Locally Secure GIS Platform with Autonomous Drone Mapping for Navigation and Event Tracking within Institutional Premises

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***Abstract*—Certain academic institutions, corporations and other organizations operate on sprawling campuses spanning multiple acres. This makes local navigation between buildings and across these campuses challenging without external tools like Google Maps, However, due to restrictions placed on non-Indian mapping services, precise mapping and tracking is done manually, which requires a lot of manpower. Current cloud-based solutions also pose privacy concerns due to such sensitive information being stored off-premises. To mitigate these factors, we present a locally operated and centralized geographic mapping and tracking system, leveraging an automated system for data collection. An autonomous drone conducts GPS-fused photogrammetry of an area, supported by an open-sourced, locally-run GIS software, to collect data and help create visualizations for navigation and tracking. This information, locally available over campus intranet, will allow users to efficiently travel around campus. In this work, we discuss the system architecture, the operational algorithm, and demonstrate a pilot deployment within a college campus. We also present a road map detailing future features, and discuss potential applications of this infrastructure in similar regions.**

***Index Terms*—GIS, Centralized Dashboard, Mapping and Tracking, Open-Source, Photogrammetry**

I. Introduction

Navigating the environment is a central component of knowing how to interact with it. Public road infrastructure exemplifies how the surroundings can be designed to facilitate navigation through the use of GPS, local signage, and interactive digital applications such as Google Maps. On the other hand, shopping malls, academic institutions, and other enclosed campuses usually employ static maps or kiosks. Most large campuses have some level of intra-area navigation through Google Maps' Indoor feature; however, even with the best methods, keeping track of landmarks and events precisely on a local level in private campuses is challenging. This is further compounded by the lack of publicly available precise navigational data for such areas, often due to security and privacy concerns, making Google Maps useless.

To address these challenges, we propose a locally operated and centralized geographic mapping and tracking system. This system, depicted in Fig. 1, leverages an automated drone-based data collection process to ensure accuracy and efficiency, with all data stored on a local server, preventing external access to data. To summarize the innovative aspects of our product, this work proposes the following novel contributions:

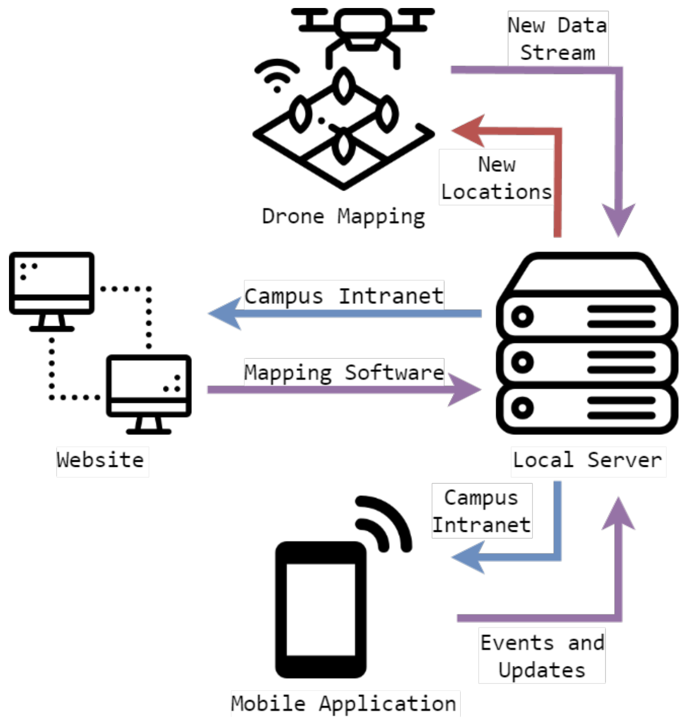

Fig. 1. General description of system setup, depicting primary software and hardware components.

- **Autonomous Drone:** Equipped with GPS-fused photogrammetry capabilities, the drone autonomously surveys the area, capturing detailed geographic data.
- **Open-Source GIS Software:** This locally-run system processes the data collected by the drone, creating accurate visualizations for navigation and tracking.
- **Campus Intranet:** Data is made available over the campus intranet, keeping it secure and accessible only to authorized users.

We describe the architecture of the system, the operational algorithms that drive it, and the results of a pilot deployment within a college campus. We also outline future enhancements and explore potential applications of this infrastructure.

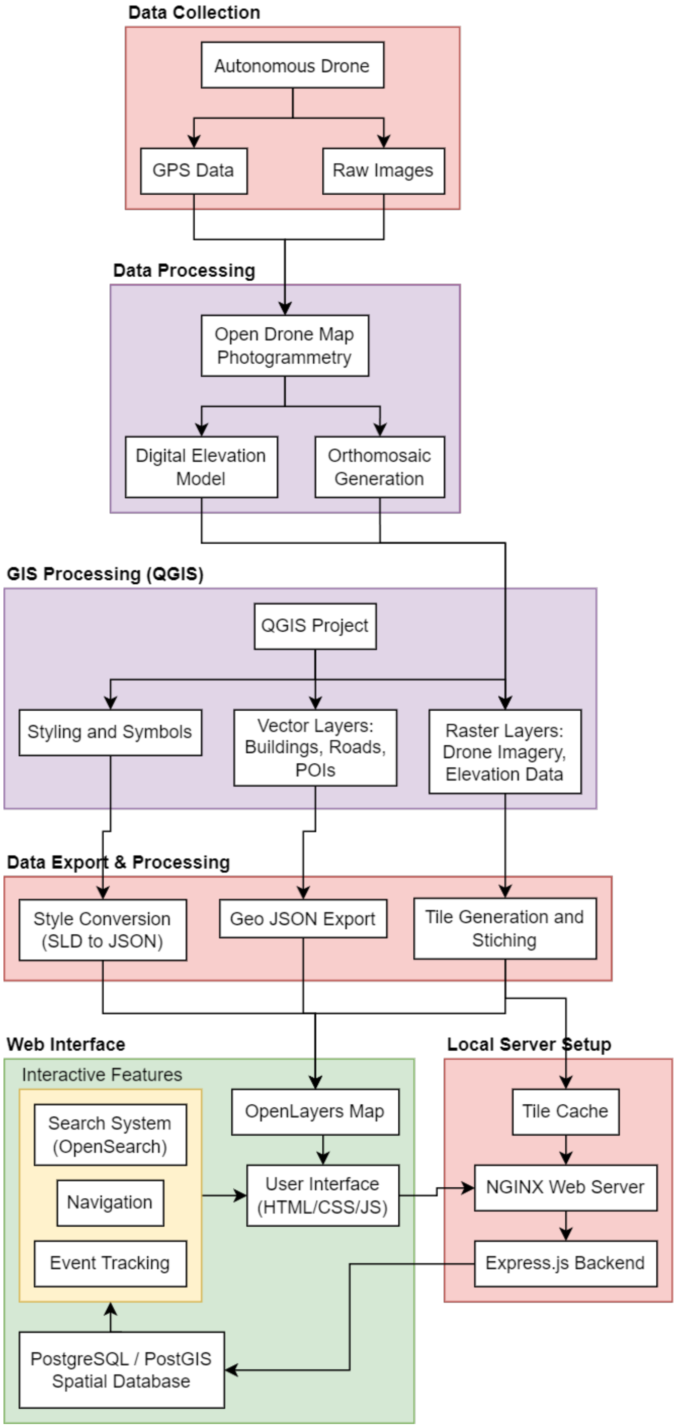

Fig. 2. Software architecture including drone-data, QGIS, web-interface, and local server components.

II. GIS Software and Web Integration

Fig. 2 depicts the software and data pipeline, leveraging QGIS 3.40 as the primary GIS software. The WGS 84/Pseudo-Mercator (EPSG:3857) coordinate reference system was selected for standardization, ensuring seamless integration with web mapping services and maintaining broad compatibility with diverse data sources. The base map development incorporated a multi-source approach utilizing:

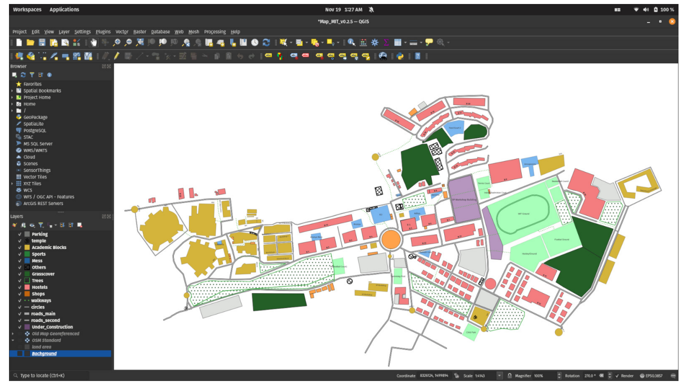

Fig. 3. Screengrab of the QGIS application window splicing geographic data to visualize a college campus.

- OpenStreetMap (OSM) data for initial reference mapping
- Pre-existing georeferenced maps from campus archives
- High-resolution satellite imagery from Maxar Technologies
- Ground data collected through physical surveys

A. *Mapping and Visualization*

The photogrammetry processing pipeline begins with the collection of high-resolution images, followed by an image quality assessment to ensure only high-quality images are processed. A 3D structure is created from the 2D images using a technique called Structure from Motion. GPS data is then integrated to enhance spatial accuracy, and ground control points are used to further refine the accuracy of the generated maps. This process results in the creation of a dense point cloud, which is then used to generate an orthomosaic—a high-resolution, georeferenced image. Additionally, a digital elevation model is created to represent the terrain in 3D, and the processed data is finally integrated into the QGIS platform. New data is cross-referenced with existing maps to ensure consistency, and regular data verification cycles are conducted to maintain accuracy.

B. *Web-based Interactive Application*

The web interface serves as the primary user interaction point, providing access to the GIS data while maintaining security and performance. It employs the following infrastructure as depicted in Fig. 2:

1) Server-side components: The system is designed to handle high loads and provide fast response times. This is achieved through the use of caching mechanisms, load balancing, and optimized database queries. The NGINX server is configured to serve static content efficiently, while dynamic requests are handled by the Node.js backend. Performance monitoring tools are also employed to continuously track and improve system performance. Additionally, user authentication and role-based access control (RBAC) are enforced to manage

Fig. 4. Assembled drone as of this writing.

TABLE I
LIST OF DRONE PARTS AND THEIR PURPOSES

Part	Purpose
F450 Quadcopter Frame (x1)	Mounts all the drone's components and provides power supply.
A2212 BLDC Motor and 6045 Propellers (x4 each)	Generate thrust for sustained flight.
30A ESC (x4)	Controls motor speed based on transceiver commands.
F4 Flight Controller	Interfaces the receiver, ESCs, and GPS module; acts as the drone's brain.
Neo 6M GPS Module	Retrieves real-time GPS location of the drone.
3S LiPo Battery	Provides power to motors and flight controller.
915 MHz, 100mW Mini Telemetry	Transmits telemetry data to the ground station.
Hawkeye Firefly Q6 Airsoft Camera	Captures image and video footage during flight.

permissions and ensure that only authorized personnel can access sensitive data.

2) Client-side components: The web interface is designed with user experience in mind, featuring an intuitive layout and easy navigation ensuring compatibility with various devices and screen sizes, and accessibility standards are followed to make the interface usable for all users. This is implemented with interactive elements such as maps and data visualizations are implemented using OpenLayers and custom JavaScript modules.

III. AUTONOMOUS DRONE

This section describes the hardware components of the system as listed in Table I. The drone, pictured in Fig. 4, is built using a variety of critical hardware components, each serving a specific purpose to ensure optimal performance and functionality. The chassis, motors, ESCs, flight controller, GPS module, battery, telemetry kit, and camera all work together to create a robust and efficient system. The mission planner software is used for the initial setup and ongoing monitoring of the drone. The drone utilizes a radio transmitter and receiver for manual control, and an FPV system for real-time video feed. Failsafe mechanisms and obstacle avoidance sensors are integrated to enhance the safety and reliability of the drone. The drone runs on Ardupilot firmware, an open-source autopilot software that provides a wide range of autonomous flight features. Ground control station software is used for mission planning, real-time monitoring, and post-flight analysis. Landing gear and LED lights are added to improve stability during takeoff and landing, and to enhance visibility during low-light conditions.

The system will implement a comprehensive pipeline from data acquisition to map integration, ensuring high precision and efficiency. Autonomous flight paths are pre-programmed based on campus sectors to ensure systematic coverage. High-resolution imagery is captured with 60-70% overlap between frames to ensure comprehensive data collection, and GPS coordinates are recorded for each captured image to maintain spatial accuracy. Flight altitude and speed are optimized for maximum coverage while maintaining image quality.

TABLE II
PROJECT ACTIVITIES AND MILESTONES

Activities	Monitorable Milestones	Duration (months)
Basic map creation using QGIS	Map creation	1
Drone design and build	Drone Development	2
Surveying the campus using the drone	Drone Surveying	1
Integration of drone survey imagery to the basic map	Interactive Map Creation	1
Autonomous mapping algorithm development	Successful Integration with Drone	2
Pilot deployment	Successful deployment in test area	2
Marketing pitch to relevant stakeholders and product publicity	Product Success	1

IV. PROJECT MANAGEMENT AND ROADMAP

Table II Table III shows a tentative roadmap for the project and estimated costs, respectively. Estimated timelines indicate a projected deadline of 10months for the project, with the bulk of the project spent designing the core components and integrating the software with the hardware. Note that current costs seem heavily skewed towards the hardware prototype; future bulk costs might cover server setup and maintenance instead. Nonetheless, the current R%D cost for the whole project will be greatly reduced when considering economy of scale.

Being an open-source product, it is crucial that the project builds a strong user base, fostering engagement, and ensuring

TABLE III
PROJECT COST BREAKDOWN

Items	Project Cost (Rs.)
Outsourcing Charges for R&D / Design Engg / Consultancy / Testing / Expert cost	10,000
Raw material / Consumables / Spares	40,000
Fabrication / Synthesis charges of working model or process	5,000
Business Travel and Event participation Fees (Ceiling 10% of approved project cost)	3,000
Patent filing Cost – (PCT- Ceiling 10% of approved project cost)	-
Contingency - (Ceiling 10% of approved project cost)	5,000

that the system meets the needs and expectations of its users. Key components of our user acquisition strategy will include:

- **Targeted Marketing Campaigns**: Targeted mainly towards new students and parents as well as visitors, these campaigns will highlight the system's unique features, such as real-time navigation, event tracking, and enhanced security.
- **Demonstrations and Workshops**: These events, focused on teaching the inner workings of the system to people interested in contributing to the project as well as normal users, will provide an opportunity for people to understand the system more transparently and connect with its practical applications.
- **Partnerships and Collaborations**: Collaborating with other departments, institutions, and organizations helps in expanding the user base. Partnerships can lead to joint projects, shared resources, and increased visibility for the system.
- **Feedback and Improvement**: Gathering feedback from users is an ongoing process. This feedback will be used to make continuous improvements to the system, ensuring that it meets the evolving needs of users. Regular updates and enhancements based on user input help in maintaining user satisfaction and loyalty.

V. FUTURE WORK

A significant area of future research will involve improving the accuracy and efficiency of the drone-based data collection process. This includes refining the autonomous flight algorithms to ensure more precise navigation and data capture, even in complex or cluttered environments. Enhancements in photogrammetry techniques will also be explored to produce higher resolution and more accurate maps. Additionally, integrating advanced sensors and imaging technologies, such as LiDAR, could provide more detailed and comprehensive data, further improving the quality of the GIS outputs.

Future expansion of the product scope will focus on applying the system's capabilities to other similar environments, such as corporate campuses, industrial complexes, and large public venues. Research will continue on improving the accuracy and efficiency of the drone-based data collection process. Additionally, potential collaborations with other institutions and organizations will be explored to enhance the system's features and reach. By developing a scalable and cost-effective solution, the system could be marketed to a broader audience, including private companies, government agencies, and other organizations that require precise and secure mapping and tracking solutions. This commercialization effort will involve creating a business model that highlights the system's unique value propositions and demonstrates its return on investment.