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AdaptX: Autonomous Surveillance and Object Detection System using Jetson Nano and YOLOv9 for Real-Time Applications

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| **Article Information** | **ABSTRACT (11 PT, Bold, Center)** |
| ***Article history:***Received Revised Accepted | *AdaptX* is an independent object recognition and monitoring system for real- time navigation and tracking in dangerous environments. It utilizes the processing capabilities of Jetson Nano along with YOLOv9, a proven object detection model, to identify and categorize objects at high speed. As with other technologies, AdaptX employs LiDAR in combination with SLAM to improve recognition accuracy for distinct areas, enabling self-driven navigation through unstructured environments. Having human-defined scope boundaries visually defined, AdaptX tracks, recognizes, and features all dynamic changes autonomously while guaranteeing real-time observation and responsiveness to shift situations. These features allow prevention and situation control that enable early danger recognition. This allows for responsive active monitoring, situation awareness, and redundant execution of high-level commands for industrial control, public safety automated systems, and military applications. AdaptX offers situation understanding enhanced with autonomous decision control, revealing versatile application scope in threat recognition for border security systems. Field adaptations showcase how object recognition that tracks functionality greatly shifts the paradigm of surveillance missions leading to effortless operational perceiving transforming AdaptX perception. |
| **KEYWORDS:** YOLOv9, Robot Operating System, Object detection, Jetson Nano, LiDAR, SLAM. |

# INTRODUCTION

With real-time situational awareness and rapid response being critical for industrial safety, public security, and defense, autonomous surveillance architecture is becoming quite important. Unlike conventional/labor-intensive manual surveillance, these systems have to be highly accurate, flexible, and reliable, especially in hazardous environments. Solutions like AdaptX consolidate cutting-edge sensing, computing, and probing technologies to address these requirements for intelligent real-time accurate monitoring. AdaptX is built upon a powerful Jetson Nano design which enables fast processing, an absolute necessity for real-time processing. Its primary feature is powered by YOLOv9 deep learning model enabling fast and accurate detection of potential threats and anomalies. This allows the system to detect objects in real-time and make quick decisions when tarry is at stake. Leveraging YOLOv9 on Jetson Nano, AdaptX achieves an optimal balance between detection accuracy and cost-effective computing, ideal for edge deployments. Other than object detection, AdaptX also applies SLAM technology and LiDAR sensors to enable free from vehicle navigation.While SLAM updates the map and location within it, the LiDAR helps the robot to obtain information by sending pulses which help to detect obstacles and develop an image.

AdaptX is able to navigate under critical situations where the visibility is low. It avoids obstacles, gives accurate data of the surrounding using object detection with the help of YoloV9 model. These features help to navigate in high security and vulnerable situations where dynamic actions are needed to counter real time barriers. The core component of this architecture is the Robot Operating System (ROS) which enables interaction between various components and coordinates all the actions in real time. These capabilities such as path planning and navigation are only possible because of ROS. With such an organization. AdaptX offers a cost-effective and dependable solution for twenty-four-hour surveillance by minimizing reliance on manual operation, thus providing safer and more secure environments. The overall aim of the AdaptX project is further to develop autonomous surveillance through a synthesis of real- time navigation, adaptive decision-making, high- performance computation, and advanced object identification. Its design, underlying methodology, and performance are analyzed in this work with identification of possible applications in security- critical markets and possible enhancement of operational effectiveness and security.

# LITERATURE SURVEY

Applying Advanced Technology With the use of sophisticated technology including deep learning models, LiDAR, SLAM, and modular frameworks like ROS, real-time object detection, mapping, and autonomous navigation for surveillance are new areas in autonomous system design. The AdaptX project, which integrates various technologies to create a strong and flexible surveillance system, is highlighted in this literature review along with current research that is relevant to it. Certain studies and approaches are encapsulated in Table I, especially those that aim to improve autonomous navigation and object detection in restricted real-time situations.

Object recognition algorithms driven by deep learning, particularly from the YOLO (You Only Look Once) family of models, form the core research topic of literature reviewed. Due to the ability to achieve the right level of speed in addition to accuracy, models in this category have been immensely successful in real-time-constrained applications. The newest member of the YOLO family, YOLOv9, is edge computing-compatible cases with restricted computation resources because it has been optimized for high-speed processing on embedded systems like Jetson Nano. YOLOv9 is speedy in detection speed without sacrificing accuracy, according to research comparing it to comparable models like Faster R-CNN and SSD. This is very helpful for defense and security applications where real-time detection and processing speed are crucial. In addition, researchers have observed that YOLOv9 is adaptable enough to be used in a variety of surveillance situations ranging from dark industrial settings to lighted public areas. Literature also discusses how object recognition can be optimized through the use of multi-sensors and fusing multiple YOLO models into specific hardware designs. Model pruning, quantization, and other optimization methods that minimize model size and computational overhead but preserve accuracy are crucial, such as according to research on edge-based AI. These methods enable models such as YOLOv9 to meet the high expectations of real-time surveillance by providing high frame rates (usually above 30 FPS) on devices such as Jetson Nano.

Autonomous navigation is required for AdaptX to succeed in dynamic environments, excluding object detection. As research typically works, when SLAM and LiDAR sensors are combined, systems are able to map and locate themselves in real time when accurate spatial awareness is required. LiDAR sensors use laser pulses to calculate distance, producing holistic three- dimensional maps that are especially beneficial in unstructured environments where visual data alone might not be enough for safe navigation. Several SLAM algorithms like Hector SLAM, Cartographer, and Gmapping have been compared under different conditions, reporting data on mapping accuracy, computational efficiency, and suitability for real-time systems.

Studies on SLAM technology underscore the importance of localization accuracy and continuous mapping, especially in GPS-denied environments.

For autonomous systems to move around obstacles and respond to environmental changes, SLAM algorithms use LiDAR, camera, and other sensor information to construct and modify maps. A closer examination of various SLAM methods reveals that Cartographer excels at creating detailed, large environments with extremely high accuracy and is therefore suitable for complicated spaces. Hector SLAM has the capability to handle dynamic scenarios by offering fast paced and accurate output results. Hector SLAM makes a great choice to be integrated in AdaptX where real time detection and response is essential. With the highly secure capabilities, AdaptX keeps an eye on the surrounding and reports any mishap before its too late. The Robot Operating System (ROS) makes it possible to carry out the tasks. Robot Operating System (ROS) is a communication layer which is used to connect various components and establish communication between them such as camera and LiDar. ROS works on the publisher-subscriber model. The decentralized operation that is supported by ROS, makes it possible to run several models concurrently without interfering with each other. The tests have proved that ROS is extremely capable and useful in real time dynamic environments where it is essential to merge inputs, process data and generate outputs.

ROS makes sure that the input is merged and processed as and when it is received. This helps AdaptX to handle intense situations and help respond in challenging terrain with the need of human intervention.

This literature review highlights the importance of object detection and SLAM algorithms for autonomous surveillance in terms of such factors as accuracy, processing rate, and low-end hardware compatibility. This research offers a detailed examination of the technologies used such as real time object detection and navigation in dynamic environments especially in terms of reliability, accuracy and adaptability to the environment. The study considers the future developments incorporating better path planning and adaptive nature.

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| **Table I.** Literature Survey |
| **Sr. No.** | **Title** | **Methodology** | **Conclusion** |
| 1 | Application of intelligent UAV onboard LiDAR measurement technology in topographic mapping.[1] | In this study, the mapping of a region in Anhui Province was done with vegetation rate of 90% and a large terrain height change was accomplished through the KQ-PSM1500 airborne LiDARsystem mounted on UAV. | This paper adopts the point cloud data technique to visualize and scan the area using LiDAR. |
| 2 | LiDAR-Based Object-Level SLAM for Autonomous Vehicles.[2] | Simultaneous localization and mapping (SLAM) is considered an important technique for autonomous driving. Recently, the combination of image recognition techniques to generate maps has become a new trend in the SLAM research. | In this proposed work, SLAM technology was used along with 3D LiDAR’s to detect poles, walls and parked cars. |
| 3 | What is YOLOv9: An In-Depth Exploration of the Internal Features of the Next-Generation Object Detector.[3] | This study provides in depth information about the evolution of YOLO and its versions. It describes the architecture and training methodologies in depth which help to understand the underlying working of the model. |  Various advancements such as Generalized Efficient Layer Aggregation Network GELAN and Programmable Gradient Information PGI, have helped in enhancing the gradient flow and the feature extraction techniques. |
| 4 | A Comparative Survey of LiDAR- SLAM and LiDAR based Sensor Technologies.[4] | Simultaneous Localization and Mapping (SLAM) helps to fulfill the goal of localization and map creation which is based on self-recognition. LiDAR-based SLAM technology has advanced due to widespread use of LiDAR sensors in a variety of technological sectors. | LiDAR-based SLAM is introduced using its mathematical and graphical models. The three main features such as navigation, localization and mapping are discussed. |
| 5 | ROS based SLAM implementation for Autonomous navigation using Turtlebot.[5] | This paper presents the autonomous navigation of a robot using SLAM algorithm. Robotic Operating System (ROS) is used as a framework in the proposed paper. The robot is simulated in gazebo and Rviz used for data visualization. | Turtle bot was used in a simulated environment created withthe help of Gazebo for experimenting and implementing autonomous navigation. Methods used for navigation are SLAMand path planning algorithms |
| 6 | Optimal Path Planning using RRT\* based Approaches: A Survey and Future Directions.[6] | Optimal path planning refers to find the collision free, shortest, and smooth route between start and goal positions. This task is essential in many robotic applications such as autonomous car, surveillance operations, agricultural robots,planetary and space exploration missions | RRT\* have provedits worth for dealing with such complex problems. This paper presents review of major contributions in optimal path planning using RRT\* planning algorithm. |

# METHODOLOGY

After reviewing the literature, we found that for autonomy, optimal path, and object detection, three algorithms were used. In this section, we are discussing those algorithms.

## Implementation of the Rapidly Researched Random Tree (RRT) Algorithm for Path Planning

* + 1. **a Algorithm Design and Tuning**

The ability of the RRT algorithm to perform an efficient sweep of a vast space for a path between a start point and an end point makes it a central component of path planning. Toning down the algorithm to meet within the constraints and functionality demanded of a ground robot is the main goal of the RRT implementation project in AdaptX. Specifically, the algorithm considers the physical constraint of the robot, e.g., motion dynamics, speed limits, and turning radius. Python and the ROS library are utilized in coding these functions to maintain modularity and compatibility. Through random sampling of points from the task space, the RRT method is designed to construct the tree incrementally. A unique feature of the RRT scheduler for AdaptX emphasizes node expansion in risky regions so that the robot can select a safer and more efficient route. This configuration keeps detours to a minimum, which prolongs and makes trips more energy-intensive, and optimizes overall trip efficiency.

## Node Sampling and Tree Expansion Strategy

To improve path stability, AdaptX employs the use of an adaptive node sampling technique, which plays a vital role in RRT performance. A technique that tends to sample nodes in unvisited high-risk regions—particularly in scenarios with dynamic obstacles or in a dynamic terrain—is applied in place of raw random sampling. The technique applies processed LiDAR information in real-time to manage the node selection process and ensures the tree grows as safely and efficiently as possible. AdaptX has optimized its tree-growing reasoning to accommodate the computational capabilities of the Jetson Nano. To enable the algorithm to construct the tree efficiently without putting excessive processing load, this involves employing techniques like capping the number of maximum nodes and applying heuristics on the likely survivability of nodes.

## 3.1.3 Integration with Collision Detection Module

In addition to path planning, RRT AdaptX planner supports a module of collision detection in order to implement safety while navigating. The module utilizes OpenCV and ROS- compliant libraries for execution on sensor data of camera and LiDAR sensor and thus verifies real-time regarding environment around each selected node for observation of any encountered obstacles in sensor data. After an intersection is identified, the planner redirects the tree growth away from possible harm, removes the offending node, and compensates by choosing a new point. The path planning system can readily accommodate environment changes because with this integration, both effectiveness and security are preserved.

## SLAM (Simultaneous Localization and Mapping) for Real-Time Mapping and Localization

* + 1. **Selection of SLAM Algorithm**

AdaptX uses Hector SLAM and Cartographer in a two-SLAM strategy to balance speed and map quality. Hector SLAM is used because it has a requirement of fast updating that is required for the case of localization when moving at high speeds and in the case where rapid adaptation is critical. It can perform adequately based on LiDAR data alone and is therefore appropriate for GPS-denied environments. Cartographer, on the other hand, is utilized for its advanced mapping capabilities, which are of use in larger, more complex environments where detailed spatial data is needed.



Fig.1 Path planning on custom hector SLAM Map

These SLAM algorithms are deployed within the **ROS** framework, ensuring seamless interaction with other system components such as the object detection and path planning modules. The SLAM

nodes are configured to operate simultaneously but focus on different aspects of mapping: Hector SLAM for localization and Cartographer for detailed area mapping.

## Data Fusion from Multiple Sensors

For proper mapping and localization, AdaptX utilizes sensor data fusion of onboard cameras and LiDAR using ROS nodes that synchronize the data in real time through libraries such as robot\_localization for sensor fusion algorithms. LiDAR yields 3D point cloud data, which is used by both SLAM algorithms to detect surfaces and obstacles, and camera data provides visual context and helps correct for any inaccuracies that might arise from LiDAR-only mapping.

This mix improves map quality and guarantees that the robot can successfully navigate even when there are occlusions or dim lighting conditions, which could weaken camera performance on its own.



Fig. 2 Visualizing map in rviz

* + 1. **Handling Dynamic Environments** Dynamic scenes pose a main challenge to SLAM systems as they continuously evolve. To remedy this, AdaptX uses real-time map adjustment through LiDAR and camera feedback so the SLAM output can change dynamically as the robot navigates. A ROS driver controls the sensor configuration so there is smooth collection of data and integration into the system as a whole. For real-time response, the setup maximizes the update rate of the LiDAR, allowing the robot to quickly adapt to changes in the environment—an important consideration for effective autonomous navigation.

## LiDAR for Enhanced Obstacle Detection and 3D Mapping

* + 1. **LiDAR Hardware Configuration**

AdaptX consists of a LiDAR sensor which has the capabilities of taking real time data as input and processing it, which in turn provides the accurate information about the environment.

The LiDAR is placed tactically which maximizes the chances of scanning maximum surrounding area, making it possible to not miss any area.

The ROS driver is used for taking care of the integration of the sensor which ensures that the data is efficiently collected and processed. The real time response is optimized by optimizing the LiDAR update rate. By using this technique it possible to successfully integrate the LiDAR in AdaptX without facing any of the compatibility issues.

## Point Cloud Processing

Point Cloud Library (PCL) is used to convert LiDAR data into a structured point cloud to process it effectively. The ROS nodes are used to deal with the filtering of data and down sampling for efficient performance and to make sure that the information is successfully retained. The system maintains real-time updates by segmenting point cloud which helps to differentiate between obstacles and objects.[7]

The processed information is given as input into the object detection and SLAM modules, providing precise mapping, obstacle detection, and smooth navigation in dynamic environments. The real-time updates help the system to improve the adaptability of the robot and enables the robot to perform well in challenging situations where continuous monitoring and actions are required without any delay.

## Object Detection and Fusion

This step involves combining the output of the YOLOV9 object detection model and LiDAR generated data to enable object detection This helps the robot to build a relation between detected objects and their 3D spatial location using LiDAR and camera. Point cloud information and the outputs from object detection are used to enable system to learn and detect dangers, make navigation decisions and get information about the environment.

## ROS for modular system integration and coordination

* + 1. **Communication of ROS nodes** ROS is used as an essential middleware to establish and coordinate communication between various elements of the system. Every core capability, like path planning, object detection, and SLAM, is an independent ROS node. As a publisher-subscriber model is used, it is possible to directly exchange data without component dependencies.[8]

## Real-time data processing and synchronization

AdaptX takes advantage of multi-threaded ROS nodes that can simultaneously handle multiple streams of sensor data in order to ensure smooth working. For winnowing and interpreting sensor

data in the right order, synchronization—and this is done by the means of message filtering and timing via ROS—is a key feature. Through combined utilization of SLAM, object recognition, and navigation modules, the real-time data processing ensures smooth responses on behalf of the robot with great accuracy.[9]

# CONCLUSION

The AdaptX project illustrates the integration of Jetson Nano, YOLOv9, LiDAR, SLAM, and ROS to create an autonomous surveillance system that is able to detect objects in real time and navigate adaptively. Under difficult environments like defense, industrial processes, and disaster recovery operations, where autonomy and situational awareness are critical, the system performs tremendously well. Strength and ability under constrained hardware regimes are identified through the navigation and dynamic response abilities of AdaptX. Building the new standard of accuracy in autonomous surveillance and setting the course to other innovation developments like deep reinforcement learning and multi-sensor fusion, it manifests the suitability to deploy in tough, high-reward mission settings.

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