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A Hybrid Raspberry Pi–Arduino Robotic System for Efficient Real-Time Control Applications

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ABSTRACT: This paper presents the design and implementation of a hybrid robotic system integrating Raspberry Pi and Arduino for efficient real-time control applications. The system leverages the high-level processing capabilities of the Raspberry Pi and the precise, low-level control features of the Arduino to achieve a balanced and optimized architecture. The Raspberry Pi acts as the central processing unit, handling tasks such as data processing, communication, and user interface management, while the Arduino is responsible for real-time control of sensors, actuators, and motor drivers.

The hybrid approach enhances system performance by dis-tributing computational and control tasks effectively, reducing latency and improving response time in dynamic environments. Communication between the two platforms is established using serial protocols, ensuring reliable and fast data exchange. The proposed system is capable of executing complex operations such as remote control, obstacle detection, and autonomous navigation. Experimental results demonstrate that the hybrid system outperforms single-controller architectures in terms of efficiency, flexibility, and scalability. This design is particularly suitable for applications in robotics, automation, surveillance, and IoT-based systems, where real-time responsiveness and processing power are critical.

I. INTRODUCTION

The rapid advancement in embedded systems and robotics has led to the development of intelligent and efficient control systems capable of performing complex tasks in real time. Tra-ditional robotic systems often rely on a single microcontroller or processor, which can limit performance due to constraints in processing power, memory, and real-time responsiveness. To overcome these limitations, hybrid systems combining multi-ple processing units have emerged as an effective solution.

In this context, the integration of Raspberry Pi and Arduino has gained significant attention in modern robotic applications. The Raspberry Pi, a powerful single-board computer, is well-suited for high-level tasks such as data processing, image handling, networking, and user interface management. On the other hand, the Arduino microcontroller excels in real-time operations, offering precise control over sensors, actuators, and motor drivers with minimal latency.

By combining these two platforms, a hybrid architecture can be developed that leverages the strengths of both devices while compensating for their individual limitations. The Raspberry Pi can handle computationally intensive and communication-based tasks, while the Arduino ensures efficient real-time control and hardware interfacing. This division of responsibil-ities results in improved system performance, reliability, and scalability.

The proposed hybrid Raspberry Pi–Arduino robotic system is designed to support real-time control applications such as remote operation, obstacle detection, and autonomous navi-gation. Communication between the two units is established through serial interfaces, enabling seamless data exchange and coordinated operation.

This paper focuses on the design, implementation, and eval-uation of the hybrid system, demonstrating how the integration of these platforms can enhance efficiency and responsiveness in robotic applications. The proposed approach provides a cost-effective and flexible solution suitable for a wide range of applications in robotics, automation, and IoT systems.



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II. LITERATURE SURVEY

Hybrid robotic systems integrating Raspberry Pi and Arduino have gained significant attention due to their complementary roles in embedded system design. Raspberry Pi handles high-level processing, networking, and data analysis, while Arduino manages real-time control and hardware interfacing, enabling efficient task distribution [1], [2], [13], [14]. Raspberry Pi is widely used in IoT applications for web-based control, data processing, and intelligent decision-making, supported by programming environments like Python [3], [5]. In contrast, Arduino microcontrollers provide reliable real-time performance, making them suitable for sensor and actuator control [4], [6].

Hybrid architectures have been applied in automation and robotics, improving efficiency by separating processing and control tasks [7], [8]. In mobile robots and unmanned systems, Raspberry Pi is used for image processing and navigation, while Arduino controls motors and hardware components, reducing latency and enhancing performance [9], [10].

Advancements in IoT and cloud technologies enable remote monitoring and control through web interfaces, increasing system flexibility and scalability [11], [12]. Additionally, frameworks like ROS support modular design and efficient communication between components, enhancing robotic capabilities [15].

The integration of computer vision further improves system intelligence through object detection and automated decision-

making [17]. However, challenges such as communication latency, synchronization, and security remain, driving research toward edge computing and secure system design [18]–[20].

III. PROPOSED METHODOLOGY

The proposed hybrid robotic system is developed by integrating the processing capabilities of the Raspberry Pi with the real-time control efficiency of the Arduino microcontroller. The methodology focuses on system design, component integration, communication establishment, and performance evaluation to achieve efficient real-time control.

A. System Design

The system is designed with a hybrid architecture that separates high-level processing and low-level control tasks. The Raspberry Pi is used as the central processing unit to handle communication, data processing, and decision-making, while the Arduino is used for executing real-time hardware control operations. This design ensures efficient utilization of system resources and improves overall system performance.

B. Component Integration

The hardware components are integrated to form a complete robotic system. The Raspberry Pi is connected to the Arduino through serial communication, enabling data exchange between the two units. The Arduino is interfaced with the motor driver, which controls the movement of the motors. Sensors are also connected to the Arduino to provide environmental feedback. Proper integration ensures stable operation and accurate control.

C. Communication Mechanism

A reliable communication mechanism is established between the Raspberry Pi and Arduino using UART serial communication. The Raspberry Pi sends control commands to the Arduino, which interprets these commands and executes corresponding actions. This communication ensures synchronization between processing and control units, enabling real-time operation with minimal delay.

D. Control Implementation

The control mechanism is implemented by processing user commands on the Raspberry Pi and transmitting them to the Arduino. The Arduino generates control signals to drive the motors through the motor driver. The system supports directional movement and can be extended to include sensor-based decision-making. This approach ensures precise and responsive control of the robotic platform.



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E. System Testing and Evaluation

The system is tested under different operating conditions to evaluate performance. Parameters such as response time, control accuracy, and system reliability are analyzed. The results confirm that the hybrid system provides efficient real-time control with reduced latency and improved stability compared to single-controller systems.

IV. SYSTEM ARCHITECTURE

The system architecture of the proposed hybrid Raspberry Pi–Arduino robotic system is designed to achieve efficient real-time control by combining high-level processing and low-level hardware control. The architecture consists of multiple interconnected modules, including the user interface, processing unit, communication module, control unit, and robotic platform. This hybrid structure ensures optimal task distribution and enhances system performance and reliability.



Fig. 1. System Architecture of Hybrid Raspberry pi-Arduino Robotic System

A. User Interface

The user interface provides a platform for interaction between the user and the robotic system. It can be implemented using a web-based interface or application that allows users to send control commands and monitor system behavior. The interface ensures ease of access and enables real-time control of the robot from remote locations.

B. Processing Unit (Raspberry Pi)

The Raspberry Pi acts as the central processing unit of the system. It is responsible for handling high-level tasks such as data processing, communication, and decision-making. The Raspberry Pi receives commands from the user interface, processes them, and transmits appropriate control signals to the Arduino. It can also support additional functionalities such as data logging, networking, and advanced computations.

C. Communication Module

The communication module enables data exchange between the Raspberry Pi and Arduino. Serial communication (UART) is commonly used to ensure reliable and fast transmission of control signals. This module plays a critical role in maintaining synchronization between processing and control units.

D. Control Unit (Arduino)

The Arduino microcontroller functions as the hardware control unit. It receives processed commands from the Raspberry Pi and executes them by generating appropriate control signals. The Arduino handles tasks such as motor control, sensor interfacing, and real-time signal processing, ensuring precise and responsive operation.



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E. Motor Driver

The motor driver acts as an interface between the Ar-duino and the motors. It controls the speed and direction of the motors based on signals received from the Arduino. This component ensures efficient power delivery and accurate movement of the robotic platform.

F. Robotic Platform

The robotic platform consists of DC motors, sensors, wheels, and a power supply system. It performs physical operations such as movement and environmental interaction. Sensors can be integrated to provide feedback, enabling the system to respond to environmental conditions.

G. System Operation

The system operates through coordinated interaction be-tween all components. The user sends commands through the interface, which are processed by the Raspberry Pi. The processed commands are transmitted to the Arduino via the communication module. The Arduino controls the motor driver and sensors, enabling the robot to perform the desired actions. Feedback from sensors can be sent back to the Raspberry Pi for monitoring and further processing.

V. BLOCK DIAGRAM

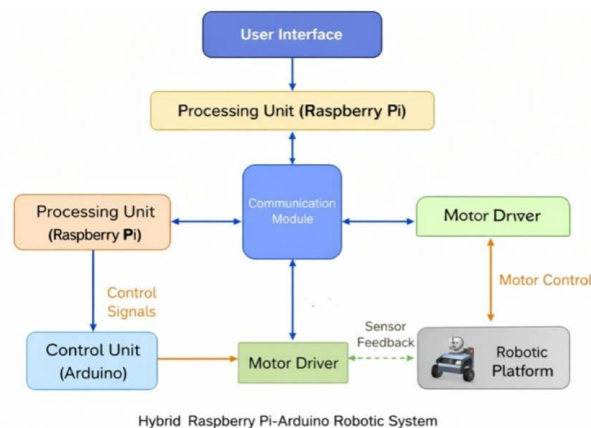


Fig. 2. Block Diagram of Hybrid Raspberry pi-Arduino Robotic System

The block diagram shows the architecture of a hybrid robotic system where the Raspberry Pi performs data pro-cessing and communication, while the Arduino handles real-time control of motors and sensors. The user sends commands through an interface, which are processed by the Raspberry Pi and transmitted to the Arduino via serial communication. The Arduino controls the motor driver, which operates the robotic platform. This hybrid approach ensures efficient, fast, and reliable real-time control.

VI. WORKING PRINCIPLE

The hybrid Raspberry Pi–Arduino robotic system operates based on a distributed control mechanism, where tasks are divided between high-level processing and real-time hardware control. Initially, the Raspberry Pi acts as the main controller and processes inputs such as user commands, sensor data, or remote instructions received through a network (Wi-Fi/hotspot). Based on these inputs, it makes decisions and generates appropriate control signals. These control signals are then transmitted to the Arduino through a serial communica-tion protocol (UART). The Arduino receives the commands and executes them instantly by controlling motors, actuators, and other hardware components. Since Arduino is optimized for real-time operations, it ensures precise timing and quick response. Meanwhile, sensors connected to the Arduino con-tinuously collect environmental data (such as distance from obstacles). This data is sent back to the Raspberry Pi for further processing, analysis, or decision-making. This cre-ates a continuous feedback loop between the two systems. Additionally, the Raspberry Pi enables remote monitoring and control using technologies like VNC, allowing users to interact with the robot from another device. The system maintains synchronization between processing and execution, ensuring smooth and efficient operation. Overall, the working principle is based on



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Fig. 5. Raspberry Pi connected to mobile hotspot with assigned IP address

Additionally, remote access through a mobile hotspot and VNC was successfully established, allowing monitoring and control from an external device. The system maintained stable connectivity and consistent performance throughout the testing process.

Overall, the results show that the hybrid approach improves system efficiency, responsiveness, and flexibility compared to single-controller systems, making it suitable for real-time robotic applications.

VIII. CONCLUSION

This paper presented the design and implementation of a hybrid Raspberry Pi–Arduino robotic system for efficient real-time control applications. By combining the high-level processing capabilities of the Raspberry Pi with the real-time control efficiency of the Arduino, the system achieved a balanced and optimized architecture.

The experimental results demonstrated that the hybrid system provides improved performance in terms of responsiveness, reliability, and flexibility. The division of tasks between the two platforms reduced processing load and ensured smooth operation of sensors, actuators, and communication modules. Additionally, the successful implementation of remote access and control further enhances the usability of the system.

Overall, the proposed approach proves to be a cost-effective and scalable solution for modern robotic applications. It can be extended to advanced domains such as automation, surveillance, and IoT-based systems, making it a promising architecture for future real-time embedded system designs.

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