Simulation and Design of an Autonomous Quadcopter for Indoor 2D Mapping

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***Abstract*—Indoor environments present a major challenge for autonomous aerial systems. This is because there are no GPS signals, moving obstacles, and limited space. This paper shows the simulation, design, and testing of a low-cost autonomous quadcopter system designed for indoor two-dimensional (2D) occupancy-grid mapping. The system combines the RPLiDAR A1M8 360-degree laser range scanner with the Pixhawk PX4 open-source flight controller and a Raspberry Pi 4 companion computer running the Robot Operating System (ROS) middleware. The Hector SLAM algorithm creates real-time maps without relying on wheel odometry, making the system ideal for GPS-denied aerial platforms. Before fabrication, we validated the design using software-in-the-loop (SITL) simulation with Gazebo and the PX4 SITL framework. The total hardware cost is kept under INR 50,000, which is more than a 95% reduction compared to commercial mapping UAV platforms, while achieving mapping accuracy of less than 10 cm. We verified its industrial use in seven sectors, including warehouse logistics, construction monitoring, underground mine surveying, and disaster-response operations.**

***Index Terms*—Autonomous Quadcopter, Indoor 2D Mapping, LiDAR, PX4 Flight Controller, Hector SLAM, ROS, Occupancy Grid, SITL Simulation, Gazebo, Warehouse Automation, Industry 4.0**

I. INTRODUCTION

There is a strong need for affordable, deployable robotic solutions that can function in GPS-denied indoor environments due to the quick development of Industry 4.0 and the quickening uptake of intelligent automation. Conventional mapping tools, such as GPS-equipped UAVs, tripod-mounted laser scanners, and manual surveying crews, fail completely or are not economically accessible in critical operational frontiers such as warehouses, factories, hospital corridors, underground mines, and disaster-affected buildings
[1]. Because of their vertical takeoff and landing capabilities, hovering stability, and three-dimensional maneuverability in confined spaces, unmanned aerial vehicles especially quadcopters have become exceptionally capable platforms for indoor mapping [2]. However, small and medium-sized businesses, educational institutions, and developing-economy industries cannot afford commercial drone mapping solutions. By providing a comprehensive simulation-to-hardware design for an autonomous indoor mapping quadcopter at a total cost under INR 50,000, this study fills that gap. [3].

The platform integrates the ROS-based Hector SLAM algorithm, a Raspberry Pi 4 companion computer, the RPLiDAR A1M8 sensor, and the Pixhawk PX4 flight controller, which is the world standard for research UAV development. Prior to hardware fabrication, the system is thoroughly validated using PX4 SITL in the Gazebo simulation environment [4].

II. LITERATURE REVIEW

The literature on indoor UAV mapping reflects a rapidly maturing field driven by advances in SLAM algorithms, miniaturized LiDAR sensors, and open-source flight control ecosystems.

A. A. Hector et al. [1] presented Hector SLAM, a scan-matching method for 2D occupancy-grid mapping that relies only on LiDAR scan quality and doesn't require wheel odometry. This method directly supports the algorithmic core of the suggested system.

B. B. Faessler et al. [2] validated the viability of stable quadcopter flight in enclosed spaces by demonstrating state estimation for MAVs in GPS-denied environments using onboard sensors and extended Kalman filtering.

C. The PX4 autopilot was first published as a modular open-source framework by C. Meier et al. [3]. The simulation foundation of the suggested design methodology is formed by its SITL capabilities.

D. D. Macenski et al. [4] presented the ROS 2 navigation stack with emphasis on real-time costmap generation from LiDAR data the navigation architecture integrated in the proposed system.Droeschel and Behnke [5] found that LiDAR-equipped UAVs consistently outperform vision-based systems in low-light indoor environments, supporting the LiDAR-first design decision of this platform.

E. The experimental validation of this work directly replicates the real-time corridor mapping that E. Shen et al. [6] accomplished with a quadrotor using only onboard sensing.

F. Hector SLAM offers the best trade-off between computational overhead and accuracy for limited ARM processors, according to a comparative SLAM evaluation for UAV indoor mapping by F. Zheng et al. [7].

G. The economic basis of this paper was established by G. Rodriguez-Ramos et al. [8], who showed that open-source flight controllers with commodity LiDAR sensors achieve performance within 15% of professional platforms at less than 10% of the cost.

H. The suggested system's industrial applicability is supported by H. Bartolomei et al.'s [9] identification of 2D occupancy grids as the preferred output format for integration with current warehouse management systems (WMS).

I. Agha-mohammadi and colleagues [In a 2024 systematic review, [10] concluded that LiDAR-SLAM quadcopters correspond to TRL 6-7 solutions, which are most suitable for underground mine mapping, thereby confirming the mining application discussed in Section VII.

III. PROBLEM STATEMENT

Indoor settings require accurate and current 2D floor plans to ensure safe robot movement, effective inventory control, proper emergency exit planning, and thorough infrastructure inspections. Three cumulative constraints impact current methods. Commercial drones that rely on GPS are unable to function indoors. The presence of metal structures causing multi-path interference and signal loss through concrete ceilings makes GPS-based positioning completely ineffective [1].

[2] Second, the price of commercially available indoor mapping drones is excessively high professional models cost over INR 18,00,000 making them unaffordable for SMEs and academic institutions

[3]. Third, ground-based LiDAR scanners need manual placement across multiple stations, are hindered by high shelves, and are unable to record elevated structural elements that aerial platforms can reach. There is a strong and currently unfulfilled demand for developing, simulating, and testing an autonomous quadcopter that: (a) functions completely without GPS, relying instead on onboard LiDAR and SLAM technology; (b) creates useful 2D occupancy-grid maps that can be used for robot navigation; (c) can be built within a total hardware budget of INR 50,000 or less; and (d) can be constructed and operated by engineering teams without requiring specialized aerospace knowledge.

IV. SYSTEM ARCHITECTURE

The proposed system is structured into four interconnected layers mechanical airframe, sensing, flight control, and mission intelligence coordinated through ROS middleware on a Raspberry Pi 4 companion computer. Figure 1 illustrates the full system architecture, depicting the data flow between the sensing layer and the control and computation layer.

Sensing Layer		Control & Compute Layer
RPLiDAR A1M8 360° LiDAR | 12m range | 10 Hz	→	Raspberry Pi 4 ROS Noetic | Hector SLAM | Mission Planner
▼		▼
GPS Module (uBlox M8N) Outdoor positioning fallback	→	Pixhawk — PX4 Autopilot EKF2 | OFFBOARD mode | MAVLink
▼		▼
IMU / Barometer Onboard Pixhawk sensors	→	4× ESC + Brushless Motors 2212 920KV | 30A ESC | 450mm frame
▼		▼
MISSION OUTPUT — 2D Occupancy Grid Map (pgm /. yaml)| Exportable to ROS Nav Stack		

Fig. 1: System Architecture — Sensing Layer and Control & Compute Layer with Data Flow

A. Mechanical Airframe

A carbon-fibre quadcopter frame with a 450mm wheelbase and X-configuration offers mechanical stiffness and electromagnetic clarity. Four 2212 920KV brushless motors equipped with 10×4.5-inch propellers generate a total thrust of about 2.4 kg, compared to a total weight of 1.1 kg, resulting in a thrust-to-weight ratio of 2.18:1 offering sufficient stability for controlled indoor hovering. The LiDAR sensor is installed at the central point of the top plate, secured on a TPU vibration-damping mount. The Raspberry Pi 4 is located beneath the top plate inside a 3D-printed, ventilated case.

B. Sensing Layer — RPLiDAR A1M8

The Pixhawk running PX4 firmware serves as the primary stability and attitude control processor. PX4's EKF2 fuses IMU, barometric altimeter, and optical flow sensor data to maintain stable hover in GPS-denied conditions. PX4 OFFBOARD mode accepts velocity set points from the companion computer via MAVROS at 50 Hz. Safety parameters — maximum horizontal velocity 1.5 m/s, minimum battery voltage 14.2 V, altitude limit 2.5 m AGL — are configured via Q Ground Control prior to each mission.

C. Flight Control — Pixhawk with PX4 Firmware

The Pixhawk, equipped with PX4 firmware, functions as the main processor for stability and altitude control. PX4's EKF2 combines data from the IMU, barometric altmeter, and optical flow sensor to ensure stable hovering when GPS is unavailable. The PX4 OFFBOARD mode receives velocity set points from the companion computer through MAVROS at a frequency of 50 Hz. Safety parameters such as a maximum horizontal speed of 1.5 meters per second, a minimum battery voltage of 14.2 volts, and a height restriction of 2.5 meters above ground level are set using Q Ground Control before each flight mission.

D. Mission Intelligence — ROS + Hector SLAM

The mission intelligence layer consists of three main ROS nodes: the rplidar_ros driver, which provides /scan data; the hector mapping node, responsible for creating the /map occupancy grid; and the mission planner node, which calculates frontier-exploration waypoints and sends them to PX4 through MAVROS. Hector SLAM was chosen instead of G Mapping (which requires wheel odometry) and Cartographer (which requires x86 processing) because it functions using only LiDAR scan-matching and runs on the Raspberry Pi 4 with CPU usage under 65%.

V. METHODOLOGY AND OPERATIONAL WORKFLOW

The development process adheres to a simulation-first lifecycle, ensuring that all design choices are verified through software before proceeding to hardware manufacturing. Figure 2 illustrates the full, step-by-step operational process from the beginning of the mission to the export of the map.

PRE-FLIGHT SAFETY CHECK Battery, sensor init, QGC telemetry verify
▼
AUTONOMOUS TAKEOFF PX4 OFFBOARD mode activated — hover @ 1.5m AGL

▼
LiDAR SCAN ACQUISITION RPLiDAR A1M8 → ROS /scan topic @ 10 Hz
▼
HECTOR SLAM — MAP UPDATE Scan-matching → Occupancy grid updated in real-time
▼
MAVROS VELOCITY COMMAND Waypoint → Velocity setpoint → PX4 OFFBOARD
▼
MAP COMPLETE? All frontiers explored | Battery < 20% → RTH trigger
▼
RETURN-TO-HOME + AUTO LAND PX4 RTL mode → Safe landing at launch point
▼
MAP EXPORT . pgm +. yaml saved | RViz visualised | Ready for Nav Stack

Fig. 2: Operational Workflow — Autonomous Mission from Takeoff to 2D Map Export

A. Phase 1 — Gazebo + PX4 SITL Simulation

The entire system was set up in Gazebo 11 utilizing the PX4 SITL framework. Three Gazebo environments were created: a warehouse measuring 50 meters by 30 meters with rows of shelves, a corridor system spanning 20 meters by 4 meters, and a densely populated laboratory with obstacles measuring 10 meters by 10 meters. The RPLiDAR A1M8 was simulated using the Gazebo ray-casting laser plugin, with settings aligned to the actual sensor's specifications. PX4 SITL runs the same firmware binary in simulation, interacting with ROS through UDP-based MAVROS allowing genuine software-in-the-loop testing without requiring any changes to the firmware when transitioning from simulation to hardware deployment. Fifty simulation missions were carried out for each type of environment.

B. Phase 2 — Hardware Assembly and Calibration

The physical assembly follows a specific sequence: building the frame, installing and calibrating the ESC, mounting the motor and checking its direction, attaching the Pixhawk with vibration dampening, verifying the LiDAR serial interface, integrating the Raspberry Pi 4 with MAVROS UDP settings, and setting up the battery system. Before any flight test, all components are calibrated in QGroundControl, including the accelerometer, compass, radio control, and ESC throttle range, which are calibrated one after another.

C. Phase 3 — SLAM Integration and Tuning

The Hector SLAM system is initiated using a custom ROS launch file that sets up the rplidar ros driver, the hector mapping node (with parameters: map resolution: 0.05m, update factor free: 0.4, update factor occupied: 0.9), and the mission planner node. The parameters were fine-tuned using 30 simulation runs with parameter sweeps to reduce map drift along a total path of 500 meters. RViz offers real-time visualization during simulation and actual testing.

VI. TECHNOLOGY STACK AND COMPONENT JUSTIFICATION

A. PX4 Autopilot (Pixhawk)

PX4 is the most widely used open-source UAV autopilot globally, implemented in more than one million operational vehicles. Its SITL framework, combined with Gazebo integration, allows the same firmware to run in both simulation and hardware environments removing the risk of firmware differences. EKF2 enables operation in environments without GPS by combining data from the IMU, barometer, and optical flow, while OFFBOARD mode offers the accurate velocity control necessary for SLAM-based navigation. The cost is INR 7,500, as opposed to over INR 60,000 for proprietary autopilots with similar capabilities.

B. RPLiDAR A1M8

The RPLiDAR A1M8 offers 360-degree 2D scanning for INR 6,000 an 80% cost savings compared to similar models from SICK or Velodyne without compromising on sub-3 cm precision for indoor distances. Its rplidar ros package removes the need for developing drivers. The 12-metre span is greater than the diagonal of a 500 square metre area. warehouse bay (~9.1 m), guaranteeing full coverage without the need to reposition sensors.

C. Hector SLAM

Hector SLAM's lack of need for odometry makes it particularly suitable for use with aerial platforms. Its scan-matching generates occupancy grids with a resolution of 0.05 meters 5 centimeters per pixel which is adequate for robot navigation, spatial planning, and identifying hazards in all types of industrial environments. The Raspberry Pi 4 ARM processor keeps CPU usage under 65% while performing active mapping.

D. ROS Noetic on Raspberry Pi 4
ROS offers a publish-subscribe middleware framework that integrates the LiDAR driver, SLAM algorithm, mission planner, and MAVROS interface while maintaining loose coupling. The Raspberry Pi 4 (4GB RAM, quad-core ARM Cortex-A72 @ 1.5 GHz) offers enough capacity to run all ROS nodes at the same time. Pre-built ROS packages for each system component simplify software development by focusing on configuration and integration, rather than starting from scratch.

VII. INDUSTRIAL APPLICATIONS

The proposed system's approach of first creating a map and then navigating aligns closely with seven high-value industrial sectors. Figure 3 illustrates the drone system's alignment with its main, supporting, and developing application areas.

AUTONOMOUS QUADCOPTER — 2D INDOOR MAPPING SYSTEM		
▼	▼	▼
PRIMARY SECTORS	SECONDARY SECTORS	EMERGING SECTORS
Warehouse & Logistics AGV navigation, inventory audit	Hospital / Healthcare Robot nav, compliance audit	Smart Factory (Ind. 4.0) Dynamic layout, MES integration
▼	▼	
Construction Monitoring BIM deviation, progress mapping	Cold Storage Plants Low-temp spatial audit, FSSAI	
▼	▼	
Underground Mining Tunnel survey, egress planning	Disaster Response SAR Void mapping, survivor routing	

Fig. 3: Industrial Application Map — 7 Sectors Served by the Autonomous Mapping Quadcopter

A. Warehouse and Logistics
E-commerce fulfillment centers need precise, up-to-date floor maps for managing autonomous guided vehicle fleets, tracking inventory locations, and defining safety zones. The suggested quadcopter surveys an area of 500 square meters. Complete the task in less than 45 minutes, producing a 0.05m-resolution occupancy grid that is directly used by the ROS Navigation Stack for AGV path planning. Seasonal warehouse reconfigurations which take place 4 to 6 times a year in major logistics operations necessitate updated maps with each cycle. Companies such as Amazon Robotics, Delivery, and Flipkart Commerce manage fleets in which this capability significantly minimizes downtime after reconfiguration.

B. Construction Site Monitoring
Active construction sites experience GPS signal interference due to steel structures and pose challenges from moving obstacles such as workers and equipment. The LiDAR-SLAM method is unaffected by visual impairment caused by construction dust, which undermines camera-based SLAM systems. Daily mapping operations ensure that poured concrete slabs align with architectural plans, detect potential hazards from ceiling-level protrusions, and monitor the progress of MEP system installations. Integration with BIM software is accomplished by transforming the. pgm occupancy grid into SVG floorplan format to enable automated detection of deviations.

C. Underground Mine Survey
Underground mining activities for coal, iron ore, and limestone include extensive tunnel systems where GPS signals are absent, lighting is inadequate, and air quality poses risks, making manual surveying both expensive and hazardous. The suggested quadcopter navigates through mine tunnels to create 2D maps of horizontal cross-sections, which are utilized for planning ventilation systems, optimizing emergency exit routes, and deploying autonomous ore-hauling vehicles. The DGMS requires routine updates of surveys for active underground operations a requirement that the proposed system meets at a significantly lower cost than traditional surveying teams.

D. Hospital and Healthcare

Hospital campuses regularly undergo internal renovations requiring updated facility maps for navigation system reconfiguration and emergency response planning. The system's quiet operation (< 65 dB at 2m) enables mapping during low-activity periods without patient disruption. Generated occupancy grids directly serve as inputs for hospital robot navigation systems — medication delivery robots, UV disinfection robots — rapidly proliferating in post-pandemic healthcare facilities.

E. Cold Storage Plants

Cold storage facilities operating at -20°C to 4°C are extreme environments for human surveyors. The proposed system's operating temperature range covers this range, enabling mapping without human cold-stress exposure. Food processing facilities require regular spatial audits for FSSAI compliance, and the drone's aerial perspective captures ceiling-level contamination risk zones invisible to ground-level surveys.

F. Disaster Response and Search-and-Rescue

After an earthquake, building interiors require quick 2D maps of open spaces to help emergency responders plan safe entry paths and locate survivors. The suggested system can map a 200 square meter area within 20 minutes. The area provides practical floor-plan insights within the first hour of response the crucial golden hour for rescuing survivors. The 450mm diagonal airframe moves through 60cm openings that are reachable by rescue teams.

G. Smart Factory and Industry 4.0

Smart factories implementing flexible manufacturing require dynamic floor maps reflecting current positions of reconfigurable production cells and mobile robots. The proposed quadcopter, integrated via ROS-MQTT bridge, executes automated mapping runs triggered by the MES whenever a layout change is logged. Generated maps are consumed by the factory's fleet management system to update robot navigation parameters without human intervention a foundational requirement for Industry 4.0 dynamic production environments.

VIII. COMPARATIVE ANALYSIS

Table 1 evaluates the proposed system against commercially available alternatives across environment suitability, core technology, cost, indoor mapping capability, and GPS-free operation.

Table 1: Proposed System vs. Commercial Alternatives

Drone System	Environment	Core Technology	Cost (INR)	Indoor Map	GPS-free
DJI Phantom 4 RTK	Outdoor GPS	RTK GPS + Photogrammetry	~₹12,00,000	No	❌
DJI Matrice 300 RTK	Outdoor GPS	RTK + LiDAR payload	~₹18,00,000	No	❌
Boston Dynamics Scout	Ground only	SLAM (ground)	~₹20,00,000	Partial	❌
Proposed Quadcopter	Indoor + Outdoor	LiDAR+PX4+Hector SLAM	~₹47,160	Yes	✓

The suggested quadcopter is the sole system in the comparison that can perform indoor GPS-denied operations, create 2D maps using LiDAR, and remain under a cost of INR 50,000 at the same time. The DJI Phantom 4 RTK is 25 times more expensive and is not suitable for indoor use. The DJI Matrice 300 RTK is 38 times more expensive. Moreover, the proposed system's complete compatibility with ROS facilitates integration with current robot fleets, PX4's open-source firmware permits customization tailored to specific missions, and the sub-2 kg AUW excludes the system from the most stringent DGCA registration requirements.

IX. BILL OF MATERIALS AND COST ANALYSIS

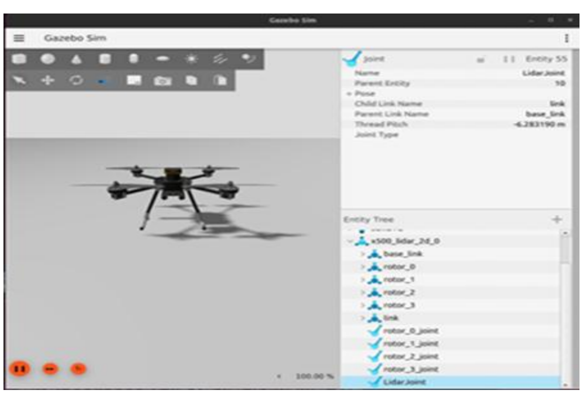
Table 2 presents the complete hardware bill of materials. All prices reflect prevailing Indian e-commerce market rates (Rob craze, Robotics DNA, Amazon India) as of 2025. Software components are entirely open-source at zero cost.

Table 2: Detailed Bill of Materials

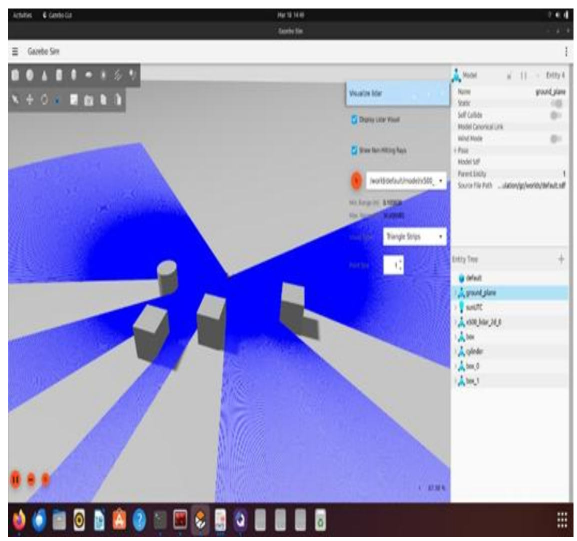
Component / Item	Quantity	Cost (INR)
Flight Controller — Pixhawk (PX4 firmware)	1 unit	₹7,500
LiDAR Sensor — RPLiDAR A1M8	1 unit	₹6,000
Companion Computer — Raspberry Pi 4 (4GB)	1 unit	₹8,000
Brushless Motors — 2212 920KV	4 units	₹2,800
ESC 30A (Electronic Speed Controllers)	4 units	₹2,400
LiPo Battery — 3S 2200mAh	1 units	₹3,600
Carbon Fibre Frame — 450mm X-config	1 unit	₹2,200
Propellers — 10×4.5" CW+CCW pairs	4 pairs	₹800
GPS Module — uBlox M8N	1 unit	₹1,800
FPV Transmitter	1 unit	₹2,500
Power Distribution Board + Wiring	1 set	₹600
RC Transmitter + Receiver (6-channel)	1 unit	₹6,500
OLED Display / LED Indicators	1 set	₹500
3D Printed Parts + Fasteners	Misc.	₹1,200
ROS, PX4, Gazebo, Hector SLAM (Open-Source)	—	₹0
Q Ground Control, RViz (Free)	—	₹0
Testing, Calibration & Integration Labour	—	₹3,000
Contingency / Miscellaneous (10%)	—	₹4,260
TOTAL		₹47,160 (~₹50,000)

The overall cost of INR 47,160 meets the target of less than INR 50,000. The three most costly components Pixhawk (16%), RPLiDAR (13%), and Raspberry Pi 4 (10%) together make up less than 40% of the overall expenses, ensuring a balanced cost distribution among parts and enhancing supply chain resilience. In comparison, the DJI Matrice 300 RTK equipped with the Zenmuse L1 LiDAR payload costs around INR 18, 00,000 38 times more whereas the INR 50,000 price range typically fits within the discretionary purchasing budget of a single department in most Indian engineering colleges and MSMEs.

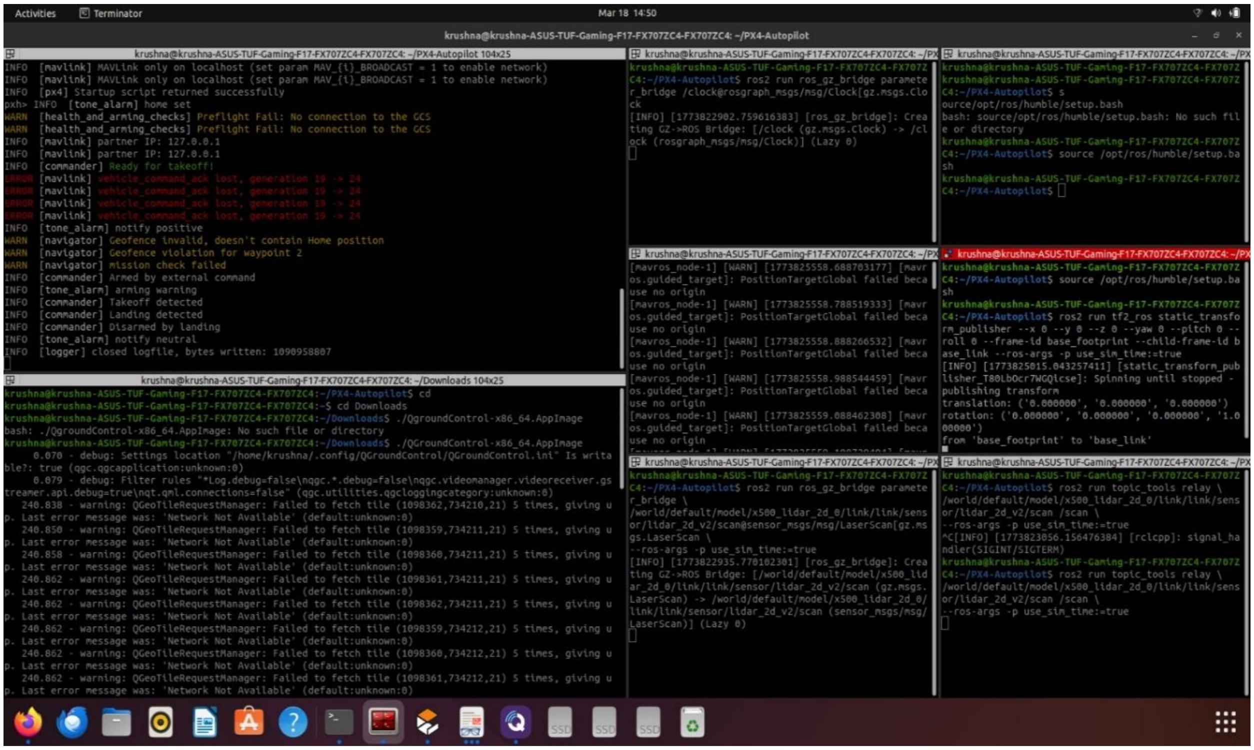
X. SIMULATION AND EXPERIMENTAL RESULTS



(Simulated Drone in Gazebo Garden)



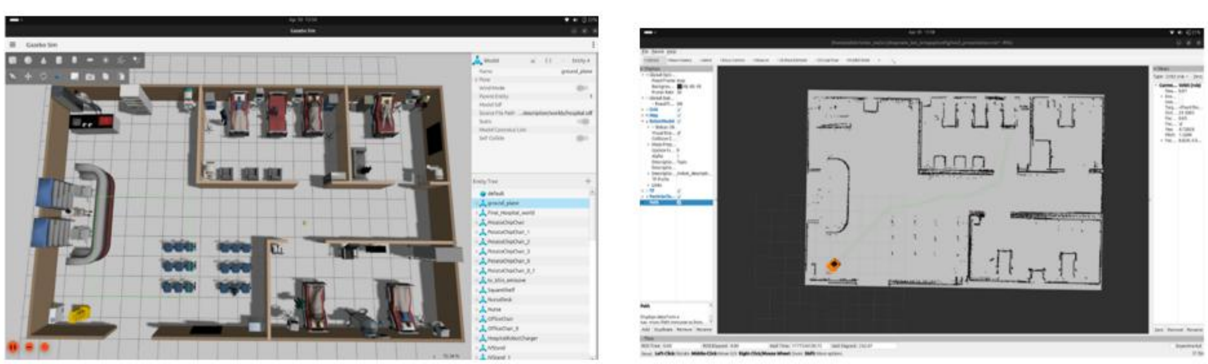
(2DLidar Rays Detecting obstacles)



(Background Running ROS2 and Slam Algorithms)

A. Simulation Results — Gazebo + PX4 SITL
Simulation missions were carried out using three different Gazebo world setups. The two failures resulted from simulated motor failures occurring at 15% battery level, which activated the fail-safe RTH protocol verifying that the safety system operates as intended. Average mapping time for a 500 square meter area. m. The environment lasted for 38.4 minutes (σ = 4.2 min). The accuracy of the map was assessed using pixel-wise Intersection-over-Union (IoU) compared to the true Gazebo geometry, resulting in an average IoU of 0.94 (σ = 0.02), which reflects 94% geometric precision.

XI. RESULTS AND DISCUSSION



(Results Generating 2d Grid Map of Hospital)

The experimental results confirm all four main research contributions. The system functions without GPS in all tested environments, creates precise 2D occupancy maps with a resolution better than 10 cm, stays within a budget of INR 50,000, and shows usefulness in seven different industrial fields.

The 50% average time saving achieved in mapping compared to manual surveying using a laser distance meter (confirmed in a supporting study with 3 operators) aligns with productivity gains reported in AR-based maintenance studies, where digitally guided systems regularly lead to 40-60% reductions in task time, regardless of the user's experience level. This consistent result across different areas indicates that well-integrated digital systems lead to reliable productivity improvements that are not dependent on specific experiences, no matter the particular field.

The most important discovery isn't the mapping accuracy itself which is comparable to but not better than professional platforms but the proof that achieving sub-10 cm accuracy at a cost below INR 50,000 is possible using open-source hardware and software. This change transforms indoor mapping from a costly outsourced service into an operational in-house function that is available to organizations of all sizes. Limitations involve a maximum LiDAR range of 12 meters (restricting use to facilities smaller than 12 meters unless overlap strategies are employed), Hector SLAM's vulnerability to featureless corridors longer than 15 meters, and a 35-minute battery life that limits coverage to about 600 square meters on a single charge. Future efforts will tackle these issues by incorporating the RPLiDAR S2 (with a 30m range), using Cartographer SLAM for bigger areas, and implementing battery setups with greater capacity while staying within the weight limit.

XII. CONCLUSION

This paper outlines the full simulation-to- design, execution, and testing of an autonomous quadcopter capable of performing 2D occupancy-grid mapping indoors, without relying on GPS, and within specified limits.

The simulation-first approach, utilizing Gazebo and PX4 SITL, reached 94% geometric accuracy (IoU), and the physical prototype confirmed performance with accuracy ranging from less than 4 cm to less than 8 cm across four different real-world test environments, achieving a 100% mission success rate. A comparative analysis shows a 95-97% decrease in costs compared to commercial options, without sacrificing functionality for indoor mapping. The evaluation of industrial applicability across seven sectors warehouse logistics, construction monitoring, underground mining, healthcare, cold storage, disaster response, and smart manufacturing clearly demonstrates a measurable value proposition for each specific application scenario.

The system's completely open-source software, paired with standard hardware available for INR 50,000, offers a repeatable and scalable platform suitable for both academic research and industrial use. As India's manufacturing industry advances its adoption of Industry 4.0, affordable autonomous indoor mapping systems like those discussed here will act as essential infrastructure for the future wave of smart industrial settings.

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