Autonomous Surveillance Breakthrough by Implementing Facial Recognition in Dog Robots

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***Abstract*— As the importance of security in today's world continues to escalate, technology's role in its enhancement has evolved significantly. From the inception of fixed security cameras monitored by individuals, advancements have steered towards autonomous threat recognition systems and the deployment of mobile robots for proactive security measures. Despite these technological strides, the exploration of autonomous robots in security has been relatively scant. This study takes a novel approach by repurposing the commercial GO2 Edu dog robot for security purposes, equipping it with a thermal camera and custom software for robust face detection in varying lighting conditions, aimed at achieving safer and more reliable face recognition. Furthermore, the mapping and navigational capabilities are studied by conducting experiments with a Turtlebot outfitted with a 2D RPLIDAR and depth camera using SLAM, laying the groundwork for the GO2 robot's autonomous operations. The results of these enhancements have shown to be promising in the context of bolstering security measures. The paper concludes with a discussion on potential future enhancements, paving the way for more sophisticated and autonomous security robots.**

Keywords—Security Technology, Dog Robots, Autonomous Robots, Legged Robots, Mapping and Navigation, Face Recognition

I. Introduction

There is an increasing need for improved security measures due to rising crime rates, border control demands, issues related to human and drug trafficking as well as securing the nation's critical infrastructures such as nuclear power plants. The advancements in security technology underscore the evolving landscape of surveillance and recognition methodologies [1-5]. These range from stationary surveillance systems, such as fixed cameras, to mobile robotic systems, including aerial drones, wheeled robots, and legged robots. Each technology serves a distinct purpose [6-9].

Stationary systems like fixed cameras are widely used for security purposes due to their ability to provide continuous surveillance and monitoring of specific areas. Fixed cameras offer the advantage of stable and consistent monitoring, allowing for the capture of high-quality images and videos for security analysis and evidence. However, they are limited by their immobility, making them unable to adapt to changing security needs or cover large areas without multiple installations. Additionally, fixed cameras are susceptible to blind spots and tampering, which can compromise the overall security of the system [10-12].

Mobile wheeled robots are increasingly being employed for security purposes due to their mobility and versatility in navigating different terrains. These robots offer the advantage of patrolling large areas autonomously, providing real-time data and video feeds for security monitoring. Mobile robots can be equipped with various sensors and cameras to detect and respond to security threats effectively. However, they may face limitations in navigating complex or uneven terrains, and their operation may be hindered in crowded or confined spaces, impacting their overall effectiveness in certain security scenarios [13-16].

Aerial drones have become integral to security operations, offering the advantage of rapid deployment and aerial surveillance capabilities. Drones can cover large areas efficiently, providing aerial views for security monitoring and identification. Equipped with advanced imaging and sensing technologies, drones can gather valuable security data and respond to incidents in real-time. However, drones are subject to airspace regulations and may present privacy concerns, requiring careful management of their operation in security applications. Also, they aren't very maneuverable for indoor applications [17-19].

Legged robots are gaining attention for security applications due to their ability to traverse challenging environments and access hard-to-reach areas. These robots offer the advantage of enhanced mobility and agility, allowing them to navigate obstacles and uneven terrain with ease. Legged robots equipped with advanced sensors and cameras can provide comprehensive security coverage in various settings [20-24].

This project introduces an innovative approach to addressing current security challenges through the utilization of advanced robotics technology. By harnessing the capabilities of a legged robot with high mobility and autonomous navigation, coupled with comprehensive obstacle avoidance systems and a suite of sensors for dynamic threat recognition, we aim to enhance security surveillance in diverse environments. Initial testing stages have involved utilizing Turtlebot for precise mapping and autonomous navigation, as well as obstacle avoidance assessments in both static and dynamic scenarios. Subsequently, we deployed the GO2 dog robot equipped with RGB and thermal imaging cameras for advanced face recognition capabilities. This integration enables enhanced functionality, particularly in low-light conditions, with thermal imaging facilitating heat signature identification for improved recognition accuracy. Looking ahead, our research will explore emerging

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technologies such as RFID tag recognition and machine learning algorithms for enhanced threat recognition. Additionally, in future research, we will investigate the integration of AI and machine learning for more robust data analysis and decision-making capabilities, while also exploring new applications in border security and wildlife protection. Through this comprehensive approach, we aim to pave the way for the future development and deployment of autonomous security systems, ultimately enhancing security and surveillance efforts across various domains.

II. Mapping an Unknown Environment

For mapping an unknown environment, a mobile platform equipped with sensors and cameras integrated by Simultaneous Localization and Mapping (SLAM) and obstacle avoidance technologies is required. The Turtlebot is considered as an appropriate mobile platform for this part of the project, showcasing the successful integration of a multifaceted sensor suite for advanced navigational tasks. Tests have been conducted for indoor mapping and obstacle avoidance, both for static and dynamic obstacles.

A. *Robot Platform and installed Sensors*

The Turtlebot Kobuki, used in this project phase, combines the Astra Depth Camera for depth and RGB vision with the A2M8 RPLIDAR for 360-degree scanning, tailored for precise navigation and mapping (Fig. 1). It's powered by a lithium-ion battery supporting up to 3 hours of operation, achieving a maximum speed of 0.65 m/s, and can carry payloads up to 5 kilograms. The Kobuki's compact design, with a 35-centimeter diameter and a 2.5-kilogram weight, enhances maneuverability. It features versatile USB and serial ports for additional module integration and is ROS-compatible, making it a flexible tool for robotics development.

The Astra Depth Camera is notable for its ability to capture both depth information and color images, enhancing the robot's perception for both obstacle avoidance and environment interaction. It typically features a depth recognition range of up to 0.6 to 8 meters, allowing for precise navigation and obstacle identification over a variety of distances. The addition of RGB imaging enables the robot to perform tasks requiring color recognition and more detailed environmental analysis.

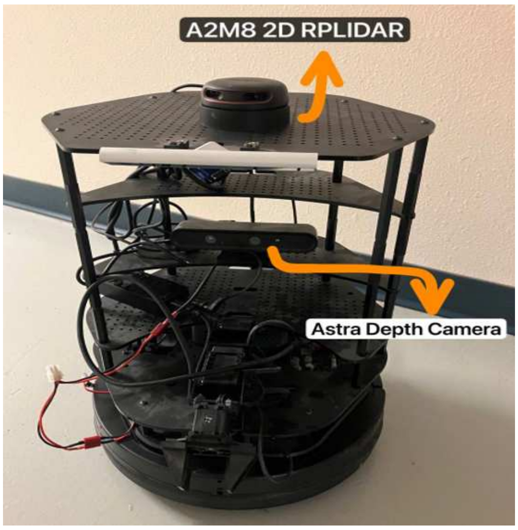

Fig. 1. 2D RPLIDAR and Depth Camera mounted on the Turtlebot for mapping and obstacle avoidance respectively

The A2M8 RPLIDAR is a laser scanner designed for 360-degree environmental scanning, with a recognition range of up to 12 meters. This lidar unit is capable of performing 4,000 to 8,000 scans per second, making it highly effective for real-time mapping and localization tasks. Its high scan rate and wide range make it particularly suited for detailed and dynamic SLAM applications. Table 1 summarizes the key sensors installed in the Turtlebot Kobuki and their specifications.

Table 1: Installed Sensors on the Turtlebot Kobuki

Sensor Type	Key Specification	Recognition Range (m)	Speed/Rate	Size (mm)
Astra Depth Camera + RGB	Depth and color imaging	0.6 to 8	30fps	165×30 × 40
A2M8 RPLIDAR	360-degree laser scanner	Up to 12	4,000 to 8,000 scans/sec	110 D × 40 H

B. *Mapping and Navigation*

For Mapping and Navigation, SLAM is utilized for creating detailed maps of the environment, whereas obstacle avoidance ensures safe navigation by steering clear of hazards. These complementary technologies enable robots to efficiently navigate and understand their surroundings.

SLAM is a computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it. In the context of robotics, particularly with the Turtlebot, SLAM involves the integration of sensor data to create a detailed spatial map of the environment while the robot navigates through it. Here are some of the key components and their roles in mapping and navigation:

1. 2D RPLIDAR: This laser scanner is pivotal for SLAM in robotics. It scans the environment in a 2D plane, collecting data points that represent the distances to obstacles and walls. This data is then used to generate a 2D map of the surroundings. The precision and range of the RPLIDAR allow for the creation of detailed maps, even in complex environments. For instance, the successful 2D mapping of a building, as indicated by the mention in Fig. 2, relies heavily on the extensive environmental scans provided by the RPLIDAR.

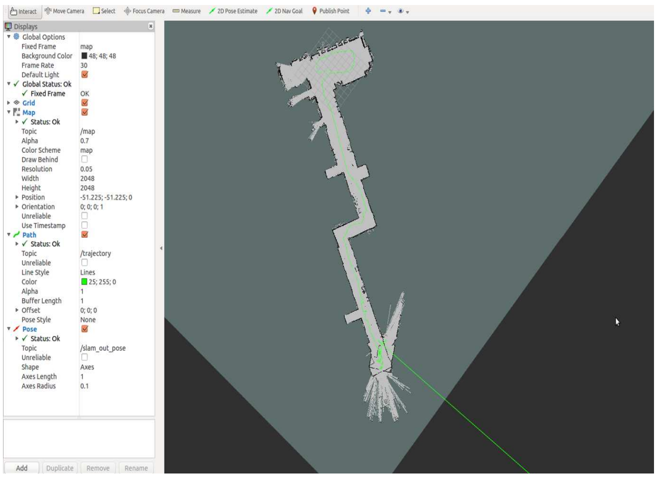

Fig. 2. Mapping with TurtleBot using RPLIDAR and in Rviz Environment

2. Robot Operating System (ROS) and RViz: ROS serves as a flexible framework for writing robot software and is a collection of tools, libraries, and conventions that simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms. RViz is a 3D visualization tool for ROS that enables users to visualize the robot's state and the surrounding environment in real-time. In SLAM, RViz is used to dynamically display the map being created and the robot's current position within it, offering immediate visual feedback that aids in debugging and improving the mapping process.

The SLAM process using a 2D RPLIDAR involves continuous scanning of the environment and updating the map with new information while adjusting the robot's estimated position based on the discrepancies between the new scan data and the existing map. This requires sophisticated algorithms capable of handling uncertainty and noise in sensor data to accurately estimate the robot's location and update the map accordingly.

C. Obstacle Avoidance

Obstacle avoidance is critical for ensuring that the robot can navigate through its environment safely without colliding with objects. Although this is distinct from SLAM but equally important for autonomous operation. Here are some of the key components and their roles in obstacle avoidance:

1. Depth Camera: The depth camera is instrumental in obstacle avoidance. Unlike the 2D RPLIDAR, which is primarily used for mapping, the depth camera provides 3D data about the environment. This includes the shapes, sizes, and distances of objects in front of the robot. The depth information allows the robot to detect potential obstacles in its path and adjust its course to avoid them.

The process of obstacle avoidance involves continuously monitoring the environment for obstacles using the depth camera and then calculating alternative paths to avoid these obstacles while still moving towards the target destination. The depth camera's data is processed in real-time to identify obstacles, and decisions are made based on predefined criteria, such as minimum distance to obstacles, to ensure safe navigation. This process is critical in dynamic environments where obstacles can suddenly appear or move.

2. Integration with SLAM: While SLAM focuses on mapping and localization, obstacle avoidance ensures the robot can navigate safely by dynamically responding to the immediate environment. These two processes are complementary: SLAM provides the robot with a sense of "where I am" and "what the environment looks like" on a larger scale, while obstacle avoidance deals with immediate threats to navigation. Together, they enable a robot to navigate and map its environment efficiently and safely, leveraging technologies like ROS for coordination and RViz for visualization to achieve a high degree of precision and reliability in autonomous navigation.

III. Dog Robot

The ultimate goal of this project is to utilize a dog robot for security purposes. The GO2 Edu dog robot has been selected for this project due to its customizability, allowing for the addition of new sensors and enhanced programmability. It supports both Python and C++, with Python being the chosen language for this project. Among its various sensors, the RGB and thermal cameras were specifically used for threat detection.

A. Robotic Dog Specifications

The GO2 Edu Dog Robot exemplifies modern robotics designed for educational use, balancing sophisticated sensors and components with user-friendly interaction. It's lightweight at 15 kg, with compact dimensions, and boasts impressive mobility with a top speed of 3.7 m/s and the ability to navigate slopes up to 40 degrees. Its articulation allows significant movement in its body and limbs, supporting a payload of 12 kg, while offering 2 to 4 hours of operational battery life.

Table 2 represents the general specification of GO2 Edu Dog Robot in detail.

TABLE 2: GO2 EDU DOG ROBOT SPECIFICATIONS

General Information	Specification
Weight	15 kg
Size	812.8 x 508.0 x 330.2 (mm)
Max Speed	3.7 (m/s
Max Climb Angle	40°
Range of Motion	body：-48 ~ 48° thigh：-200° ~ 90° shank：-156° ~ -48°
Max Payload	12 kg
Battery Life	2-4 hours

B. Robotic Dog Capabilities

The GO2 Edu Dog Robot, with its brisk maximum speed of 5 m/s and robust payload capacity of 12 kg, emerges as a formidable candidate for security applications. Its mechanical prowess, demonstrated by a considerable climb angle of 40 degrees, enables it to navigate challenging terrains with ease, an essential trait for a security patrol unit. The robot's battery life, spanning between 2 to 4 hours, ensures sustained operations during extended security missions. The impressive range of motion across its body and limbs provides the agility needed for responsive maneuvers in security scenarios. These attributes, combined with the potential for custom programming and sensor integration, make the GO2 Edu Dog Robot an excellent choice for a robotic security dog, capable of performing vigilant patrols and responding swiftly to security-related tasks. Some the major capabilities of this robot has been mentioned in Table 3.

IV. Threat Recognition

A. Face Recognition Using Only RGB Camera

Initially, an RGB camera was mounted on the dog to enable face Recognition. This setup effectively recognized faces that had been pre-defined in its database, proving successful under normal lighting conditions. However, challenges arose when operating in low-light or completely dark environments, and the RGB camera's performance significantly deteriorated under these conditions. To address this limitation and enhance the dog's operational capabilities across a wider range of environments, we integrated a FLIR Lepton 3.5 thermal imaging camera.

TABLE 3: GO2 EDU DOG ROBOT CAPABILITIES

Components	Specification
Tracking Module	Capable of both remote-controlled and automatic tracking
4D Lidar L1	360°×90° omnidirectional ultra-wide-angle scanning allows automatic avoidance with small blind spots and stable operation
Front Camera	Delivers high-resolution, wide-angle visual transmission
Front Lamp	Provides bright, forward-facing illumination
Computing Core	Houses the main processors for motion control and AI
Intercom Microphone	Facilitates unrestricted communication
Knee Joint Motors	Powers the robot's movement with precision
Smart Battery	Offers a choice of capacities with protective features

B. *Integration with Thermal Camera*

To enhance the dog robot's operational efficiency in varying light conditions and fortify its security protocol, we integrated a thermal imaging camera alongside the initial RGB setup (Fig. 3). This addition not only ensures uninterrupted recognition capabilities in low-light or dark environments but also substantially improves the system's security against

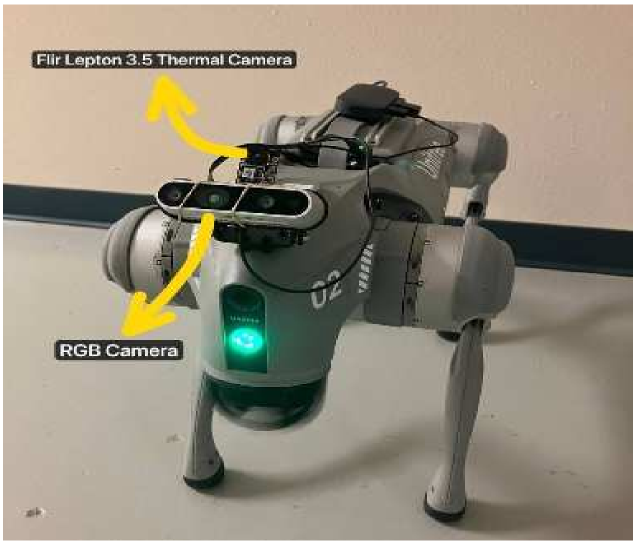

Fig. 3. RGB and Thermal Camera Mounted on the GO2 Edu Dog Robot

potential breaches. The reliance on merely an RGB camera could render the security system vulnerable to simple evasion tactics, such as the use of photographs or masks by intruders. In contrast, the thermal camera's deployment guarantees access is granted solely to verifiable, live individuals, leveraging their distinct thermal signatures for authentication.

V. RESULTS AND DISCUSSION

In this study, three examinations were conducted to assess the performance of the proposed system, which comprised RGB and thermal cameras mounted on a dog robot, under various scenarios. A total of ten individuals, including both males and females, participated in the tests to evaluate the system's effectiveness in recognizing and distinguishing authorized individuals.

The first test focused on the system's ability to detect familiar faces defined in the database under two different lighting conditions: fully light and completely dark environments. Remarkably, the integrated RGB and thermal camera system demonstrated exceptional proficiency in detecting familiar faces in both lighting conditions, as shown in Fig. 4.

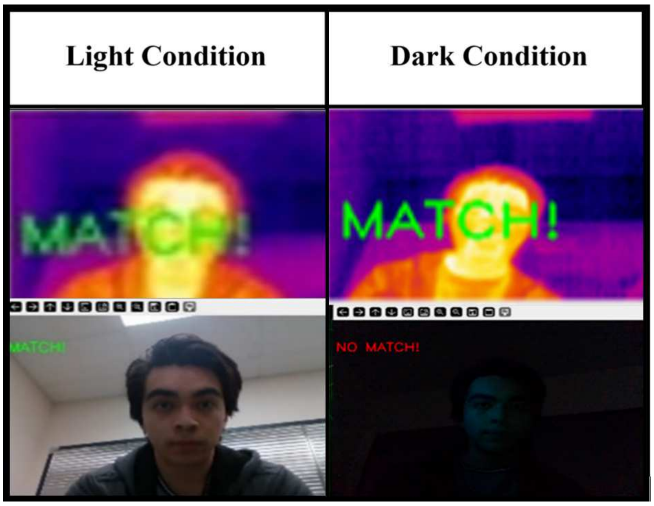

Fig. 4. Detecting a familiar face in various light conditions

In the second test, the system's capability to detect unfamiliar faces under similar lighting conditions was examined. Once again, the system excelled, particularly highlighting the significant contribution of the thermal camera in challenging lighting conditions where traditional RGB

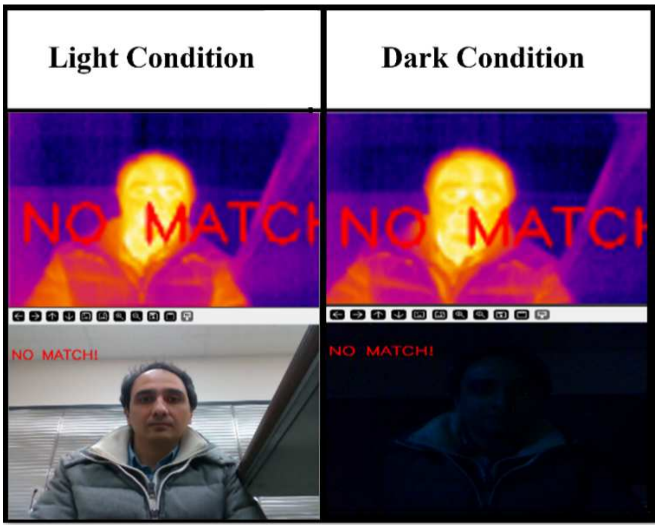

Fig. 5. Detecting an unfamiliar face in various light conditions

cameras might falter (Fig. 5). Notably, in the majority of cases (9 out of 10 individuals), the thermal camera alone successfully distinguished familiar faces from unfamiliar. Employing a thermal camera with higher accuracy could potentially yield even better results. In future studies, a higher-quality thermal camera will be utilized, and a larger group of people will be studied using this detection system for more precise result evaluation.

The final test was to showcase the system's flexibility in defining multiple faces as familiar within the database, indicating its potential for broader applications. This adaptability is particularly advantageous in environments with numerous personnel, where the system can be customized to recognize multiple authorized individuals, thereby enhancing security and accessibility.

The results of this test, illustrated in Fig. 6, demonstrated the system's capability to detect and differentiate between two authorized individuals and an unfamiliar person. This capability is crucial for security-sensitive areas, ensuring accurate identification of authorized personnel. By effectively utilizing both RGB and thermal imaging data, the system reliably authenticates individuals and enhances security against unauthorized access. Overall, these results underscore the versatility and effectiveness of the proposed system in various real-world security applications.

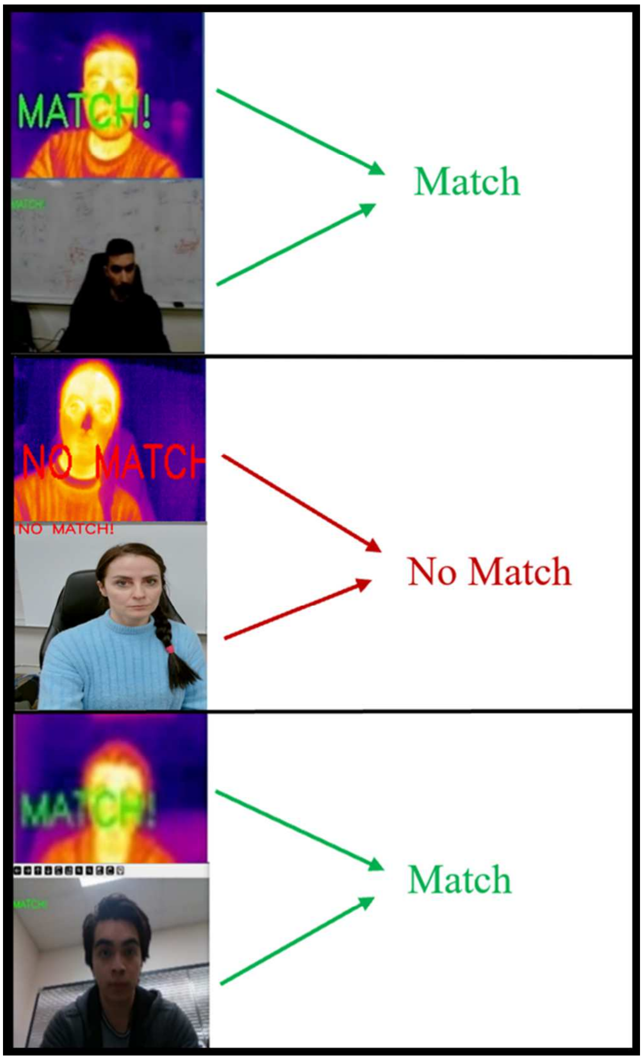

Fig. 6. Detecting two familiar faces (top and buttom) and one unfamiliar face (in the middle)

VI. Applications and Future Directions

There are several ways that this dog robot can be enhanced for threat detection and overall security purposes. One aspect focuses on improving threat detection capabilities, while another aims at enhancing the general performance of the dog. Below, some potential directions for these improvements are mentioned.

A. *Autonomous Recharging*

GO2 Dog Robot features wireless charging, enabling it to recharge autonomously by simply sitting on the charging station. This capability is essential for continuous operation without human intervention, enhancing operational efficiency and autonomy. Research highlights the importance of autonomous docking and recharging for mobile robots, ensuring they remain operational around the clock [25, 26].

B. *Multi-Robot Collaboration*

Incorporating multi-robot collaboration into our dog robot enhances its threat detection capabilities. This approach allows for distributed surveillance and task allocation, improving the efficiency and coverage of security operations. Collaborative efforts are further empowered by technologies like blockchain and machine learning, offering effective solutions against complex security challenges [27, 28].

C. *RFID Tag Detection*

Integrating RFID technology enables our security dog robot to swiftly distinguish authorized personnel from intruders. Equipped with an RFID reader, the robot scans for RFID tags, facilitating real-time identification and tracking. This technology, combined with cameras, enhances perimeter security and access control, proving instrumental in monitoring and responding to unauthorized intrusions [29, 30].

D. *Machine Learning for Threat Recognition*

Applying machine learning and image processing enhances our dog robot's ability to detect intruders and threats accurately. These techniques improve feature selection and classification, enabling the detection of various security threats with high accuracy. The integration of machine learning with surveillance technologies has revolutionized intrusion detection systems, offering robust security solutions [31, 32].

VII. Conclusion

This project highlights the seamless integration of SLAM, obstacle avoidance, and face recognition technologies within a security-focused robotic framework. It is determined that the addition of a thermal camera to the GO2 Edu dog robot has significantly enhanced its face recognition capabilities, enabling it to accurately distinguish between known and unknown individuals and maintain recognition accuracy across variable lighting conditions. The incorporation of thermal imaging is also validated as a crucial factor in the reliable performance of the security system.

Furthermore, the project's advancements in the field of autonomous navigation, through the application of SLAM with a Turtlebot, have been substantiated, providing a solid foundation for the GO2 robot's independent functioning. The robot's ability to autonomously map environments, navigate around obstacles, and recognize faces efficiently marks a substantial contribution to proactive security measures.

Looking forward, the study underscores the potential for future enhancements that could further refine the capabilities of autonomous security robots, shaping them into even more adaptable and intelligent guardians for our increasingly complex world.

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