

# An Autonomous Fixed-Wing UAV System for Automatic Payload Delivery and Linear Surveillance

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**ABSTRACT**

This paper describes the development of an autonomous fixed-wing Unmanned Aerial Vehicle (UAV) system designed for linear area monitoring and precise payload distribution. The proposed system can be implemented in border surveillance, precision agriculture, and disaster response scenarios by integrating a servo-based payload drop mechanism, GPS waypoint navigation, and real-time image capture. It is ideal for long-distance missions due to its fixed-wing configuration, allowing longer flying times. Post-flight, to

create panoramic picture mosaics, recorded videos are processed using computer vision techniques, namely Scale-Invariant Feature Transform (SIFT) and homography methods. The ground evaluations verified the UAV's capacity to fly steadily, deliver payloads precisely, and process images. Consequently, it demonstrated for the first time in a lightweight, low-cost fixed-wing platform, the integration of fully autonomous waypoint-guided payload delivery and image-based linear surveillance within a single mission. This dual-function capability, validated through real-world flight tests and panoramic mapping, offers a scalable solution for fast deployment in disaster relief, border security, and precision agriculture.

*Keywords-fixed-wing UAV; autonomous payload delivery; linear surveillance; Gps navigation; servo mechanism; image stitching; computer vision; SIFT; panoramic mapping*

## I. INTRODUCTION

UAVs, commonly referred as drones, are increasingly employed across various sectors, including logistics, agriculture, infrastructure inspection, environmental monitoring, and disaster response. In contrast to the unsafe and inefficient traditional methods, UAVs possess the ability to access remote locations and deliver real-time data. Additionally, fixed-wing platforms, which constitute a UAV type, offer significant advantages for long-range operations. This is attributed to their aerodynamic efficiency, extended flight endurance, and higher payload capacity compared to their rotary-wing counterparts.

The effectiveness of fixed-wing UAVs has been demonstrated in a diverse range of applications. For example, UAVs have been developed for disaster area observation and mapping, autonomous payload delivery, and medical supply transport [1-4]. In [5-7], the integration of AI and vision-based systems is explored to enhance the autonomous navigation, landing, and obstacle avoidance capabilities. Advanced control algorithms, such as model predictive control and complementary filtering, have been employed to improve the flight stability and precision in small-scale UAV platforms [8-10]. Furthermore, innovations in the design and fabrication, ranging from modular architectures to VTOL configurations, have expanded the UAV capabilities in both research and field deployments [8, 11-13]. In [14], UAVs are utilized for aerial mapping with systems, achieving high positional accuracy by incorporating the Global Navigation Satellite System (GNSS), Ground Control Points (GCPs), and photogrammetry techniques.

Nevertheless, most existing UAV systems are purpose-built for either payload delivery or surveillance tasks, limiting their flexibility in dynamic, real-world missions. High-cost systems with complex architectures are often inaccessible to resource-constrained environments. Additionally, affordable solutions typically lack the autonomous coordination of multi-functional tasks. These gaps highlight the need for a cost-effective, self-operating UAV platform that can combine logistics capabilities and real-time visual intelligence.

To address these challenges, this work presents an autonomous fixed-wing UAV system capable of both linear surveillance and automatic payload delivery in a single mission. The proposed system integrates GPS-based waypoint navigation, a servo-actuated release mechanism, and an onboard camera for aerial imaging. Post-flight, captured video data are processed through computer vision techniques, specifically SIFT and homography, to generate panoramic stitched maps of the surveyed region. The system's design

focuses on simplicity, reliability, and affordability; thus, it is a suitable solution for disaster aid, border patrolling, and agricultural monitoring.

## II. SYSTEM ARCHITECTURE AND DESIGN

### A. UAV Hardware Components

To enable effective Vertical Take-Off and Landing (VTOL) capabilities, the designed autonomous UAV uses a hybrid five-motor configuration. The configuration consists of a primary forward-facing propulsion motor and four auxiliary motors installed on the wings. The propulsion system uses an 11 × 5.5E propeller and a 4-cell Li-Po battery, driven by a 2320SL 860KV brushless motor, capable of producing 2.4 kg of thrust. A 50A Hobbywing ESC, rated for burst currents up to 65A, is incorporated into the system to ensure reliable operation under high current demands.

The flight control architecture includes a Pixhawk 2.4.8, with its 32-bit ARM Cortex M4 processor. Several communication interfaces are included, such as UART, I2C, SPI, and CAN, also supporting up to 14 PWM outputs. To improve the operating safety in the event of a breakdown, the controller is developed with redundancy in mind, integrating multiple power input channels and failover capabilities. Both manual pilot control and autonomous flying are supported.

The NEO GPS module includes quick acquisition performance (-148 dBm) and high tracking sensitivity (-161 dBm), involving near-instant hot start capability within about 1 s. This is employed to control the positioning and navigation. Because of these features, it works especially well for time-sensitive UAV operations that need accurate geolocation information.

Power for the entire system is provided by an 11.1 V, 5200 mAh 3-cell Lithium Polymer battery. This unit offers a continuous discharge rate of 35 C and supports bursts up to 80 C, ensuring a robust power delivery during the peak loads. The communication between the UAV and the ground station is maintained via the FlySky FS-i6 radio system, which operates on the 2.4 GHz band and supports six channels through its dual-antenna receiver, making it an appropriate choice for fixed-wing configurations.

### B. Endurance Estimation

The endurance of the UAV is estimated based on the available battery capacity and the measured average current draw during operation. The endurance is calculated using:

$$\text{Battery Endurance} = \frac{C \times 60}{\alpha \times 0.8} = \frac{5.2 \times 60}{11.9 \times 0.8} = 20.97 \quad (1)$$

where  $C$  is the battery capacity in Ah,  $I$  is the average current draw in A, and the factor 0.8 accounts for using only 80% of the battery's capacity to extend the battery life and avoid over-discharge. Substituting these values, the endurance is obtained as 20.97 min. Consequently, the UAV can achieve an estimated flight time of approximately 21 min under typical operating conditions.

### III. AUTONOMOUS OPERATION AND MISSION PLANNING

#### A. Mission Planner Overview

The fixed-wing UAV is controlled by a Ground Control System (GCS) with Mission Planner software, which allows autonomous flight via waypoint navigation and altitude management. Designed with a Pixhawk flight controller onboard using ArduPlane firmware, the UAV remains stable and performs missions without human intervention. An embedded payload deployment system provides accurate delivery at target sites, improving the efficiency and accuracy of the mission.

#### B. Mission Planner Setup

Mission Planner plays a crucial role in configuring the UAV, uploading flight plans, and enabling autonomous operations through an intuitive, step-by-step interface. Figure 1 illustrates the software's interface at different stages of the mission planning workflow.

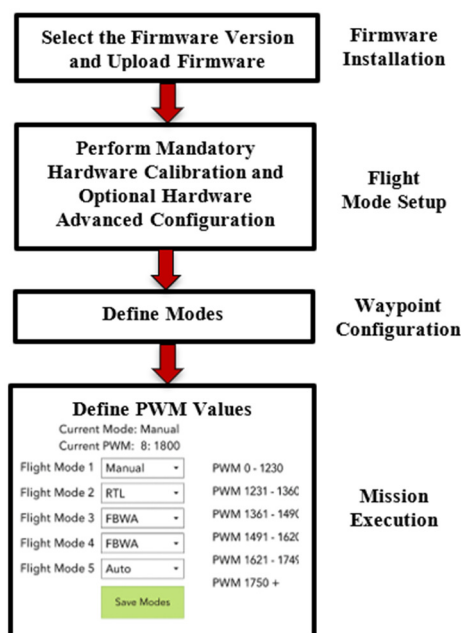


Fig. 1. Mission planner setup and workflow.

#### 1) Pixhawk Firmware Installation

To enable fixed-wing operations, the ArduPlane firmware needs to be loaded onto the Pixhawk flight controller. The following are the steps to install the firmware:

- The Pixhawk flight controller is connected to a ground control station via USB, enabling firmware installation through the Mission Planner interface.
- Firmware is selected by opening Mission Planner and selecting the "Install Firmware" tab. From the list of options, pick the ArduPlane firmware.
- To flash the firmware onto the Pixhawk, adhere to the on-screen directions. To prevent incompatibilities, make sure that the right board is chosen.

#### 2) UAV Parameter Configuration

After completing the firmware installation, Mission Planner is employed to configure and initialize the mission parameters for the UAV.

- Setting Initial Parameters: Power on the Pixhawk flight controller and establish a connection to the GCS via a USB UART interface. Navigate to the "Initial Setup" section in Mission Planner to perform sensor calibrations, including the GPS, compass, and accelerometer.
- Flight Mode Configuration: Proceed to the "Config/Tuning" tab to assign desired flight modes, such as "Manual", "Loiter", and "Auto". This setup allows for seamless transitions between different operational modes during the flight missions.

#### 3) Mission Planning Workflow

The mission planning workflow in Mission Planner involves the following key steps:

- Waypoint Definition: By setting waypoints directly on the map interface, users can specify the UAV's flight path under the "Flight Plan" tab. Specific altitude and speed settings can be assigned to each waypoint in order to conform to the mission requirements. Critical navigation points, like takeoff, loiter, and landing, must be included in order to provide a comprehensive and secure mission profile.
- Automated Payload Release Setup: Choose the "DO\_SET\_SERVO" command from the list of potential waypoint actions to set up an automated payload drop. By using this command, the system precisely delivers the payload at the designated position by turning on the servo mechanism at a predetermined waypoint.
- Mission Upload to Flight Controller: To upload the mission to the Pixhawk, click "Write WPs" once all waypoints and associated parameters have been finalized. In order to prepare the mission plan for completely autonomous execution during the UAV's flight, this stage passes it to the flight controller.
- Mission Execution: The UAV can be launched in Auto mode, and the flight will follow the predetermined waypoints when the mission plan has been uploaded to Pixhawk. The operator can keep an eye on the mission's progress and take appropriate action thanks to the GCS. Without requiring human involvement, the payload will release itself at the specified waypoint.

#### IV. FLIGHT TESTING AND PERFORMANCE EVALUATION

##### A. Environment and Setup Testing

The autonomous flight testing was conducted at Bellipadi Chandrahasa Alva, Stadium in Karkala, an open space with no obstacles. Mission Planner was utilized to program a set of GPS waypoints for the fixed-wing UAV, enabling autonomous navigation along the planned route. Figure 2 shows images taken during flight testing conducted at the Bellipadi Chandrahasa Alva Stadium in Karkala.



Fig. 2. UAV autonomous flight testing.

The flight path, as exhibited in Figure 3, captured on a satellite map, demonstrated a looping flight path, which indicated that the UAV followed a dynamic flight path when it was approaching the payload drop point. This demonstrated that the UAV was navigating from the first waypoint to the second waypoint autonomously since active course corrections from the autopilot system saw it maintaining course about the mission plan. The flight demonstrated the UAV's ability to show complex routes with dynamic adaptation, even in external environments. The red dot marks the destination end point of the payload delivery, and the blue dot marks either the beginning point or the previous waypoint along the route.

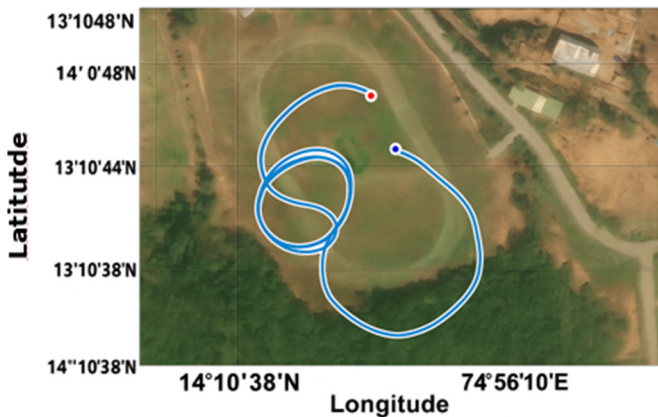


Fig. 3. UAV autonomous flight path.

Figure 4 presents the yaw, pitch, and roll attitude. It corresponds on the way the UAV responded to waypoints and adjusted its orientation to maintain a stable flight.

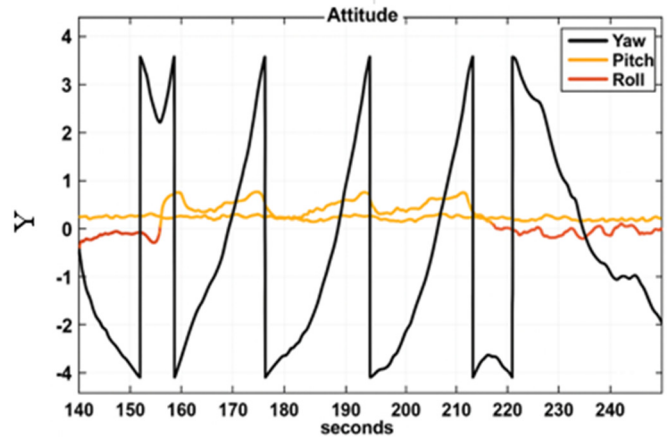


Fig. 4. UAV attitude stability graph.

The following parameters are utilized to assess the flight stability:

- **Yaw:** The data of yaw demonstrated a rapid and frequent change of the heading, indicating its transition between the waypoints.
- **Pitch:** The pitch was constant throughout the flight, demonstrating consistent altitude. This is required for a level and smooth flight, ideal for the delivery of accurate payloads.
- **Roll:** The roll data reflected moderate fluctuations, particularly in turns, and verified the efficient banking maneuvers, characteristic of fixed-wing UAV dynamics. The coordination between the roll changes and the sharp yaw changes indicates that the UAV performed coordinated turns while approaching each waypoint. These turns are a coordination of yaw and roll, which are typical in fixed-wing UAV flight dynamics. This coordination proves that the autopilot was able to control the UAV orientation exactly tracking the path and with a balanced trajectory.

##### B. Payload Drop Accuracy Evaluation

The UAV released its payload at pre-programmed GPS coordinates during flight testing with servo-controlled release. The flight lasted over 21 min with a payload capacity of 1.2 kg. Its onboard camera also assists in surveillance missions for monitoring, inspection, support, and search and rescue purposes. Therefore, the UAV is a well-suited platform for real field applications, integrating visual intelligence and logistics.

#### V. VISUAL DATA PROCESSING AND MAPPING

##### A. Frame Extraction from Video

The process of frame extraction from video is depicted in Figure 5. The first step is the extraction of individual frames, serving as the foundation for the subsequent analysis. This involves the selection of specific still frames from recorded video at regular intervals. This method avoids processing every single frame, which is computationally heavy, while the redundant frames are sparsely sampled at fixed intervals. Reducing the amount of data to be processed still provides a good enough coverage to create a continuous image, which is

necessary for stitching. These extracted frames are saved as high-quality images and later used as input for image stitching processes. The frames must overlap so that this repetitive feature matching can be done in the later stages. The primary input to this process is the video file itself, which can be of any format.

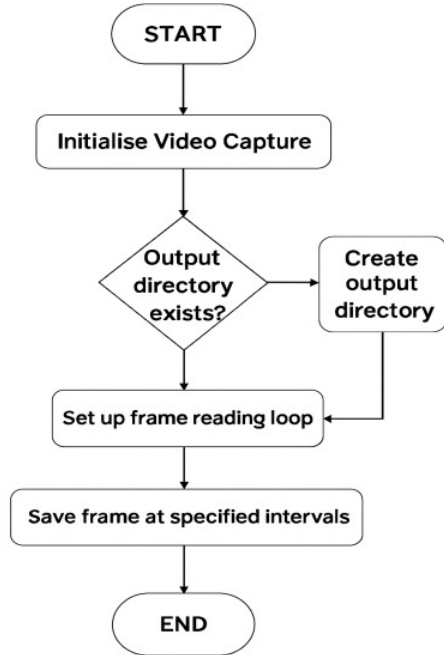


Fig. 5. Video frame extraction process flowchart.

### B. Image Alignment and Stitching

In image stitching, similar features or details are selected from nearby video frames and are aligned. The overlapping parts can be combined into a single image. This process creates a seamless panoramic image, commonly used in aerial mapping and surveillance to provide a continuous visual overview.

The method, as described in Figure 6, begins with feature detection using SIFT. This method derives the key points of every image that are invariant to scale, rotation, and light. Each feature, edge, or corner is given a descriptor based on mathematically describing its local image patch. Descriptors are used to match the key points of two images. Moreover, the BFMatcher compares the descriptors from consecutive frames to establish point correspondences based on visual similarity. Accurate feature matching ensures the precise alignment of overlapping regions and significantly improves the stitching quality. The better the feature matching is, the better is the overlap of images in the final panorama. The matched points are utilized to compute a homography matrix and to determine the transformation needed to align one image to the next. This matrix compensates for perspective differences to ensure a smooth alignment between the frames.

After computing the homography, the images are aligned and blended. Each frame is adjusted to match the next one and all of them are placed side by side. The stitching process happens in batches of three images to improve the memory and

processing speed. Once the stitching for each batch is complete, the batches are merged into the final panoramic image. To clean the final stitched output, a cropping process is applied to remove the black borders caused by warping. Subsequently, the image undergoes conversion to grayscale, followed by thresholding to produce a binary mask. The contour detection locates the largest region, which is cropped using a bounding rectangle. The resulting panoramic image is saved in high-quality JPEG format, suitable for UAV surveillance and mapping applications.

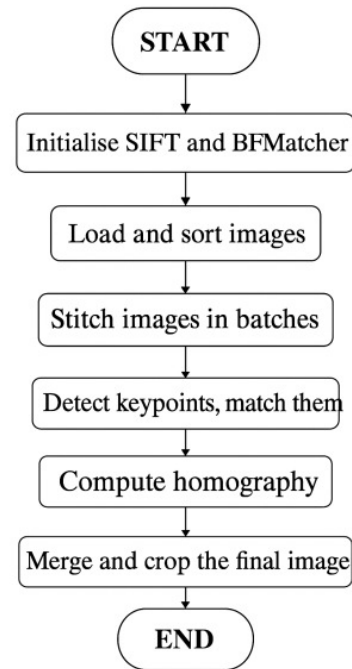


Fig. 6. UAV image stitching pipeline process flowchart.

### C. Testing on Sample Flight Video

The visual post-processing pipeline is evaluated through a publicly available UAV video dataset [15]. This dataset, hosted on GitHub, simulates real-world UAV flight patterns with varied motion and image conditions. This particular video was selected due to its real-world UAV flight description, including shifts in speed, resolution, and drone movement.

The video was processed through the full post-flight analysis pipeline to assess the system robustness. First, the individual frames were selected. Subsequently, SIFT was employed to find key features, then matched them using BFMatcher and produced the homography. The next step included stitching everything together and finally trimming the result. The final result was a clear panoramic image that brought together all the frames into one smooth scene, as presented in Figure 7. This test indicated the system's ability to handle videos from other outside. It verified the strong and consisted setup is for varying conditions.



Fig. 7. Final stitched panoramic output.

## VI. CONCLUSION

This study presents the development and validation of an autonomous fixed-wing Unmanned Aerial Vehicles (UAV) system capable of performing both precise payload delivery and navigation during a single mission. Through the integration of GPS-based waypoint navigation, a servo-driven release mechanism, and an onboard video capture unit, the UAV demonstrates the dual-purpose capability. Subsequently, it can be deployed in disaster relief, border security, and large-scale agricultural monitoring scenarios. The flight tests confirmed the UAV's stability, mission accuracy, and endurance of 20.97 min, supporting its viability for operations in remote areas.

The image stitching process, based on Scale-Invariant Feature Transform (SIFT) feature detection and homography transformation, successfully produced clear panoramic maps. Despite its effectiveness, the system presented certain limitations. These include the dependence on stable weather and the lack of onboard obstacle detection, issues that will be addressed in future iterations. Additional enhancements, such as real-time visual processing, AI-based path optimization, and field deployment under varying terrain and payload conditions will further strengthen the system's capabilities.

This study demonstrates, in a small, low-cost fixed-wing UAV, the combined capabilities of precise payload delivery and panoramic image-based surveillance, producing stitched flight maps validated in field tests.

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