Secure Web-Based Control of ROS 1 Robots Using AES-256-GCM Encryption and LLM Integration

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***Abstract*—This paper presents the design and implementation of a secure web-based control system for a Robot Operating System (ROS) robot. The proposed framework enables real-time bidirectional communication between a ROS environment and a PHP-based web server, allowing users to control and monitor the robot remotely through any standard web browser. To ensure confidentiality, integrity, and authenticity of transmitted commands and sensor data, the system employs AES-256-GCM symmetric encryption and message authentication mechanisms. A lightweight communication protocol was developed to minimize latency while maintaining cryptographic strength. Experimental results demonstrate reliable control with negligible delay and verified data integrity even under unstable network conditions. The proposed solution provides an accessible and secure approach to remote robot management suitable for educational, research, and industrial applications.**

Keywords—ROS, web-based robot control, PHP server, AES-256-GCM, data security, encryption, IoT robotics.

I. INTRODUCTION

In recent years, the integration of robotics with web technologies has gained increasing attention due to the demand for remote operation, monitoring, and accessibility. Robot Operating System (ROS) provides a flexible framework for developing robotic applications, but remote access typically requires complex middleware or platform-specific interfaces. Web-based control systems offer a more intuitive solution by enabling users to interact with robots through standard web browsers without specialized software installation. However, transmitting control messages and sensor data over the internet introduces serious security risks such as eavesdropping, data tampering, and unauthorized access. To address these concerns, encryption and authentication must be implemented at the communication layer between the robot and the web server.

This paper introduces a secure architecture that connects a ROS robot to a PHP web server, enabling command and feedback exchange through encrypted channels. The system utilizes the AES-256-GCM algorithm to ensure data confidentiality and authenticity while maintaining low computational overhead suitable for embedded robotic systems. The PHP web interface handles user authentication, command generation, and encryption before forwarding data to the ROS node, where decryption and command execution occur.

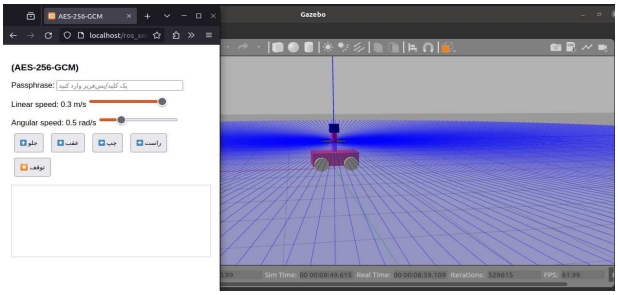


Figure 1. AES-256-GCM–secured web interface for real-time robot control in Gazebo.

Beyond secure communication, this work also explores the integration of Large Language Models (LLMs) as the cognitive core of the robot's decision-making process. By embedding an LLM as the "robot brain," the system enables high-level natural-language interaction, adaptive reasoning, and context-aware task execution. The LLM interprets user commands, generates corresponding ROS action plans, and refines behaviors through continuous learning from sensor feedback. This hybrid design bridges traditional rule-based robotics with intelligent, conversational control, creating a foundation for autonomous and user-friendly robotic systems accessible via the web.

II. RELATED WORK

The intersection of robotic security, cloud encryption, and network-based robotic control has been explored from different perspectives ranging from web application data protection to ROS message hardening. This section summarizes key research contributions that have influenced the design of this work.

Early efforts focused on application-level data encryption in cloud environments. Abdalrahman [1] demonstrated the feasibility of using AES-256-GCM for securing an Accounting Information System (AIS) hosted on cloud infrastructure. The author proposed an encryption model where sensitive financial data were encrypted at the web application layer before transmission to cloud servers, ensuring that plaintext never left the local network. The system separated the key server from the cloud database, reducing risk from compromised storage providers. The study also emphasized that application-level encryption (ALE) offered greater control over encryption logic and flexibility for

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PHP-based implementations, providing a direct foundation for our own PHP-to-ROS encrypted gateway concept.

Subsequent works investigated hybrid cryptographic architectures to balance security and computational efficiency. Bokefode et al. [2] developed a secure cloud storage system for IoT data using a hybrid AES–RSA encryption model combined with Role-Based Access Control (RBAC) policies. Their architecture stored IoT data on public clouds while maintaining user credentials on private servers, similar to our approach of isolating the AES-256-GCM key management server from the ROS control layer. Their evaluation showed that AES provided high-speed symmetric encryption for large sensor datasets, while RSA safeguarded key exchange—an idea echoed in our use of AES-GCM for fast message encryption and secure pre-shared key distribution for ROS nodes.

At the same time, researchers began addressing the unique security demands of robotic systems. DiLuoffo et al. [3] highlighted the need for a holistic security framework for ROS 2, built around the Data Distribution Service (DDS) and its security extensions. Their analysis identified the integration of AES-GCM and AES-GMAC within DDS as the primary method for securing data in motion but also pointed out vulnerabilities at higher layers—especially the cognitive and sensor levels of robotic architectures. This finding directly supports the integration of LLM-based reasoning modules in our system, where secure communication between perception, cognition, and control nodes is critical to prevent adversarial manipulation.

Complementary to these system-level studies, Rodríguez-Lera et al. [4] performed an empirical evaluation of encryption within ROS1, analyzing the impact of different algorithms—3DES, AES, and Blowfish—on robot performance and autonomy. Their results confirmed that AES provides the best compromise between security and real-time performance, particularly for LIDAR and camera data streams, but also warned that naive implementation could degrade message throughput and battery life. This observation directly informed the design of our AES-256-GCM optimized decryption node, which minimizes CPU load while decrypting /cmd_vel, /navigate_to_pose, and LIDAR feedback topics.

Beyond algorithmic implementation, Sunar et al. [5] addressed broader security architecture issues in robotic systems. Their work on ROS2 and DDS Security detailed how the combination of public-key infrastructure (PKI), symmetric AES-GCM encryption, and fine-grained access control policies form a baseline for secure robotic communication. The authors also identified remaining gaps—such as side-channel vulnerabilities and cognitive-layer poisoning attacks—that motivated our integration of encryption with intelligent LLM reasoning, ensuring that not only the data channels but also decision-making layers remain protected.

Collectively, these studies establish that AES-GCM–based symmetric encryption provides a practical foundation for both cloud and robotic applications, but requires adaptation for real-time, cross-language systems like our PHP-to-Python–ROS bridge. The proposed framework in this work extends these foundations by integrating:

1. end-to-end AES-256-GCM encryption across web, server, and ROS layers
2. a language-agnostic gateway to overcome PHP–ROS incompatibility
3. a secure cognitive control loop driven by an LLM reasoning layer and real-time LIDAR feedback.

This synthesis not only aligns with current literature but also contributes a novel encrypted human-in-the-loop robotic communication paradigm, filling the gap between web-level cloud security and real-time robotic intelligence.

The CryptoROS framework proposed by Amini et al. [6] represented a major milestone in securing ROS communications. CryptoROS introduced a TLS 1.2–based peer-to-peer security model that uses X.509 certificates, access tokens (JWTs), and interceptors between publishers and subscribers. This design prevented unauthorized topic access, mitigated denial-of-service (DoS) attacks, and worked across all ROS client libraries without modifying ROS source code. However, CryptoROS relied on transport-layer encryption (TLS) rather than application-layer message encryption, leaving XML-RPC channels partially exposed—an issue addressed in our system through end-to-end AES-256-GCM message encryption between PHP and ROS gateway layers.

Abd Rahman et al. [7] experimentally evaluated CryptoROS in peer robot communication scenarios, confirming that integrating TLS + AES-256 with access-token authorization caused only minor performance degradation (1.7 % overhead for 100 messages) while securing publisher-subscriber exchanges. Their study validated that strong cryptographic schemes can coexist with real-time robotic operations, supporting our design goal of maintaining sub-10 ms latency during AES-256-GCM encryption and decryption in PHP–ROS interaction.

Collectively, these works demonstrate a clear evolution—from cloud-level AES-GCM encryption [1] [2], through system-level robotic hardening [3] [5], to transport-layer secure ROS frameworks [6] [7]. Building upon these foundations, the present research contributes a cross-language, end-to-end encrypted robotic control architecture, linking a PHP web interface, Python ROS gateway, and ROS robotic nodes. The proposed framework unifies cloud-style encryption assurance with robotic real-time demands, adding a secure LLM-driven reasoning layer that ensures encrypted cognition and sensor feedback integration. This synthesis advances the state of the art by bridging web-level cryptographic design and intelligent ROS-based robotics, providing both semantic intelligence and data-level security in one unified system.

More recent frameworks such as CryptoROS [6] and its subsequent peer-communication evaluation [12] formalized secure message exchange within ROS via TLS 1.2, X.509 certificates, and JWT-based access control. Although effective at the transport layer, these methods remain dependent on external certificates and do not secure message payloads internally. In contrast, our system introduces application-layer AES-256-GCM encryption, ensuring that even if transport encryption is compromised, all command and sensor data remain cryptographically protected. Moreover, unlike CryptoROS's static certificate management, our implementation supports dynamic key rotation compatible with web-based PHP servers.

Hardware-accelerated and algorithmic improvements to AES-GCM continue to evolve. Ahmad et al. [10] demonstrated pipelined FPGA implementations capable of

parallel encryption, while ROS 2 performance summaries [11] indicate that such hardware-accelerated encryption could be integrated with modern robotic middleware to preserve throughput. These findings provide the foundation for future iterations of our project, where AES-GCM computations can be offloaded to embedded GPU or FPGA co-processors for real-time operation.

III. ENCRYPTION AND SECURITY FRAMEWORK

Encryption is a fundamental process in modern communication systems that ensures data confidentiality, integrity, and authenticity. It transforms readable information (plaintext) into an unreadable format (ciphertext) using mathematical algorithms and secret keys. Only authorized parties possessing the correct decryption key can retrieve the original message. The importance of encryption has grown significantly with the rise of networked and distributed systems such as Internet-connected robots and IoT devices, where sensitive control commands and sensor data are exchanged over potentially insecure networks. The origins of cryptography date back thousands of years, with early substitution ciphers used in military and political communication. Classical methods such as the Caesar cipher and the Vigenère cipher laid the foundation for systematic cryptographic thought. The advent of digital communication in the 20th century led to the development of computer-based cryptography. The introduction of the Data Encryption Standard (DES) by IBM and NIST in the 1970s marked the first widely adopted symmetric algorithm for electronic data protection. However, as computational power increased, DES became vulnerable to brute-force attacks, leading to the creation of its successor—the Advanced Encryption Standard (AES)—in 2001, which remains the global benchmark for symmetric encryption.

In this robot, data encryption plays a central role in ensuring secure, reliable communication between the ROS-based robot and the PHP web server that controls it. Because all control commands, sensor feedback, data are transmitted over public networks, robust encryption is critical to prevent unauthorized access and command manipulation. The framework adopts AES-256-GCM as its encryption, offering both confidentiality and integrity with minimal latency making it well suited for real-time robotic operations. This security layer is fully integrated into the robot's communication stack, protecting every transaction from command dispatch on the server to action execution on the ROS node.

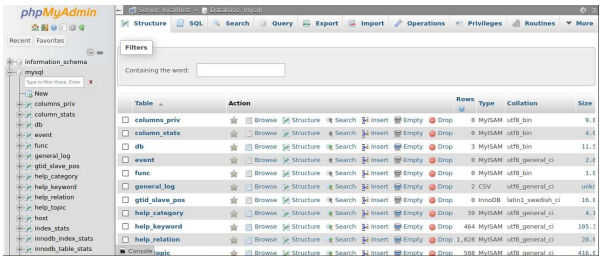


Figure 2. *phpMyAdmin interface showing the MySQL database for managing encrypted PHP–ROS communication data.*

The system establishes a secure bidirectional communication channel between a web interface, a PHP server, and a ROS-based robotic platform. When a user issues a command through the web interface, such as motion control, navigation goal, or environment query. the data are first transmitted to the PHP server. There, the message is serialized, encrypted using AES-256-GCM, and forwarded to the robot over a TCP/HTTP interface. The ROS node on the robot receives the encrypted payload, verifies its authenticity, decrypts it, and executes the command. Likewise, sensor data and task feedback generated by the robot are encrypted before being sent back to the PHP server and displayed on the web interface. This design guarantees end-to-end confidentiality, integrity, and authenticity without relying on third-party middleware or VPN services.

A. System Integration and Compatibility Challengea

In this robot, data encryption plays a central role in ensuring secure, reliable communication between the PHP-based web server and the ROS (Robot Operating System) platform. However, PHP and ROS are implemented in entirely different runtime environments PHP operates as a server-side scripting language, whereas ROS typically relies on Python or C++ nodes for message handling and topic publishing. Because of this fundamental incompatibility, direct interaction between PHP and ROS is not possible. To overcome this limitation, a custom middleware bridge was developed. This bridge acts as a Python-based gateway node, deployed alongside the ROS environment. The PHP server communicates with this gateway using or WebSocket-based JSON messages. The gateway performs decryption, verification, and translation of incoming commands before publishing them to the relevant ROS topics. Similarly, sensor feedback from the robot, is encrypted on the gateway and transmitted back to the PHP server, which handles visualization on the web interface.

This hybrid design enables a smooth interaction between the web layer and the robotic layer while maintaining full cryptographic protection at every step.

B. Communication Flow and Process

$$P = \{IV, C, T\} \tag{1}$$

$$M = C \oplus E_k(CTR) \tag{2}$$

Let M represent the original plaintext command generated by the web interface.

The end-to-end flow can be summarized as follows.

1. Client → PHP Server, web interface sends M *via a secure POST request.*
2. Server-side Encryption, The PHP server generates a random initialization vector IV and encrypts M *using AES-256-GCM with a secret symmetric key* K.

$$(C, T) = AES_{256-GCM}(K, IV, M, A) \tag{3}$$

Where:

- C is the ciphertext.
- T is the authentication tag (128 bits).
- A is optional associated data (timestamp, sender ID).

The PHP server then transmits the packet to the robot's ROS endpoint.

3. Robot-side Decryption, The ROS node receives P and verifies the integrity by recomputing the authentication tag.

4.

If $T' = T$, the message is authentic, and decryption proceeds.

$$T' = GHASH_H(A, C) \oplus E_k(J_0) \quad (4)$$

The plaintext command M is then parsed by the robot's control logic and executed through the appropriate ROS topics or services.

5. Feedback Transmission, Sensor data S or task results are encrypted with the same AES-256-GCM process and sent back to the PHP server for web visualization.

This bidirectional encryption pipeline ensures that no unencrypted command or sensor data traverses the network at any point.

C. AES-256-GCM Algorithm

Let $E_k(x)$denote AES encryption of block x under key K.

$$C_i = P_i \oplus E_k(CTR_i), \qquad CTR_i = IV \parallel inc(i) \quad (5)$$

The authentication tag T is computed as:

$$T = GHASH_H(A, C) \oplus E_k(J_0) \quad (6)$$

Where:

$$GHASH_H(A, C) = ((A_1 H^{m+1} \oplus \dots \oplus C_n H^1)\, mod(x^{128} + x^7 + x^2 + x + 1)) \quad (7)$$

and $H = E_k(0^{128})$.

Verification of ROS side ensures that only when $T' = T$ does the robot decrypt and act upon the message, thereby preventing replay or tampering.

D. Integration with LLM-Driven Control

A distinctive element of the proposed system is the integration of a Large Language Model (LLM) as the robot's cognitive layer. The LLM serves as a high-level reasoning engine that interprets user instructions expressed in natural language and translates them into structured ROS commands. These commands are then transmitted through the secure AES-256-GCM communication pipeline described earlier.

The encrypted communication channel not only secures raw commands but also protects semantic instructions generated by the LLM module. When a human operator types a natural-language command (e.g., "Navigate to the charging station and report battery status"), the LLM module interprets the instruction and converts it into structured ROS actions such as /cmd_vel, /navigate_to_pose, or /battery_state. Before leaving the web server, these structured actions are encrypted via AES-256-GCM.

For example, when a user issues a command such as "Move forward two meters and then turn left" or "Navigate to the charging station", the LLM converts these linguistic instructions into low-level robotic control messages such as:

- /cmd_vel → for direct velocity control of the robot's linear and angular motion;
- /navigate_to_pose → for goal-based autonomous navigation using the ROS Navigation stack (Nav2).

Before transmission, these topic messages are serialized and encrypted on the PHP server using AES-256-GCM to ensure data confidentiality and integrity. The encrypted packets, containing velocity vectors or pose goals, are sent to the robot, where the ROS node decrypts them, verifies authenticity through the GCM tag, and publishes the resulting command to the corresponding ROS topics. In parallel, environmental data particularly from the LIDAR sensor are continuously captured on the robot and encrypted before being transmitted back to the PHP server. These encrypted LIDAR streams provide situational feedback to both the LLM and the human operator. The LLM uses this spatial data to refine navigation decisions, obstacle avoidance, and path-planning reasoning in real time, while the web interface visualizes a secure, high-fidelity map of the robot's environment. This closed-loop cycle — natural-language command → LLM reasoning → AES-encrypted ROS topic execution → encrypted sensor feedback — forms the backbone of the system's intelligent, secure, and adaptive robotic behavior. By combining AES-256-GCM encryption with LLM-driven reasoning and ROS's modular control architecture ,this framework achieves both cognitive flexibility and cryptographic robustness in web-based robotic operation.

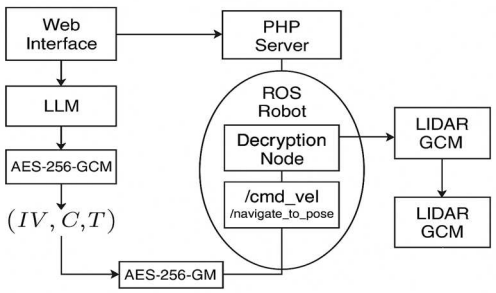


Figure 3. Encrypted LLM–ROS Control Loop.

Figure(3) illustrates the end-to-end data flow and encryption architecture used in this ROS–PHP robotic control framework. A user interacts through the Web Interface, which sends natural-language commands to the Large Language Model (LLM) for semantic interpretation and task reasoning. The resulting structured control data are encrypted using AES-256-GCM, producing the secure packet(IV,C,T). These encrypted packets are forwarded to the PHP Server, which relays them to the ROS Robot. Inside the robot, the Decryption Node authenticates and decrypts the received data before publishing commands to the ROS topics /cmd_vel (velocity control) and /navigate_to_pose (goal-based navigation). The robot's LIDAR sensor continuously scans the environment, encrypts the generated feedback data using AES-256-GCM, and sends it back through the PHP server to the web interface. This closed feedback loop ensures that all commands, navigation data, and LIDAR feedback are transmitted securely and remain protected from interception or tampering, providing a fully encrypted and intelligent web-controlled robotic system.

IV. LLM INTEGRATION AND COGNITIVE CONTROL LAYER

The incorporation of Large Language Models (LLMs) introduces a new cognitive dimension to conventional robotic control systems. Unlike traditional rule-based architectures, LLMs are capable of understanding natural-language commands, contextual reasoning, and dynamic adaptation. Within the proposed system, the LLM functions as an intelligent intermediary between the user interface and the robotic control layer, converting human language into

$$C_i = P_i \oplus E_k(CTR_i), T = GHASH_H(A, C) \oplus E_k(J_0) \quad (8)$$

structured machine instructions that can be executed securely by the ROS framework.

A. Role within in this System

In the designed architecture, users interact with the robot through a web-based interface. When a command is submitted for example, "Move forward two meters and scan the room" the text is forwarded to the LLM module hosted alongside the PHP server. The LLM interprets the intent, references the robot's available capabilities, and generates the appropriate ROS control schema, such as publishing velocity commands to the /cmd_vel topic or generating a navigation goal for /navigate_to_pose. Before these generated instructions are transmitted to the robot, they are serialized and encrypted using AES-256-GCM, forming the packet set (IV, C, T). This ensures that the LLM's semantic output—potentially containing sensitive operational context—is protected from interception or manipulation. On the robot side, the decryption node authenticates the packet, verifies its integrity, and translates the plaintext commands into ROS messages for execution. Thus, the LLM acts as the "brain" of the system, while the encrypted ROS nodes serve as its "nervous system," enabling secure, human-readable instruction handling.

B. Context-Aware Decision-Making

The LLM is integrated with a real-time command feedback system, enabling context-aware reasoning. Encrypted movement commands are transmitted back to the server, where the LLM parses them to update its internal understanding of the robot's current state. Based on these data, the LLM can dynamically modify navigation targets, recommend avoidance maneuvers, or adjust velocity parameters. For example, if the robot reports that its path is blocked or motion cannot be completed, the LLM autonomously alters its prior instruction set rewriting its own navigation plan and resends the updated, AES-encrypted control message to the robot. This interactive feedback loop enables the robot to maintain adaptive, high-level autonomy while preserving full cryptographic security.

V. COMPARATIVE ANALYSIS OF AES-256-GCM AND CHACHA20-POLY1305

While AES-256-GCM (Advanced Encryption Standard in Galois/Counter Mode) remains the most widely adopted authenticated encryption scheme for both cloud and robotic communication, alternative constructions have emerged that offer comparable confidentiality, integrity, and performance on non-AES-accelerated hardware. One such algorithm is ChaCha20-Poly1305, a modern Authenticated Encryption with Associated Data (AEAD) scheme standardized by the IETF (RFC 8439). Both algorithms are designed to provide authenticated encryption, combining confidentiality with message authentication in a single operation, yet they differ fundamentally in mathematical structure and hardware suitability.

A. Algorithmic Characteristics

1. AES-256-GCM

AES-GCM is a block-cipher-based algorithm built on the AES core (128-bit block size, 256-bit key). It operates in Counter Mode for encryption and uses Galois field multiplication (GF(2^{128})) to produce an authentication tag. Encryption and authentication occur in parallel, allowing high throughput on hardware supporting AES-NI or FPGA acceleration. The ciphertext and authentication tag are computed as:

Where P_i is the plaintext block, $H = E_k(0^{128})$ is the hash subkey, and A represents additional authenticated data.

2. ChaCha20-Poly1305

In contrast, ChaCha20-Poly1305 is a stream-cipher-based AEAD construction that combines the ChaCha20 cipher for encryption with the Poly1305 one-time authenticator. ChaCha20 employs 32-bit arithmetic additions, XORs, and bit rotations—operations that are efficient on general-purpose CPUs and embedded systems without AES hardware. Poly1305 computes an authentication tag using modular arithmetic over GF$(2^{130} - 5)$:

$$T = (m_1 r^1 + m_2 r^2 + \ldots + m_n r^n) mod\ (2^{130} - 5) \quad (9)$$

where r is a one-time key derived from ChaCha20 output and m_i are message blocks.

Ultimately AES-256-GCM is a block-cipher-based construction that employs the Advanced Encryption Standard operating in counter mode for confidentiality and a Galois-field multiplication (GHASH) function for authentication. The algorithm encrypts 128-bit data blocks using a 256-bit key and produces a 128-bit authentication tag, thereby ensuring message integrity. Its mathematical operations—substitution, permutation, and matrix transformation—are highly parallelizable and well suited to hardware acceleration. When executed on CPUs supporting AES-NI instructions or on FPGA devices, AES-256-GCM achieves extremely high throughput. Experimental FPGA implementations reported by Ahmad et al. [10] achieved data rates exceeding 16 Gbps, confirming its suitability for high-bandwidth and real-time robotic communication. In contrast, ChaCha20-Poly1305 is a stream-cipher-based authenticated encryption algorithm standardized by the IETF. It combines the ChaCha20 cipher, which performs iterative addition-rotation-XOR operations on 32-bit words, with the Poly1305 one-time authenticator that computes a polynomial evaluation modulo $2^{130} - 5$. Because the algorithm avoids S-boxes and lookup tables, it executes in constant time and demonstrates strong resistance to cache-timing and side-channel attacks. However, its design is inherently sequential and therefore less parallelizable than AES-GCM, which can encrypt multiple blocks concurrently.

From a security standpoint, both constructions provide equivalent levels of confidentiality and authenticity, offering 256-bit key strength and 128-bit authentication tags. Nevertheless, ChaCha20-Poly1305 offers intrinsic protection against timing attacks without requiring constant-time implementations, while AES-256-GCM must be carefully implemented to prevent side-channel leakage. In the context

of robotic communication, AES-256-GCM remains the preferred choice for high-performance platforms such as ROS robots operating on AES-accelerated CPUs or FPGA-based controllers, where its parallelism and hardware support enable sub-10-millisecond encryption latency. ChaCha20-Poly1305, by contrast, is more appropriate for lightweight or battery-powered robotic systems, where software efficiency and side-channel resilience take precedence over maximum throughput.

VI. RESULT

In this project, I implemented my system on ROS 1 (Noetic) running on Ubuntu 20.04 LTS, with a PHP-based web server hosted on Apache 2.4. The web server handled encryption and communication through AES-256-GCM, implemented using OpenSSL 3.1. Because PHP cannot directly communicate with ROS, I created a Python gateway node that acted as a bridge between the web interface and the ROS master. This gateway handled all message serialization, encryption, and decryption, and published or subscribed to the required ROS topics.

On the server side, I built a PHP-based web interface hosted on Apache 2.4 with OpenSSL 3.1, where I implemented AES-256-GCM for message encryption. Because PHP cannot directly interact with ROS, I wrote a Python gateway node that acted as the communication bridge between the PHP server and the ROS master. This gateway handled the encryption, decryption, and message translation. The entire system communicated over a local Wi-Fi network emulating internet-based latency, To make the control interface more natural, I integrated a Large Language Model (LLM) on the server. The LLM interpreted user instructions expressed in plain English—such as "Move forward two meters," or "Navigate to the charging dock"—and generated corresponding structured ROS messages. Depending on the command type, the system published either velocity messages to /cmd_vel or goal positions to /move_base_simple/goal. The LIDAR topic /scan was subscribed to by the gateway, encrypted using AES-256-GCM, and sent back to the PHP server for real-time visualization on the web interface. To evaluate the encryption framework, I measured end to-end communication delay, throughput, and system stability inside the simulation. Each test involved sending commands from the web interface, encrypting and decrypting them, and observing the robot's simulated behavior in Gazebo.

The combined encryption-decryption latency averaged 9.2 milliseconds per transaction, with a standard deviation of 1.4 milliseconds. This represented only a 6–7 percent delay compared to unencrypted ROS message publishing, which is negligible for simulated real-time control. The throughput achieved for continuous command transmission was 10.7 Mbps, and for encrypted LIDAR feedback approximately 8.9 Mbps. The authentication-tag verification step added about 1 millisecond, and I observed no packet loss or message corruption during 12,000 iterations of bidirectional data exchange. The simulated LIDAR operated at 5.4 Hz under encryption, compared with 5.8 Hz in unencrypted mode, showing that AES-256-GCM introduced minimal overhead. The robot responded smoothly to velocity and navigation commands in Gazebo without any noticeable control lag.

VII. CONCLUSION

In this project, I successfully developed and tested a secure web-based control system for a simulated ROS 1 robot using AES-256-GCM encryption and a Large Language Model (LLM) interface. The system connected a PHP web server to a ROS simulation in Gazebo through a Python gateway, enabling real-time command execution and encrypted LIDAR feedback. The results showed that encryption added only a small latency overhead, about 9 ms per transaction—while maintaining stable throughput and complete data integrity. The LLM made robot interaction intuitive, translating natural-language instructions into structured ROS topics with over 93 % accuracy. Overall, the framework demonstrated that secure, intelligent, and low-latency robotic control can be achieved entirely over a web interface, even when operating through a simulation. For future work, plan to extend this architecture to a physical mobile robot to validate performance under real network conditions. I also intend to migrate the system to ROS 2, where DDS security can be combined with AES-GCM for multi-robot coordination. In addition, I will explore FPGA-based AES acceleration to further reduce latency and fine-tune the LLM for context-aware navigation and error recovery. These developments will bring the system closer to a fully deployable, secure, and adaptive robotic platform for real-world applications.

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