IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 6, June 2026

DOI: 10.17148/IJARCCE.2026.15653

Smart Perception And Autonomous Response Core

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Abstract: The increasing deployment of Unmanned Aerial Vehicles (UAVs) in surveillance, inspection, and defense applications has highlighted the need for reliable obstacle detection and avoidance systems. Conventional approaches primarily depend on centralized processing architectures, which may introduce computational overhead and response delays during close-range obstacle encounters. This paper presents the Smart Perception and Autonomous Response Core, a dedicated low-latency perception module designed to enhance obstacle awareness and autonomous response capabilities in UAV platforms. The proposed system integrates a Time-of-Flight (ToF) sensor with an STM32H7-based embedded processing unit to independently monitor the environment and perform rapid decision-making. The module incorporates dedicated power management circuitry and MAVLink-compatible communication interfaces for seamless integration with existing flight control systems. By offloading proximity-related processing from the primary flight controller, This module aims to improve responsiveness and operational safety in dynamic environments. The modular architecture of the proposed system also provides a foundation for future enhancements involving multi-directional sensing and advanced autonomous navigation capabilities. The developed prototype demonstrates the feasibility of implementing a compact perception framework for close-range obstacle detection in UAV applications.

Keywords: Smart Perception and Autonomous Response Core, Unmanned Aerial Vehicles (UAVs), Time-of-Flight (ToF) Sensor, Obstacle Avoidance, Edge Computing, MAVLink Communication, Real-Time Embedded Systems, Autonomous Navigation.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are increasingly being deployed in applications such as surveillance, inspection, disaster response, and defense operations. As these systems operate in dynamic and complex environments, obstacle detection and avoidance have become critical requirements for ensuring flight safety and mission reliability. Conventional approaches often rely on centralized processing architectures, where perception and decision-making tasks are handled by the primary flight controller or companion computers. Such systems may introduce additional computational load and response delays, particularly during close-range obstacle encounters. To address this limitation, this paper presents the Smart Perception and Autonomous Response Core, a dedicated perception module designed for low-latency obstacle detection and response. The proposed system employs Time-of-Flight (ToF) sensing integrated with an STM32H7-based embedded processing unit to independently monitor the environment and generate rapid response decisions. By offloading proximity-related processing from the main flight controller, This project aims to enhance responsiveness while maintaining compatibility with existing UAV platforms.The developed prototype incorporates sensing, embedded processing, power management, and MAVLink-based communication interfaces within a compact and modular architecture. The proposed approach serves as a foundation for improving close-range autonomous navigation and can be extended toward future multi-directional perception systems for advanced UAV applications.

II. PROBLEM STATEMENT

Existing UAV obstacle avoidance systems primarily depend on centralized processing architectures, where environmental perception and decision-making tasks are executed by the main flight controller or external companion computers. This approach may introduce additional computational load and communication delays, particularly during close-range obstacle encounters that require immediate response. The absence of a dedicated low-latency perception framework can compromise operational safety and reduce the effectiveness of autonomous navigation in dynamic environments. Therefore, there is a need for a compact and modular perception system capable of independently monitoring the vehicle's path, processing proximity information locally, and communicating critical responses with minimal delay.

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III. PROPOSED SYSTEM

A. System Overview

The **Smart Perception and Autonomous Response Core** is a dedicated embedded perception module developed to enhance close-range obstacle awareness in Unmanned Aerial Vehicles (UAVs). The system is designed to operate independently of the primary flight controller by locally processing proximity information and generating rapid response data with minimal latency.

This module utilizes a **Time-of-Flight (ToF) sensor** as its primary sensing element to continuously monitor the environment in the direction of travel. The acquired distance measurements are processed by an **STM32H743 microcontroller**, which executes the predefined decision logic for obstacle assessment. Based on the detected proximity conditions, the processed information is communicated to the flight controller through a **MAVLink-compatible interface**, enabling timely corrective actions to improve operational safety.

The proposed architecture integrates sensing, embedded processing, communication, and power management subsystems within a compact and modular framework. By offloading obstacle perception tasks from the central flight controller, this module aims to reduce processing overhead and improve response effectiveness during close-range navigation scenarios. The modular design also provides flexibility for future expansion toward multi-directional sensing and enhanced autonomous capabilities.

B. Hardware Architecture

The hardware architecture of module is designed as a compact and modular embedded system comprising sensing, processing, communication, and power management subsystems. The architecture is centered around the **STM32H743 microcontroller**, which serves as the primary processing unit responsible for acquiring sensor data, executing decision logic, and coordinating communication with the flight controller.

A **Time-of-Flight (ToF) sensor** is employed as the perception element for close-range obstacle detection. The sensor continuously measures the distance to nearby objects and transmits the acquired data to the microcontroller through an I²C communication interface. The STM32H743 processes the received information to determine the presence of potential obstacles within predefined safety thresholds.

Communication between module and the flight controller is achieved through a **MAVLink-compatible UART interface**, enabling the exchange of obstacle-related information and facilitating integration with existing UAV platforms such as Pixhawk-based systems. This approach allows module to function as an independent perception module while maintaining compatibility with established flight control ecosystems.

The module incorporates a dedicated **power management subsystem** consisting of input protection circuitry and voltage regulation stages to provide stable operating voltages to the sensing and processing components. Additionally, **USB-UART and SWD interfaces** are integrated to support firmware development, debugging, and system validation.

The complete hardware organization of the proposed system is illustrated in Figure 1.

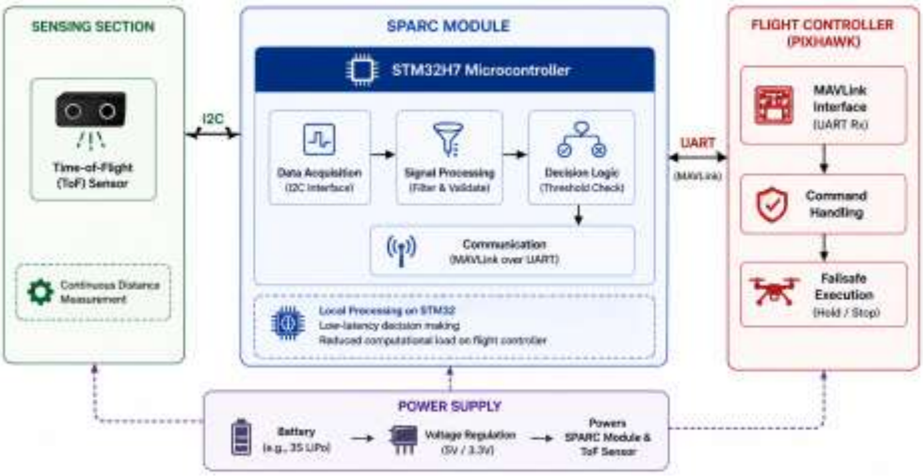

Fig. 1 Hardware Architecture

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IV. METHODOLOGY

The proposed Smart Perception and Autonomous Response Core follows a structured perception-to-response methodology to enable low-latency obstacle awareness for UAV applications. The system operates through a sequence of sensing, data acquisition, local processing, decision-making, and communication stages.

A. *Sensor Initialization and Data Acquisition*

The operational cycle begins with the initialization of the Time-of-Flight (ToF) sensor and communication interfaces by the STM32H743 microcontroller. Once initialized, the ToF sensor continuously measures the distance between the UAV and nearby obstacles in the sensing direction. The acquired distance information is transferred to the microcontroller through the I²C communication protocol at predefined intervals.

B. *Local Data Processing*

The received sensor data are processed locally by the STM32H743 microcontroller. The microcontroller validates the incoming measurements to ensure reliable operation and extracts the relevant proximity information required for obstacle assessment. By performing these computations locally, the system minimizes dependency on the primary flight controller and reduces overall processing overhead.

C. *Obstacle Assessment and Decision Logic*

The processed distance measurements are compared against predefined safety thresholds. Based on the proximity values obtained from the sensor, the decision-making algorithm determines whether the detected object poses a potential collision risk. If the measured distance remains within acceptable limits, the system continues environmental monitoring. Conversely, if an obstacle is identified within the specified safety range, module classifies the situation as requiring immediate attention.

D. *Communication with Flight Controller*

Upon detecting a critical proximity condition, the microcontroller generates the corresponding response information and transmits it to the flight controller through a MAVLink-compatible UART interface. The transmitted information enables the flight controller to incorporate obstacle-related awareness into its navigation strategy while maintaining compatibility with existing UAV ecosystems.

E. *Continuous Monitoring Cycle*

The sensing, processing, decision-making, and communication stages are executed repeatedly throughout system operation. This continuous monitoring framework allows module to function as an independent perception subsystem capable of rapidly identifying close-range obstacles and communicating relevant information with minimal delay.

The overall operational methodology adopted by the proposed system is illustrated in Figure 2.

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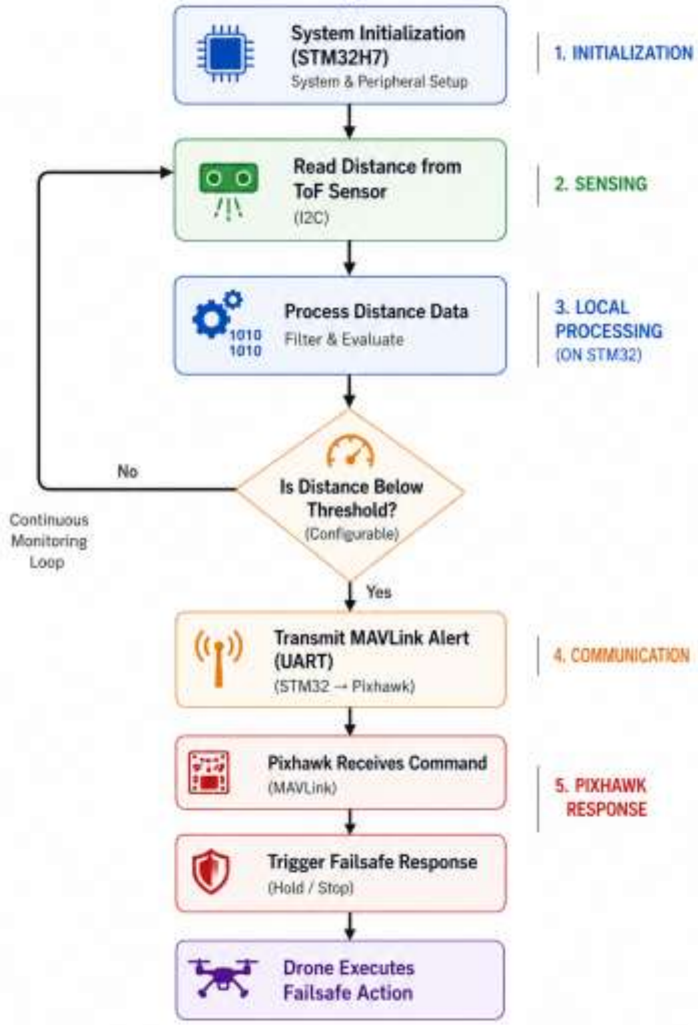

Fig. 2 Operational Flowchart

V. RESULTS AND DISCUSSION

The developed prototype demonstrated the practical feasibility of implementing a dedicated perception framework for close-range obstacle awareness in UAV applications. The integration of the Time-of-Flight sensor with the STM32H743 microcontroller enabled effective acquisition and processing of proximity information within the intended sensing region. The experimental observations indicated that the system was capable of identifying nearby obstacles within the predefined operational range, thereby addressing the primary objective of close-range environmental perception.

The local processing approach adopted by this project reduced the reliance on the primary flight controller for obstacle-related computations. This architectural separation supported the objective of minimizing perception-related processing overhead and improving the responsiveness of the overall system during obstacle encounters. Furthermore, the communication framework established compatibility with MAVLink-based flight control ecosystems, demonstrating the module's potential for integration with existing UAV platforms.

The obtained outcomes suggest that the proposed approach successfully achieved the major objectives associated with modular design, dedicated perception, and flight controller interoperability. However, the performance characteristics of the system remain influenced by factors such as sensing range limitations, environmental conditions, and threshold selection strategies. Consequently, further investigations involving multi-directional sensing arrangements and extensive field evaluations may contribute to enhancing the robustness and applicability of the proposed framework.

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Overall, the developed prototype exhibited encouraging results in relation to the defined project objectives and established the viability of employing dedicated low-latency perception modules to support close-range autonomous navigation tasks in UAV systems.

VI. CONCLUSION

This paper presented the design and development of the Smart Perception and Autonomous Response Core, a dedicated perception module intended to enhance close-range obstacle awareness in UAV applications. The proposed framework integrated Time-of-Flight sensing, embedded edge processing using the STM32H743 microcontroller, and MAVLink-compatible communication to support rapid perception and response capabilities while reducing dependence on centralized processing architectures.

The developed system successfully addressed the primary project objectives related to obstacle detection, local decision-making, modular hardware integration, and flight controller compatibility. The obtained outcomes demonstrate the feasibility of employing dedicated low-latency perception modules to improve situational awareness during close-range navigation scenarios.

Although the present work focused on single-direction obstacle perception, the proposed architecture provides a foundation for future enhancements involving multi-directional sensing, adaptive response strategies, and extended autonomous navigation capabilities. Overall, SPARC represents a promising step toward the development of intelligent and scalable perception systems for next-generation UAV platforms.

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