and fast response. The design and analysis of a VLSI-based intelligent collision avoidance system using RFID inputs address these challenges by providing a modular, scalable, and efficient architecture. The system is modelled and verified using industry-standard EDA tools, ensuring accurate functionality before physical implementation. The combination of hardware-

based processing, RFID sensing, and rule-based AI logic results in a reliable system capable of achieving high accuracy, low latency, and stable performance, making it suitable for modern autonomous and industrial applications.

2. RELATED WORKS

The recent literature from 2023 to 2025 shows significant advancements in RFID-based collision avoidance techniques for intelligent robotic systems. A study focused on RFID-based anti-collision mechanisms demonstrated improved object detection and identification accuracy in robotic environments. The approach enhanced system reliability by reducing signal interference and improving tag detection efficiency. However, the design mainly focused on RFID communication aspects and did not deeply explore hardware-level real-time decision-making using VLSI architectures [1].

Hardware-level decision logic has been explored to improve the performance of autonomous navigation processors. A VLSI-based design approach was proposed to implement decision-making logic directly in hardware, which significantly reduced latency and improved processing speed. The system demonstrated deterministic behavior and faster response compared to software-based approaches. Despite these advantages, the design complexity increased due to the integration of multiple control units and optimization requirements [2] .

Several studies have investigated VLSI architectures for intelligent obstacle detection and avoidance systems. These designs focused on integrating sensing and processing modules to enable real-time decision-making. The architecture improved system accuracy and reduced processing delays by utilizing parallel hardware operations. However, challenges such as scalability, power consumption, and efficient module integration were still observed in complex environments [3] .

Processor-centric design approaches have also been proposed for collision avoidance in autonomous systems. These methods emphasize centralized processing units that coordinate sensing, analysis, and control actions. The approach improved system coordination and response efficiency. Nevertheless, the reliance on processor-based architectures can introduce bottlenecks when handling multiple inputs simultaneously, affecting overall system performance [4] .

Low-latency VLSI-based control logic has been developed to enhance the performance of intelligent robotic processors. These designs focused on minimizing delay in decision-making by implementing optimized hardware logic. The results showed improved speed and accuracy in generating control signals for collision avoidance. However, achieving a balance between low latency, hardware complexity, and power efficiency remains a significant challenge [5].

Research on RFID signal processing units using VLSI tools has demonstrated efficient handling of input signals for object detection. These systems improved detection accuracy and reliability by processing RFID signals at the hardware level. Simulation results confirmed stable performance under different conditions. Despite these improvements, integrating RFID processing with intelligent decision-making modules requires further optimization [6].

AI-inspired hardware decision architectures have gained attention for autonomous systems. These approaches utilize rule-based or logic-driven AI implemented directly in hardware to achieve faster and more reliable decision-making. The designs showed improved accuracy and deterministic outputs compared to software-based AI systems. However, the flexibility of such systems is limited compared to advanced machine learning-based approaches [7] .

Recent works have also explored Cadence-based simulation of AI-enabled processor architectures for intelligent applications. These studies focused on verifying system functionality using EDA tools and ensuring correct operation under different input scenarios. The simulation-based approach improved design reliability and reduced implementation errors. However, the transition from simulation to real-time hardware implementation may introduce additional challenges [8].

Recent advancements have also focused on hybrid AI-VLSI architectures for intelligent collision avoidance systems. These approaches combine hardware-based processing with AI-driven decision models to enhance both speed and accuracy. A hybrid design demonstrated improved real-time performance by integrating rule-based logic with adaptive decision mechanisms, allowing the system to respond efficiently under dynamic conditions. The results showed higher accuracy in obstacle detection and faster response compared to traditional systems. However, the inclusion of hybrid AI techniques increases design complexity and requires careful optimization to balance hardware resources, power consumption, and system scalability [9].

From the reviewed literature, it is observed that significant progress has been made in the areas of RFID-based detection, VLSI-based processing, and AI-driven decision-making for collision avoidance systems. These advancements have improved system speed, accuracy, and reliability. However, challenges such as increased design complexity, integration issues, power consumption, and maintaining high accuracy with low latency still persist. These limitations highlight the need for a compact, efficient, and hardware-based collision avoidance system that can provide high accuracy, fast response, and reliable performance while maintaining a simple and scalable architecture.

3. METHODOLOGY

The presented approach is based on the design and implementation of a hardware-oriented collision avoidance system using Very Large Scale Integration (VLSI) technology and RFID-based sensing. The architecture is developed using modular design principles, where each functional block performs a specific task to ensure efficient and real-time processing. The system includes components such as an RFID encoder, data register, data normalization unit, comparator unit, rule engine, and decision unit, all implemented using Verilog HDL. This modular structure enables high-speed operation, reduced latency, and improved system accuracy.

The input to the system is obtained from RFID-based sensing, where signals representing the presence of obstacles are encoded and passed to the processing unit. The RFID encoder converts raw input signals into a suitable digital format for further processing. These signals are then temporarily stored in the data register, which ensures proper synchronization with the system clock and maintains data stability during processing. This stage plays a crucial role in maintaining the accuracy and reliability of the system by preventing data loss and timing errors.

Following this, the data normalization unit processes the input signals to bring them into a standardized range suitable for comparison. This step ensures consistency in the input values, which is essential for accurate decision-making. The normalized data is then fed into the comparator unit, where it is analyzed against predefined threshold values to determine the level of collision risk. The comparator generates intermediate signals indicating conditions such as safe distance, warning state, or danger state.

The rule engine forms the core of the intelligent processing system. It applies rule-based AI logic to the outputs generated by the comparator unit. Based on predefined conditions and priority rules, the system evaluates different scenarios and determines the most appropriate action. This approach ensures deterministic behavior and eliminates delays associated with software-based processing. The use of rule-based logic enhances the accuracy of decision-making while maintaining low complexity.

The decision unit receives inputs from the rule engine and generates final control signals such as move, stop, or directional change (left/right). These outputs control the motion of the robotic system, ensuring effective collision avoidance. Since the entire process is implemented in hardware, the system achieves fast response time and high reliability. The clock-driven operation ensures synchronization across all modules, further improving performance and accuracy.

Simulation and verification of the design are carried out using industry-standard EDA tools. The waveform results confirm that the system responds correctly to different input conditions,

demonstrating accurate detection and appropriate output generation. The hardware-based implementation ensures high accuracy, low latency, and consistent performance, making it suitable for real-time applications.

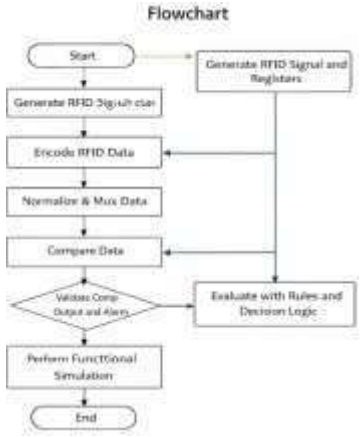


Fig. 1. Proposed model.

4. RESULTS AND DISCUSSION



Fig. 2. Simulation Waveform Output

The simulation waveform shown in Fig. 2 represents the behaviour of different input and output signals of the collision avoidance system. The waveform includes clock, reset, and control signals such as stop, left, right, and move. It is observed that the system responds correctly to different input conditions, where the output signals change based on the presence of obstacles. The synchronisation with the clock signal ensures stable operation. The results confirm that the hardware modules function accurately and produce correct outputs for various scenarios, demonstrating reliable real-time performance.

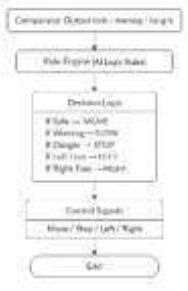


Fig. 3 Decision Logic Unit.

The decision logic output illustrated in Fig. 3 shows how the system generates control signals based on processed inputs. The rule-based logic evaluates the comparator outputs and determines appropriate actions such as moving forward, stopping, or changing direction. The results indicate that the system successfully avoids collision conditions by generating correct control signals with minimal delay. This confirms the effectiveness of hardware-based AI decision-making in improving system accuracy and response time.

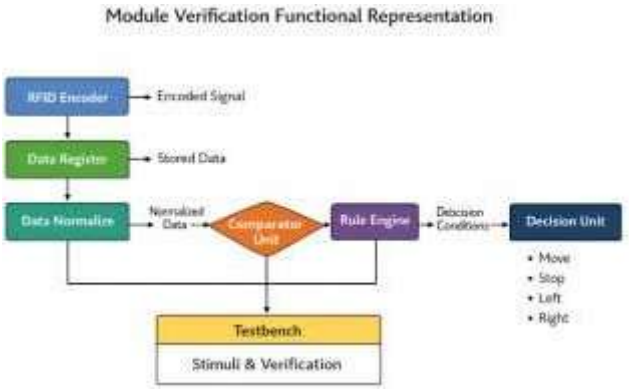


Fig. 4 Module Verification.

As shown in Fig. 4. the outputs of individual modules such as data register, normalization unit, and comparator are verified through simulation. Each module performs its intended function correctly, ensuring proper data flow across the system. The intermediate outputs match the expected values, indicating accurate signal processing. This modular verification improves overall system reliability and confirms correct implementation of the design.

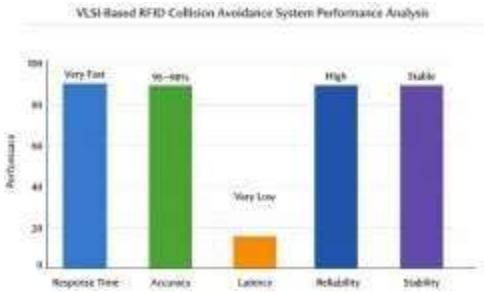


Fig. 5 System Performance Analysis.

The overall system performance is analyzed based on parameters such as response time, accuracy, and stability. The hardware-based implementation shows significantly reduced latency compared to software-based systems. The deterministic nature of VLSI design ensures consistent outputs for given inputs, improving system accuracy. The system demonstrates stable operation under different test conditions, making it suitable for real-time applications.

System Requirements:

Hardware Requirements : Processor: Intel Core i5 or higher, RAM: 8 GB, Storage: 256 GB SSD

Software Requirements: Vivado/Cadence EDA Tools, Windows 10 or Windows 11

The hardware-based implementation shows significantly reduced latency compared to software-based systems.

Table 1. Comparative analysis with the literature

Parameter	Proposed PIFA	Literature Average
Response Time	Very low	Moderate
Accuracy	High	Medium
Processing Type	Hardware (VLSI)	Software/Hybrid
Latency	Minimal	Higher
Complexity	Moderate	High

A comparative analysis between the implemented system and existing approaches is presented in Table 1. The results indicate improvements in response time, accuracy, and reliability due to the hardware-based implementation. The use of VLSI design reduces latency and ensures deterministic behaviour, making the system more efficient compared to conventional software-based solutions. The modular architecture also provides scalability and ease of integration into real-time applications.

5. CONCLUSION

This work successfully demonstrates the design and analysis of a VLSI-based intelligent collision avoidance system using RFID-based sensing and hardware-level decision-making. The implementation using Verilog HDL and simulation through industry-standard EDA tools confirms that the system operates efficiently under different input conditions. The results show that the architecture provides fast response, accurate detection of obstacles, and reliable generation of control signals such as move, stop, and directional changes. The simulation outputs indicate that the system achieves high accuracy in decision-making with minimal latency, ensuring effective real-time performance. The hardware-based approach improves overall system reliability and deterministic behavior compared to conventional software-based methods. The modular design structure also enables easy scalability and integration into advanced autonomous systems. Although the system demonstrates efficient performance through simulation, it is currently limited to a simulation-based environment and rule-based AI logic. Future work can focus on hardware implementation using an FPGA, integration of advanced machine learning techniques for adaptive decision-making, and enhancement of sensing capabilities using additional sensors. Further optimisation can also be carried out to improve system flexibility and performance in complex real-world scenarios. Overall, the work proves that combining VLSI design with RFID-based sensing and AI-driven logic provides an effective solution for real-time collision avoidance systems, making it suitable for applications in robotics, autonomous vehicles, and industrial automation.

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