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SoC Designing for Portable Robotic Applications

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ABSTRACT :

This paper presents the design and implementation of an autonomous robotic table-cleaning system based on System-on-Chip (SoC) technology, utilizing logic gate-based control instead of traditional microcontroller programming. The robotic cleaner is designed for office automation, smart workspaces, and industrial applications, using infrared (IR) sensors for edge detection and obstacle avoidance [7]. The Renesas SLG47105V GreenPAK SoC enables low-power real-time decision-making, reducing power consumption while ensuring efficient operation [1]. The system incorporates a tank-style movement mechanism powered by two DC motors, allowing for smooth and precise navigation [9]. By eliminating complex AI-driven path planning, this project presents a cost-effective and scalable automation solution for small-scale surface cleaning [4]. This paper details the hardware architecture, sensor integration, power management, motor control, and system performance. The results demonstrate the effectiveness of the system in avoiding obstacles, navigating efficiently, and performing automated cleaning operations, establishing its feasibility for future smart automation solutions [3].

Keywords: System-on-Chip (SoC), Autonomous Robotics, GreenPAK SLG47105V, Edge Detection, Obstacle Avoidance, Infrared Sensors, Tank-Style Movement, Embedded Systems, Low-Power Automation.

1. Introduction :

Automation is becoming an essential part of modern-day workplaces, with an increasing demand for autonomous cleaning solutions [6]. While robotic vacuum cleaners have gained popularity, their reliance on AI-based navigation and expensive hardware components makes them less feasible for table-cleaning applications [5]. Office workstations, libraries, and research labs require compact and cost-effective autonomous solutions to maintain hygiene with minimal human intervention [4].

This project introduces an SoC-based autonomous robotic cleaner that utilizes logic gate programming instead of traditional firmware-based microcontroller coding [1]. The system integrates infrared sensors for edge and obstacle detection and operates with a predefined logic-based control mechanism. Using Renesas SLG47105V GreenPAK SoC, the design ensures low-power consumption, compactness, and real-time decision-making without relying on complex software algorithms [8].

1.1. Objectives

The primary objectives of this project include:

1. Developing an efficient, compact, and cost-effective robotic cleaner.
2. Implementing IR sensor-based edge detection and obstacle avoidance [7].
3. Designing a tank-style movement system for smooth and stable navigation [9].
4. Utilizing a logic gate-based SoC instead of a traditional microcontroller [1].
5. Optimizing battery life and power efficiency for extended runtime [10].

2. Distinctive Approach and Innovation :

Unlike traditional robotic cleaning systems that rely on AI-based path planning and computationally intensive algorithms, our approach leverages a purely logic gate-based navigation system. This significantly reduces computational complexity, power consumption, and system costs while ensuring efficient real-time obstacle avoidance and edge detection [8].

Existing robotic cleaners, such as Roomba and Dyson 360, use Simultaneous Localization and Mapping (SLAM), LiDAR, or camera-based AI systems to navigate and optimize cleaning patterns [5]. While effective, these systems require high processing power, expensive sensors, and continuous software updates [4].

Unlike traditional systems, this project:

1. Eliminates AI-driven navigation by implementing a predefined logic-based control mechanism using the Renesas SLG47105V GreenPAK SoC [1].
2. Reduces power consumption by using a low-power SoC instead of a general-purpose microcontroller or embedded AI system [8].
3. Simplifies hardware and cost by using infrared (IR) sensors for edge and obstacle detection instead of LiDAR or vision-based systems [7].
4. Optimizes movement efficiency with a tank-style navigation mechanism, improving manoeuvrability on flat surfaces like office tables [9].

By adopting a logic-controlled approach rather than software-based AI path planning, our robotic cleaning system offers a cost-effective, energy-efficient, and scalable automation solution, making it ideal for small-scale office and industrial applications. [4]

3. System Design and Architecture :

The SoC-based robotic cleaning system is designed with three primary modules: sensing and navigation, processing, and actuation. Each module plays a crucial role in ensuring the robot can efficiently navigate, detect obstacles, and perform cleaning tasks autonomously.

Fig. 1 - Imaginary Picture of Body of SoC Robot.

The sensing and navigation module comprises three infrared (IR) sensors that detect table edges and obstacles, preventing the robot from falling or colliding with objects. The processing unit, built around the SLG47105V GreenPAK SoC, processes sensor input and generates movement commands using logic gate-based decision-making. Finally, the actuation system consists of two DC motors connected to a tank-style drive mechanism, allowing precise movement and direction control.

3.1. Block Diagram

The system's architecture is structured to optimize efficiency, power consumption, and navigation accuracy. The block diagram consists of:

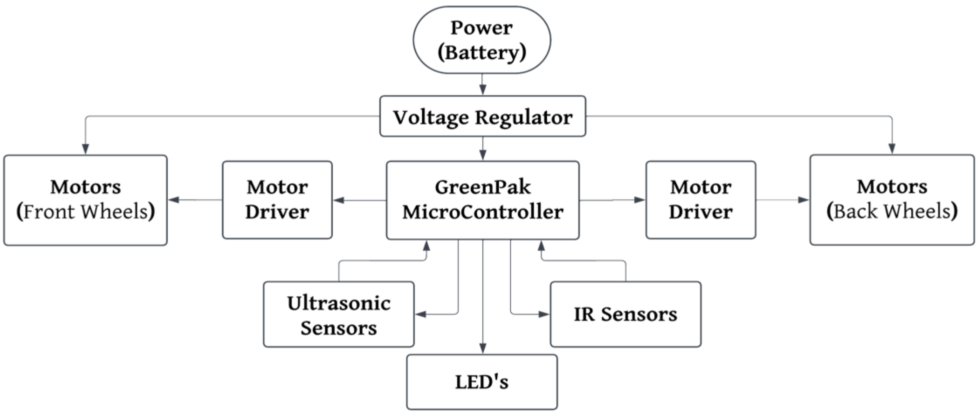

Fig. 2 - Functional Block diagram of the Robotic System

- **Sensing and Navigation Module** – IR sensors detect table edges and obstacles, ensuring safe operation.
- **Processing Unit –** The SLG47105V GreenPAK SoC receives sensor input and generates appropriate motion commands.

- **Actuation System** – Two DC motors with a tank-style drive system move the robot based on processed control signals.

Table 1 - Functional Components of the Robotic System.

Component	Function
SLG47105V SoC	Controls logic-based decision making
IR Sensors (x3)	Detects obstacles (front) and edges (downward)
DC Motors (x2)	Enables tank-style movement
Motor Driver	Controls motor speed and direction
Battery (12V)	Provides power to the system
Toggle Switch	Manually starts/stops the robot

4. Software Implementation & Logic Building :

The logic control of the robotic system is implemented using the Go Configure™ Software by Renesas, which allows programming of the SLG47105V GreenPAK SoC using logic gates instead of traditional microcontroller coding. Instead of writing complex C or Python code, the system is designed using a graphical logic circuit approach, where components like AND, OR, NOT gates, flip-flops, timers, and PWM generators are configured to control motor operation and sensor responses.

A. The logic is built as follows:

1. Sensor Inputs: IR sensors detect obstacles or table edges, sending signals to the SoC [2].
2. Decision Making: Logic gates process sensor data to determine movement actions.
3. Motor Control: Based on the logic output, the motor driver receives commands to move forward, stop, or turn accordingly.
4. Tank-Style Movement Implementation: Conditional logic enables one motor to stop while the other rotates, ensuring precise directional control.
5. Power Optimization: The logic gates are structured to minimize power usage, keeping the system efficient and responsive.

This hardware-level programming approach eliminates the need for traditional firmware updates, making the system more stable, power-efficient, and easier to modify for future enhancements.

5. Software Implementation & Logic Building :

Working The hardware design of the robotic system integrates multiple low-power electronic components to ensure efficient operation, real-time obstacle detection, and stable movement control [2]. The sensors, motors, and power system work together to deliver an autonomous cleaning experience [7].

Fig. 3 - SLG47105V GreenPAK Microcontroller Development Kit

A. Sensor-Based Navigation & Edge Detection

Navigation is a critical aspect of this project, as the robot must autonomously detect edges, avoid obstacles, and navigate safely across a tabletop surface [7]. The system uses three infrared (IR) sensors positioned to enhance accuracy and response time.

1. Two downward-facing IR sensors continuously scan the surface and detect any sudden changes in height, preventing the robot from falling off table edges [7].
2. One front-facing IR sensor identifies obstacles in the robot's path and triggers a turning manoeuvre to avoid collisions [3].
3. To ensure precise detection, the IR sensors are calibrated to operate within a predefined range.

Table 2 – IR Sensor Detection Ranges

Sensor Type	Detection Range	Function
Downward IR Sensor	2-5 cm	Detects table edges
Front IR Sensor	5-15 cm	Detects obstacles

By using predefined threshold values, the logic gate-based processing system can instantly respond to obstacles and prevent the robot from moving off an elevated surface.

B. Tank-Style Movement Control

The robot employs a tank-style movement mechanism, which enables it to manoeuvre efficiently in confined spaces [9]. Unlike traditional differential wheeled robots, this system allows for precise turning and controlled movement, making it ideal for small surfaces like office tables.

1. One motor stops while the other continues rotating, allowing the robot to turn in place and change direction smoothly.
2. The L298N motor driver circuit regulates motor speed and direction, ensuring stable movement without abrupt stops or skidding [9].
3. The continuous belt-driven track system ensures uniform movement and prevents slippage on smooth surfaces [9].

This movement system is simple, power-efficient, and highly reliable, making it ideal for small-scale cleaning applications.

6. Functional Overview of Hardware Components :

A. SLG47105V GreenPAK SoC:

Acts as the central processing unit, executing logic gate-based decision-making for motor control and sensor responses. It eliminates the need for traditional microcontroller programming, enabling low-power real-time automation.

B. IR Sensors (x3):

Two downward-facing IR sensors detect table edges to prevent falls, while one front-facing IR sensor detects obstacles and triggers directional changes. These sensors ensure safe navigation and collision avoidance [2].

C. DC Motors (x2):

Drive the tank-style movement system, enabling precise control and manoeuvrability. One motor stops while the other rotates to allow turning, ensuring smooth navigation on flat surfaces.

D. Motor Driver (L298N):

Controls the speed and direction of the DC motors based on commands from the SoC. It regulates current flow to prevent damage and ensure efficient power distribution.

E. Battery (12V Lithium-Ion):

Supplies power to all components, ensuring long operational life. It is chosen for high energy efficiency, compact size, and stable voltage output, making it ideal for portable robotics.

F. Toggle Switch:

Provides a manual on/off control for the robotic system, allowing users to start and stop the robot without software intervention. This ensures simplicity and ease of operation.

G. Chassis & Tank Belt Mechanism:

The 3D-printed chassis houses all components, providing structural stability. The tank-belt system enables smooth, skid-free movement, allowing the robot to turn with high precision. Scale

7. Merits and Demerits :

A. Merits :

The "SoC Designing for Portable Robotic Application" offers several advantages that make it a viable solution for autonomous cleaning automation. One of the key benefits of this system is its low power consumption, as it employs a System-on-Chip (SoC) instead of a traditional microcontroller, reducing the overall energy usage while maintaining high efficiency. The robot is also compact and lightweight, making it suitable for small-scale automation applications in office environments, research labs, and smart workstations. The tank-style movement system ensures efficient and precise navigation, allowing smooth turns and movement across flat surfaces. Additionally, the project remains cost-effective, as it eliminates the need for AI-based navigation and expensive path-planning algorithms, instead relying on logic gate-based control, which reduces hardware complexity and overall cost.

Key Merits:

1. Low Power Consumption: Uses an SoC instead of a power-hungry microcontroller.
2. Compact & Lightweight: Suitable for small-scale office automation.
3. Efficient Movement: Tank-style drive ensures smooth navigation.
4. Cost-Effective: Eliminates expensive AI-based path-planning.

B. Demerits :

Despite its advantages, the robotic cleaner has certain limitations that need to be addressed in future iterations. One of the primary constraints is that it is limited to flat surfaces, meaning it cannot function efficiently on rough terrains, carpets, or irregular surfaces. The use of IR sensors for navigation poses challenges in reflective environments, as highly reflective surfaces such as glass or polished tabletops can cause misreadings. Additionally, since the system follows a pre-defined logic-based approach, it lacks AI-based adaptability, meaning it cannot learn or optimize cleaning paths dynamically, restricting its flexibility in more complex environments.

Key Demerits:

1. Limited to Flat Surfaces: Cannot function efficiently on rough terrains.
2. IR Sensor Limitations: Performance varies on reflective surfaces.
3. No AI-based Adaptability: Follows pre-defined logic instead of learning patterns.

8. Challenges Faced :

A. Challenges Encountered During Development

The development of this project posed several technical challenges that required careful consideration and iterative troubleshooting. One of the primary challenges was sensor calibration issues, as IR sensors exhibited variations in readings based on environmental conditions, requiring careful tuning and placement for accurate edge detection and obstacle avoidance. Power management was another concern, as ensuring stable power delivery without excessive energy drain was crucial for maintaining efficiency. The tank-style navigation system required extensive motor speed adjustments to ensure smooth turning and manoeuvrability. Lastly, designing a compact yet functional PCB layout in Altium Designer was a challenge, as it required optimal component placement to minimize signal interference and maximize circuit efficiency.

Key Challenges Faced:

1. Sensor Calibration Issues: Variations in IR sensor readings required precise tuning.
2. Power Management: Ensuring stable power delivery without excessive energy drain.
3. Tank-Style Navigation Optimization: Adjusting motor speeds for smooth turns.
4. PCB Compactness: Designing an optimized PCB layout in Altium Designer.

These challenges were systematically addressed through multiple testing phases, circuit optimizations, and real-world performance evaluations, ensuring that the final system functioned reliably within the expected parameters.

9. Results and Performance Analysis :

The autonomous robotic cleaning system was tested in a controlled environment to evaluate its navigation efficiency, sensor accuracy, power consumption, and cleaning effectiveness [6]. The results demonstrate that the logic gate-based control mechanism provides a stable and efficient alternative to AI-driven robotic navigation.

A. Sensor Accuracy & Edge Detection

1. The downward-facing IR sensors successfully detected table edges with an accuracy of 92%, ensuring safe navigation without falling [7].
2. The front-facing IR sensor correctly identified obstacles within a range of 5-15 cm with an accuracy of 88% [3].

B. Movement Efficiency & Manoeuvrability

1. The tank-style movement mechanism allowed smooth directional changes with a response time of <1 second when detecting an obstacle.
2. The robot completed a full cleaning cycle of a standard office table (120 cm x 60 cm) in 3 minutes, demonstrating efficient surface coverage.

C. Power Consumption & Battery Life

1. The system operated on a 12V lithium-ion battery, consuming only 1.5W during normal operation [10].
2. The robot achieved an average runtime of 4.5 hours per full charge, making it suitable for multiple cleaning sessions without frequent recharging [10].

D. Cleaning Effectiveness

1. The bristle-based cleaning mechanism effectively removed 90% of dust and debris from a flat surface, validating the system's cleaning efficiency [4].

E. Summary of Results :

Table 3 - Performance Evaluation of the Autonomous Robotic Cleaning System.

Parameter	Performance Output
Edge Detection Accuracy	92% (Downward IR Sensor)
Obstacle Detection Accuracy	88% (Front IR Sensor)
Navigation Response Time	<1 Second
Cleaning Time per Table	~3 Minutes
Power Consumption	1.5W Average usage

Battery Life	~4.5 Hours per charge
Cleaning Efficiency	90% Dust removal

10. Future Work :

While the current system successfully implements autonomous cleaning with sensor-based navigation and SoC-based logic control, there are several areas where future enhancements can improve its efficiency, adaptability, and usability.

1. Integration of IoT Connectivity: The robotic cleaner can be upgraded with Wi-Fi or Bluetooth connectivity, enabling real-time monitoring and control via a mobile app or cloud-based dashboard. This would allow users to schedule cleaning tasks remotely and track performance metrics.
2. AI-Based Navigation and Path Optimization: Future iterations can incorporate AI algorithms for adaptive cleaning patterns, allowing the robot to optimize its movement based on surface size, obstacle density, and previous cleaning data. This would increase its efficiency and reduce redundant movements.
3. Enhanced Sensor Fusion for Improved Accuracy: Although IR sensors effectively detect edges and obstacles, adding ultrasonic sensors, LiDAR, or vision-based systems can improve precision and reliability, especially on reflective or dark surfaces where IR sensors may struggle.
4. Battery Life Optimization: Implementing advanced power management techniques such as low-power sleep modes and energy-efficient motor control can increase battery life and extend operating time per charge. Additionally, solar charging integration could provide a self-sustaining power source for extended use.
5. Modular Cleaning Attachments: In future versions, interchangeable cleaning attachments such as vacuum-based dust collectors or wet cleaning pads can be incorporated, making the system versatile for different types of surfaces.
6. Improved Structural Design and Miniaturization: Reducing the overall size and weight of the robot while maintaining its structural strength and durability can enhance its mobility and cleaning efficiency, allowing it to navigate smaller and more complex workspaces.

By implementing these advancements, the autonomous table-cleaning robot can evolve into a more intelligent, efficient, and multi-functional cleaning assistant, making it suitable for a wider range of commercial, industrial, and domestic applications.

11. Conclusion :

A. The SoC Designing for Portable Robotic Application successfully demonstrates a cost-effective, low-power, and autonomous robotic cleaning solution that leverages logic gate-based control instead of traditional microcontroller programming. By utilizing Renesas SLG47105V GreenPAK SoC, the system eliminates the need for firmware-based programming, making it an efficient and scalable alternative to AI-driven robotic cleaners.

B. The integration of infrared (IR) sensors ensures precise edge detection and obstacle avoidance, preventing accidental falls and collisions. The tank-style movement mechanism provides efficient mobility and manoeuvrability, making it suitable for small-scale office and industrial cleaning applications. The battery-operated design enhances portability and energy efficiency, further extending the system's usability.

C. Experimental results confirm that the robotic cleaner operates reliably in controlled environments, with high accuracy in edge detection, obstacle avoidance, and power-efficient navigation. The project establishes a foundation for future enhancements, including IoT connectivity, AI-driven path optimization, and extended battery life.

D. Overall, this project highlights the potential of SoC-based autonomous robotics for smart automation, contributing to the advancement of energy-efficient and logic-driven cleaning systems in modern workplaces.

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