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Autonomous UAV-Based Mortar Round Deployment with Real-Time Ballistic Correction

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Abstract:

This article describes airborne release of a mortar round from the UAV. Our software estimates downwind drift from onboard wind direction and speed, then commands the UAV to offset upwind before release. In field tests at 200 m, 400 m, and 600 m, this approach reduced drift distance by an average of about 40 % versus no compensation, validating predictive accuracy and operational reliability. The system integrates a ballistic solver using ultrasonic wind data, plus ground-control functions for mission execution. We built the UAV's 3D model, tested the workflow in Gazebo, and evaluated performance under realistic weather. The article summarizes the development process, objectives, and outcomes.

Keywords:

autonomous navigation, ballistic modeling, mortar round, UAV

1 Introduction

The application of unmanned aerial vehicles (UAVs) in modern military operations has expanded rapidly, playing a significant role in missions that require high precision, such as aerial surveillance, reconnaissance, and air-to-ground munition deployment [1, 2]. Quadcopter-type UAVs have gained attention due to their stability, maneuverability, and payload-carrying capabilities, making them suitable platforms for advanced mission-specific integrations.

One of the primary challenges in air-to-ground munition delivery using UAVs lies in achieving accurate targeting. Conventional methods typically involve releasing the munition directly above the target. However, such approaches often fail to account for external environmental factors such as wind speed and direction, aerodynamic

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properties of the projectile, and air resistance. These factors contribute to horizontal drift, leading to significant deviations from the intended impact point [3].

Recent advancements have introduced the integration of real-time environmental data into ballistic computation models. Such models aim to estimate the deviation of the projectile from the target due to external influences by analyzing physical and dynamic parameters such as mass, aerodynamic drag, wind vector, and initial launch velocity [4]. Lightweight state–observer architectures with an analytical correction loop have proven effective for high-maneuverability missiles under severe on-board CPU constraints [5]. This evidence motivates adopting a similar resource-efficient correction strategy for our quad-rotor airdrop platform.

In this context, a computational approach has been implemented whereby the UAV evaluates these ballistic factors in real time during flight. Instead of releasing the munition from a fixed position above the target, the UAV dynamically adjusts its location based on the predicted drift and launches the munition from an optimized offset point. This ensures that the mortar round drops either directly on or near the intended target.

System performance has been evaluated through real-world field trials conducted at altitudes of 200 m, 400 m, and 600 m. The experimental results indicate that the application of real-time ballistic correction algorithms can reduce drift distance by more than 40 % on average, thereby demonstrating the operational effectiveness and practical utility of the system.

The approach presented in this study not only enhances the functional capabilities of current UAV delivery systems but also introduces a novel methodology that integrates autonomous navigation with real-time ballistic computation. This integration offers substantial potential for future applications in both military and high-precision civilian domains [1, 6].

The subsequent sections of this paper provide a detailed overview of the system architecture, software structure, validation results from the Gazebo simulation environment, and outcomes from field experiments. Additionally, the 3D design of the UAV platform, modeled in SolidWorks and analyzed for aerodynamic and structural performance, is presented in a dedicated section.

The purpose of this research is to enhance the precision of air-to-ground mortar round drops using UAVs by developing a ballistic correction model. Building on previous studies in autonomous airdrop systems and UAV-based launch platforms, this research extends the application to real-time correction based on wind and altitude data [7, 8]. The system aims to minimize the impact of environmental factors on accuracy and to improve UAV mission reliability in dynamic conditions.

2 Related Work

Like previously developed UAV-based airdrop ballistic models [8], this study adapts ballistic flight corrections and control mechanisms for air-launched mortar round drops from a UAV platform. Inspired by previous works on autonomous airdrop missions using machine vision for target localization [9], this study extends the concept towards air-to-air mortar round launching with dynamic target position estimation. Building on previous research on UAV-mounted launch devices and the analysis of ballistic impacts on UAV attitude and targeting accuracy [1], this study extends these principles to air-to-air mortar round launching missions with dynamic target tracking. Consistent with prior studies focusing on quadcopter stability using PID controllers within the Gazebo simulation environment [10], the preliminary phase of this research involved verifying the UAV control system before implementing ballistic launch experiments.

The methodology of validating quadrotor dynamics and controller performance across multiple simulation platforms, as described in [11], provided a foundational framework for ensuring the UAV's flight stability before conducting ballistic launch experiments. Consistent with prior research focusing on estimating external impact forces on UAVs and dynamic response modeling in Gazebo simulation environments [12], this study implements and extends such methodologies towards ballistic mortar round launching from UAV platforms. In UAV missions that involve dynamic operations such as ballistic launching, the mechanical robustness and crashworthiness of the quadcopter frame are critical for maintaining flight stability and operational reliability, as highlighted in prior structural optimization studies [13].

3 System Overview

The proposed system consists of a UAV-based mortar round launching platform that leverages real-time ballistic computation and autonomous navigation to compensate for wind effects during aerial targeting operations. This integrated system is designed to launch an 82 mm mortar round from a UAV at an optimal release point, ensuring accurate impact on a ground target despite varying wind conditions.

The UAV is a quadcopter with a 70×70 cm frame and a payload capacity of 8 kg. It is equipped with a vertical lift propulsion system enabling vertical speed of 4 ± 1 m s^{-1} and horizontal speed of up to 10 m s^{-1}. The flight duration is approximately 20 minutes under standard operating conditions. The UAV is equipped with a custom mounting mechanism to carry and release a single 82 mm mortar round. Fig. 1 shows the model of the mortar round and UAV in SolidWorks.

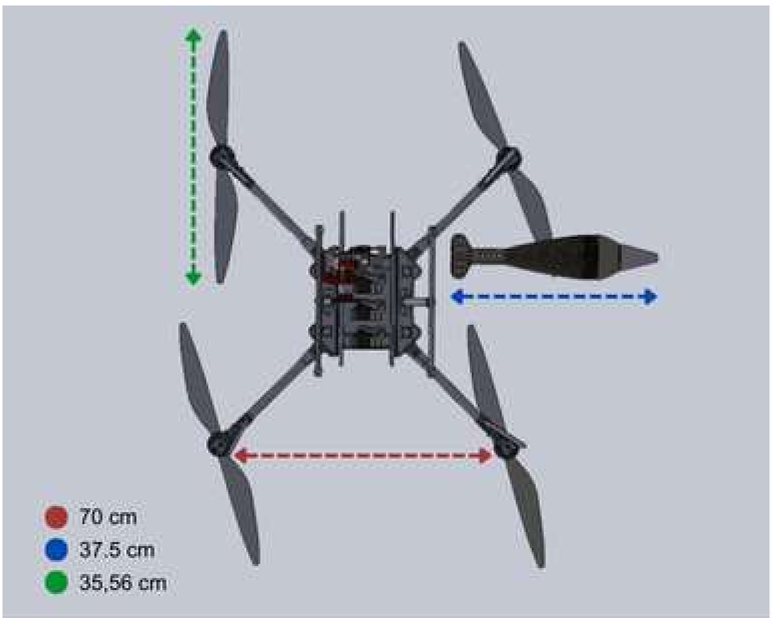

Fig. 1 3D models of the 82 mm *mortar round and UAV*

3.1 Ballistic Calculation Algorithm

The ballistic computation algorithm forms the core of the UAV’s targeting system, enabling real-time prediction of munition impact points under varying environmental conditions [14]. The algorithm processes key parameters such as:

- wind speed and direction from on-board ultrasonic wind sensor,
- gravitational acceleration and aerodynamic drag,
- launch altitude and velocity vector ($v_0 = 0$ m s^{-1}),
- the mass and aerodynamic profile of the munition.

Based on these inputs, the module estimates horizontal drift and calculates an optimal offset release point upwind of the target. This ensures the projectile reaches the intended impact zone with high precision, even in the presence of crosswinds.

We mounted the sonic anemometer on a mast 20 cm above the fuselage, above the propeller plane. Comparing ground (props-off) with 15 m hover (props-on) showed propeller-induced turbulence: wind-speed differences $\Delta v_w \approx (0.4 \pm 0.1)$ m s^{-1} and direction differences ≈ ± (10–15)°. During firing trials, we did not compensate these biases; real-time ballistic calculations used onboard readings. Our aim was to minimize high-altitude impact error, and the results confirmed this.

3.2 Ground Control and Navigation

Dual-mode ground control software enables both manual and autonomous UAV operation. The software:

- receives telemetry data via a 915 MHz module with up to 30 km range,
- transmits real-time position updates and environmental parameters,
- displays ballistic computation results,
- sends waypoint navigation commands to the UAV for optimal positioning.

Navigation is performed via GPS and IMU fusion, allowing precise hovering and controlled movement to the calculated drop point. The UAV automatically stabilizes before mortar round release to maintain accuracy.

The target is uploaded to the UAV as a georeferenced waypoint (lat/lon/alt) via GCS. Pre-flight, the operator selects the coordinates on the map and sends them to the autopilot. In flight, RTK GNSS guides the UAV to a precise hover at the commanded altitude. We initially used a CUAV NEO-3 Pro (≈ 0.7 m horizontal accuracy), then added a CUAV C-RTK 9P with RTK corrections (≈ 0.01 m). Ballistic release trials were conducted under RTK-fixed conditions, so the release-point uncertainty was bound by the 9P’s centimeter-level accuracy.

3.3 Gazebo Simulation Environment

Prior to field testing, the UAV platform and ballistic behavior are modeled and validated in the Gazebo simulation environment [15]. The simulator includes:

- wind field simulation,
- mortar round physics with air resistance,
- sensor and communication delays,
- visual debugging of trajectories and impact zones.

This provides a safe and cost-effective testing ground for verifying system algorithms, flight dynamics, and release timing strategies.

3.4 Multi-munition Capability and Software Scalability

Although the prototype UAV used in this project was configured to carry and deploy a single 82 mm mortar round for testing purposes, the final design of the system envisions a fully operational UAV platform capable of carrying up to four munitions simultaneously. This limitation in the prototype was intentional and allowed for focused evaluation of ballistic accuracy under controlled conditions.

The ballistic control and ground command software was developed with full scalability in mind. It supports:

- single-fire mode: launching individual mortar rounds one at a time,
- dual-fire mode: launching two munitions simultaneously,
- full-salvo mode: launching all four mortar rounds concurrently toward the target.

Each mode uses independent trajectory corrections based on real-time environmental inputs, ensuring that all munitions, regardless of launch configuration, reach the designated impact area with high precision.

4 Pre-flight Simulation of UAV Ballistic Targeting

Before engaging in live-release trials, the complete mortar round–carrier stack is subjected to a high-fidelity, hardware-in-the-loop rehearsal in the Gazebo simulator. This digital proving ground couples a six-degree-of-freedom multirotor model, the physical characteristics of an 82 mm mortar round, and a custom Python control algorithm that replicates the avionics stack slated for field deployment. The objective is two-fold: 1) to verify that the on-board release-control algorithm can compute an impact point with ≤ 5 m circular error probable (CEP) under representative wind profiles, and 2) to ensure that the autopilot can autonomously reposition the carrier to the computed release waypoint while maintaining safe flight envelopes.

4.1 Ballistic Force Modeling and Target Coordinate Estimation

We consider an 82 mm projectile (mass m = 4.2 kg) suspended under a multirotor UAV at an initial release altitude h_0 above ground. After the operator specifies the target geolocation $\boldsymbol{p}_{\mathrm{tgt}} = (x_{\mathrm{tgt}}, y_{\mathrm{tgt}})$, the system predicts the impact point for any candidate release pose and computes an upwind offset position for the UAV to fly to and release from so that the projectile lands on the target.

We model three forces: gravity, aerodynamic drag, and wind via the relative flow. Gravity: $\boldsymbol{g} = (0, 0, -9.81)$ m s^{-2}. Air density: constant $\rho = 1.225$ kg m^{-3}. Drag coefficient $C_{\mathrm{D}} = 0.32$, reference area $A = 5.15 \times 10^{-3}$ m^2.

Wind is measured by the ultrasonic sensor as a direction $\psi \in [0, 360°]$ and a scalar speed U [m s^{-1}], which are then converted into a ground-fixed horizontal wind vector at the release altitude.

$$\boldsymbol{w} = \begin{pmatrix} U\cos\psi \\ U\sin\psi \\ 0 \end{pmatrix} \tag{1}$$

Define the state $\boldsymbol{s} = (\boldsymbol{p}, \boldsymbol{v})^{\mathrm{T}}$, with the position $\boldsymbol{p} = (x, y, z)$ and the velocity $\boldsymbol{v} = \mathrm{d}\boldsymbol{p}/\mathrm{d}t$. The equations of motion in an Earth-fixed frame (upwards + z) are

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = \boldsymbol{v}, \quad \frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = \boldsymbol{g} - \frac{1}{2m}\rho C_D A \,\|\, \boldsymbol{v} - \boldsymbol{w} \,\|\, (\boldsymbol{v} - \boldsymbol{w}) \tag{2}$$

At the instant of release,

$$p(0) = \boldsymbol{p}_0 = (x_0, y_0, z_0), \quad z_0 = h_0 + z_{\text{ground}}, \quad v(0) = \boldsymbol{v}_0 = \boldsymbol{v}_{\text{UAV}} \tag{3}$$

where $\boldsymbol{v}_{\text{UAV}}$ is the UAV ground-relative velocity from INS/GNSS. The trajectory is propagated until the projectile intersects the terrain:

$$z(t_f) = z_{\text{ground}}\big(x(t_f), y(t_f)\big) \tag{4}$$

The predicted impact point is $\bar{\boldsymbol{p}} = (x(t_f), y(t_f))$

For trajectory propagation we integrate (3) with a fixed-step explicit Euler method. For time step Δt and step index k:

$$\begin{aligned} \boldsymbol{a}_k &= \boldsymbol{g} - \frac{\rho C_D A}{2m} \| \boldsymbol{v}_k - \boldsymbol{w} \| (\boldsymbol{v}_k - \boldsymbol{w}) \\ \boldsymbol{v}_{k+1} &= \boldsymbol{v}_k + \Delta t \boldsymbol{a}_k \\ \boldsymbol{p}_{k+1} &= \boldsymbol{p}_k + \Delta t \boldsymbol{v}_k \end{aligned} \tag{5}$$

We use Δt = 0.01 s. Linear interpolation on the last step refines the ground-hit time t_f when z crosses z_{ground}.

From the current UAV pose (same release altitude and initial velocity), propagate once to get the predicted impact $\bar{\boldsymbol{p}}$. The horizontal drift (from release to impact) is

$$\boldsymbol{o} = \bar{\boldsymbol{p}} - \boldsymbol{p}_{\text{UAV}} \tag{6}$$

Then the desired release position $\boldsymbol{p}_{\text{des}}$ for target $\boldsymbol{p}_{\text{tgt}}$ is

$$\boldsymbol{p}_{\text{des}} = \boldsymbol{p}_{\text{tgt}} - \boldsymbol{o} \tag{7}$$

4.2 Software Integration and Pre-Flight Simulation in Gazebo

The software application calculates the mortar round's ballistic trajectory by considering wind direction, speed, and other influencing factors [16]. Written in fully object-oriented Python, the program transmits the computed impact coordinates to the UAV's control system. The user interface, shown in Fig. 2, integrates real-time ballistic calculations for the mortar round at the current simulated altitude and includes buttons to redirect the UAV to the newly calculated coordinates. The operator can launch mortar rounds in various combinations by pressing the "Mortar-1", "Mortar-2", "Mortar-3", and "Mortar-4" buttons.

This ballistic reporting software supports various mission tasks and functions as a ground control application to monitor and manage UAV performance within the simulation. Controllers use the program to oversee simulated UAV operations, plan flight paths, and collect telemetry data. Using sensor data simulated from the drone model, the software calculates necessary adjustments to ensure accurate mortar round release on target, accounting for wind effects during flight.

Technically, the software connects to the simulated UAV via a telemetry module interface within Gazebo. The interface displays telemetry data, real-time camera feed, and current GPS coordinates and provides controls such as connect, disconnect, start, and stop. Mortar round release is managed through dedicated buttons, allowing the operator effective and precise control over firing sequences. This setup enhances the program's functionality and operator efficiency during simulation.

To validate the software, the UAV's 3D model is first created in SolidWorks or a similar CAD tool and then imported into the Gazebo simulation environment. Gazebo, an open-source physics engine and simulation platform, provides realistic modeling of UAV behavior under various conditions. All described ballistic calculations, control functions, and mortar round launch procedures are tested and verified within this simulation environment. These simulation tests evaluate mortar round launch accuracy and UAV response to control inputs, ensuring the program's reliability and operational effectiveness before deployment.

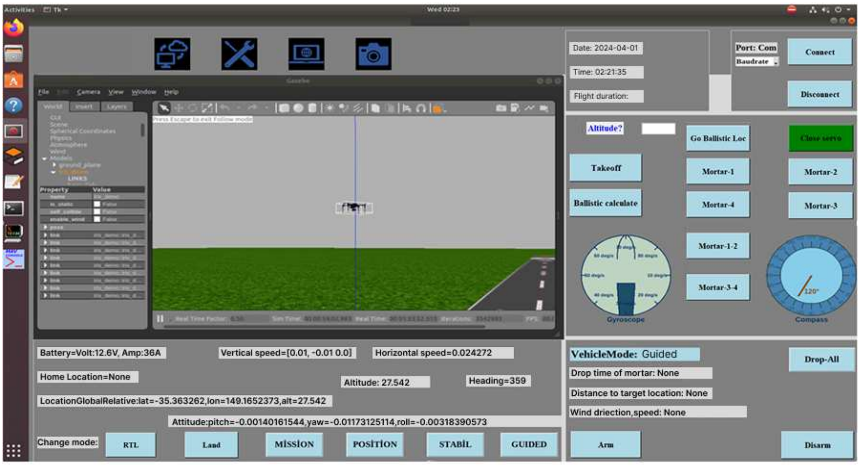

Fig. 2 Software test on Gazebo

5 Electrical and Control Hardware

The electrical and control architecture of the UAV is designed to ensure precise navigation, stable propulsion, and accurate mortar round release in airborne conditions. The system integrates multiple modules, including flight control, telemetry, environmental sensing, motor control, and payload deployment. Fig. 3 illustrates the physical structure of the avionics system.

At the center of the control system is the CUAV V5+ flight controller, which features a triple redundant IMU and on-board barometer for stable flight in three-dimensional space [17]. The controller manages both navigation and mission-specific tasks such as servo activation for payload deployment. It communicates with peripheral modules through PWM, UART, I2C, and GPS interfaces. To ensure accurate positioning, the UAV employs the CUAV Neo3 Pro GPS module. This module supports multiple GNSS constellations (GPS, Beidou, Galileo) and includes an integrated digital compass, enabling precise localization and orientation even under dynamic wind conditions.

Real-time environmental data is acquired through an on-board wind sensor, resembling a compact meteorological station. This sensor provides wind speed and direction readings directly to the flight controller, forming the basis of the ballistic calculation engine. Based on this data, the UAV determines the optimal upwind location to release the mortar round.

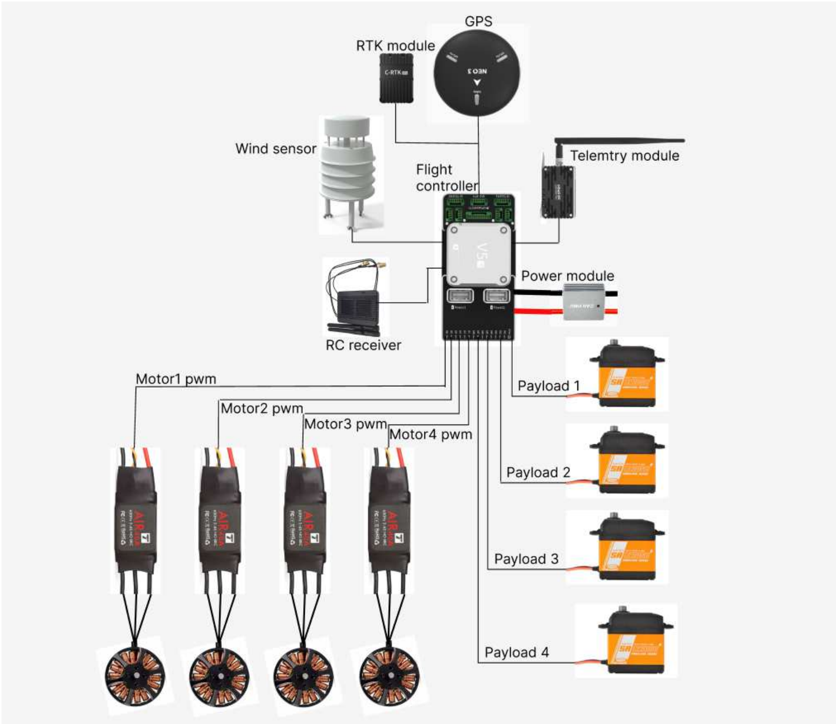

Fig. 3 Physical wiring diagram of UAV avionics system

For communication with the ground control station (GCS), the UAV is equipped with the CUAV P9 telemetry module, which operates at a frequency of 915 MHz and supports full-duplex communication at distances of up to 30 km. The GCS software uses this link to send mission updates, receive telemetry data, and issue mortar round release commands.

Manual override and field testing are supported via the Skydroid H16 receiver, which links to a handheld RC transmitter. This 16-channel receiver ensures safe fallback control and direct testing of subsystems.

The UAV's propulsion system comprises four brushless DC motors, each controlled by individual ESCs (electronic speed controllers). Each motor delivers approximately 2.8 kg of thrust at full throttle, providing a total lift capacity exceeding 11 kg. The ESCs are opto-isolated and controlled via PWM signals from the flight controller. Mortar round deployment is achieved using four high-torque servo motors, each attached to an individual munition release mechanism. These servos allow for various firing modes, including single-drop, dual-drop, and simultaneous four-mortar salvo. The servo actuation is precisely timed based on the calculated trajectory correction to compensate for wind drift.

Power distribution is managed by the CUAV PMU (power management unit), which regulates voltage to critical subsystems and monitors overall power consumption. The battery system used is 24 V, 5 000 mAh, providing a stable energy supply during the typical 20-minute flight duration.

Finally, the UAV is equipped with a video transmitter and on-board camera, allowing visual confirmation of target location and mortar round release events. The video stream is received by GCS and assists the operator in mission assessment and feedback logging.

The hardware design also supports software scalability. Although the prototype tested in this study was limited to carrying one munition, the flight control and mission software have been developed to handle up to four mortar rounds. This flexibility is essential for adapting to various mission profiles and target types. The main specifications of key hardware components used in this system are summarized in Tab. 1.

Tab. 1 Technical specifications of electrical and control modules used in the UAV system

Component	Model	Key technical parameters	Function
Flight controller	CUAV V5+	IMU, Barometer, PWM/UART/I2C	Central control unit for flight and payload
GPS module	CUAV Neo3 pro	GNSS (GPS, Beidou, Galileo)	Positioning and directional heading
Telemetry module	CUAV P9	915 MHz, up to 30 km	Communication with GCS
Wind sensor	Meteo station module	Wind speed [m s^{-1}], wind direction [degrees]	Ballistic correction input
RC receiver	Skydroid H16	2.4 GHz, 16 channels	Manual control and testing
Power module	CUAV PMU	7–62 V input, 100 A, 5.2 V regulated output	Power regulation and monitoring
Motors	Brushless DC motors	2.8 kg thrust each, 4 units	Propulsion
ESCs	40 A ESCs (PWM control)	throttle management	Motor control
Servo motors	Metal gear servos	10–15 kg cm torque, 4 units	Munition release mechanisms

The system can be configured to drop each munition independently, in pairs, or all simultaneously, depending on tactical objectives. Fig. 4 illustrates the logical structure of the avionics system.

6 Flight Control and Mission Software Architecture

The mission control software developed for this UAV system provides a graphical user interface (GUI) that integrates flight control commands, telemetry monitoring, ballistic computation, and servo-based mortar round deployment. The software interacts with the CUAV V5+ flight controller over MAVLink protocol and visualizes real-time telemetry data while allowing the operator to send mission-critical commands.

The graphical interface of the initial version in

Fig. 5 includes two primary functional sections: Command and control buttons, live telemetry display and camera feed.

The software interface incorporates an array of command buttons that trigger autonomous behaviors, switch flight modes, and supervise the mortar round release sequence, while simultaneously presenting comprehensive telemetry streams and a real-time camera feed. Tab. 2.

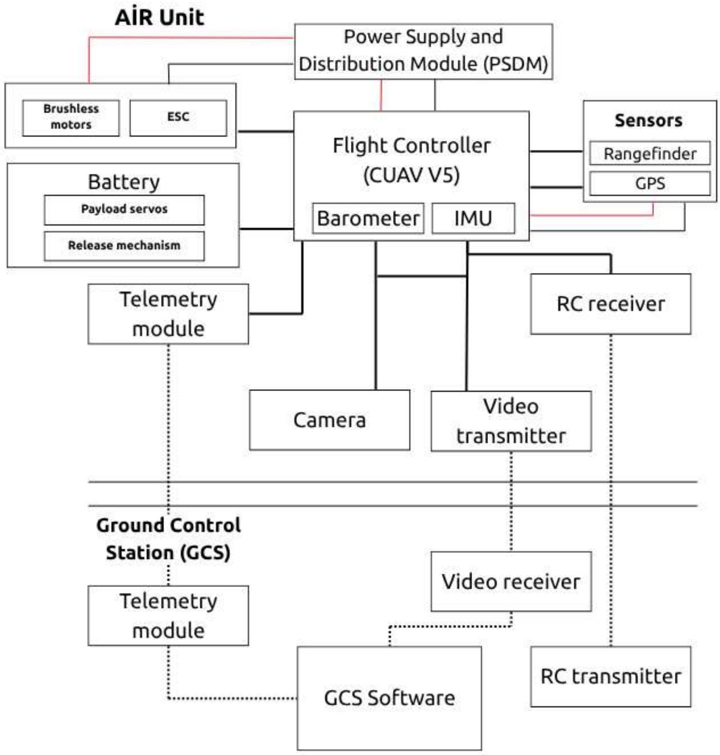

Fig. 4 Logical architecture of UAV control and communication system

Fig. 5 Initial version of mission software interface

6.1 Final Version: Multi-Munition and Sensor Visualization Interface

In the final version of the mission control software in Fig. 6, several enhancements were implemented to enable full operational control of the multi-munition UAV system. The interface was upgraded to support the simultaneous deployment of up to four mortar rounds, as well as provide improved situational awareness through real-time sensor visualization and mission configurability.

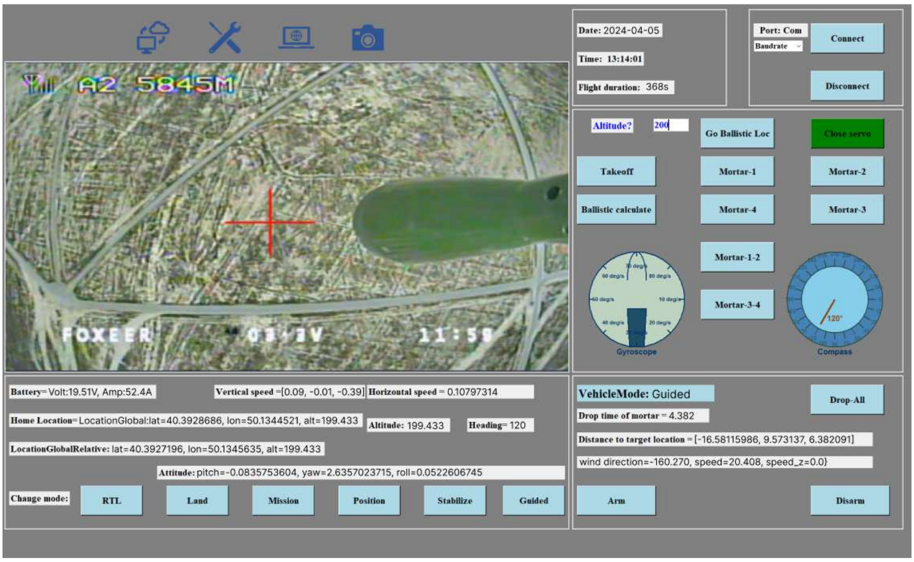

Fig. 6 Final version of mission software interface showing full munition control, sensor visualization

Tab. 3 lists the core elements of the ground-station interface: buttons for flight-mode selection, takeoff, landing, and munition release; live telemetry with time, date, and elapsed-time counters; gyroscope and compass attitude indicators; and a real-time camera feed.

7 Experiments and Results

To evaluate the effectiveness of the developed ballistic computation software in real flight conditions, a series of field experiments were conducted using an unmanned aerial vehicle (UAV) equipped with a free-fall bomb release mechanism. The purpose of these experiments was to compare the dispersion distance (horizontal drift) of the munition from the intended target point under two different conditions: with and without ballistic computation-based targeting correction.

7.1 Experimental Setup

All experiments were conducted in open field conditions with an average wind speed of approximately 5 m s^{-1}. A UAV was programmed to release an 82 mm mortar round (mass: 4.2 kg, drag coefficient: 0.32, reference area: 0.00515 m^2) from different altitudes (200 m, 400 m, and 600 m). At our test site, the aviation authority capped UAV operations at 600 m AGL. To obtain broader results from the test, two more altitudes were chosen. The release was executed under two different modes:

Tab. 2 Description of GUI functionalities in initial flight control software

Element	Type	Description
Arm / Disarm	Button	Activates or deactivates the UAV motors and, required before takeoff
Takeoff / Land	Button	Initiates autonomous takeoff and landing sequences
Go to target location	Button	Navigates UAV to computed ballistic release point.
Calculate ballistic Point	Button	Computes wind-compensated optimal release location for the mortar round.
Flight mode buttons (Auto, RTL, Loiter, Guided)	Button	Switches between standard ArduPilot flight modes
Release mortar round	Button (red)	Activates servo to release the mortar round
Close servo	Button (green)	Returns servo to neutral/safe position
Telemetry fields	Labels/Text boxes	Displays real-time data: position, wind, heading, altitude, velocities
Live video feed	Display (Foxeer FPV)	Confirms visually target and mortar round release

Tab. 3 Additional functionalities in final software version

Element	Type	Description
Mortar 1–4	Button	Releases corresponding mortar round via servo
Mortar 1–2 / 2–3	Button	Releases simultaneously e selected munition pairs
Mortar-All	Button	Releases full salvo of all 4 munitions simultaneously
Input altitude	Input field	Sets target flight altitude before autonomous takeoff
Gyroscope dial	Visual gauge	Displays roll, pitch, and yaw angles in real time
Compass dial	Visual gauge	Displays heading angle (0–360°) from onboard magnetometer
Connect / Disconnect	Buttons	Establishes or closes MAVLink telemetry session
Clock / Date	Label	Shows current system time for operator reference and log synchronization

- without ballistic computation: The munition was released directly above the takeoff point,
- with ballistic computation: The UAV autonomously calculated the drift distance caused by environmental forces (mainly wind), repositioned in the opposite direction accordingly, and released the munition from that adjusted location.

The impact points were marked with "X" symbols on the ground and photographed. The horizontal drift was measured as the linear distance between the UAV's original vertical launch position (target point) and the actual impact point. Remarkably, all experiments in which ballistic correction was applied, as summarized in Tab. 4.

Tab. 4 Results

Experiment	Altitude [m]	Ballistic computation	Drift Distance [m]	Wind Speed [m s^{-1}]
1.1	200	No	5.6	5.0
1.2	200	No	4.0	5.7
1.3	200	Yes	1.8	4.0
2.1	400	No	7.0	4.8
2.2	400	Yes	3.3	5.0
3.1	600	No	8.2	5.5
3.2	600	Yes	5.8	4.5

The wind conditions slightly fluctuated during the test days, with values between 4.0 m s^{-1} and 5.7 m s^{-1}. The wind speed and direction were measured in real time by a drone-mounted wind sensor, and the onboard ballistic calculations used these measurements as their primary input. The highest drift values were observed during stronger wind speeds, especially in Experiment 2.1 (400 m, 5.7 m s^{-1}) and Experiment 3.1 (600 m, 5.5 m s^{-1}), where no ballistic compensation was applied. When ballistic calculations were incorporated, the horizontal drift decreased by more than 40 %, validating the effectiveness of the system in compensating for environmental effects. The UAV takeoff and target point was marked with an "X" on the ground, as shown in Fig. 7 (left, experiment 1.3). The actual impact point of the projectile is illustrated in Fig. 7 (right), with the distance from the target used to determine the drift.

To further analyze the effect of wind on projectile drift, a scatter plot was generated using experimental data (Fig. 8). The horizontal axis represents the measured wind speeds during each test, while the vertical axis shows the corresponding drift distances of the projectile.

The data points clearly illustrate a positive correlation between wind speed and horizontal drift, particularly in experiments without ballistic computation. For instance, at 5.7 m s^{-1}, the drift distance reached up to 7.0 m in experiment 2.1, whereas the same wind speed under ballistic correction in experiment 3.2 resulted in a significantly lower drift of 5.8 m.

Notably, experiments where ballistic correction was applied, i.e. experiments 1.3, 2.2, and 3.2, consistently demonstrated reduced drift, even at similar or identical wind speeds. This confirms the efficiency of the on-board ballistic computation algorithm in compensating for wind-induced deviations. The annotations on each point of the graph

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indicate the experiment number, altitude, and whether ballistic compensation was used, providing a comprehensive visual understanding of how environmental forces, particularly wind, affect precision in munition delivery from UAVs.

Fig. 7 Image of the point where the projectile hits the ground

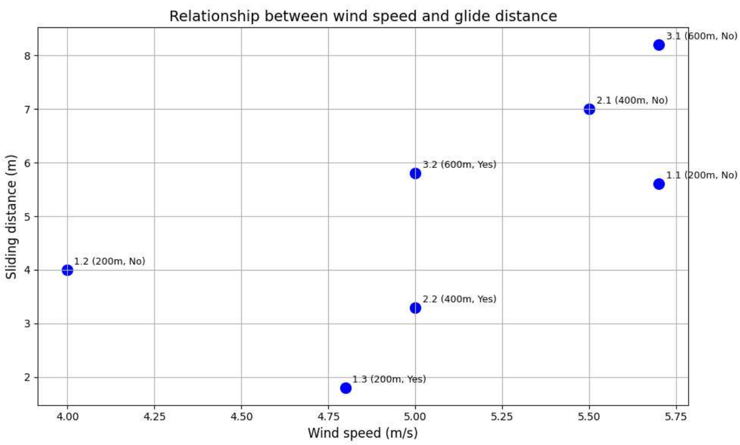

Fig. 8 Relationship between wind speed and glide distance

8 Conclusion

The achievements of the project show the effectiveness and accuracy of the software developed to launch the mortar round on the target by UAVs. This project opens a new way of launching mortar rounds on target by combining ballistic reporting and drone technologies. Advances in technology allow UAVs to be increasingly used in the armed forces, security, and civilian sectors. In the future, the potential directions of this project are related to the further development of sensor and camera technologies on UAVs, increasing the efficiency of the mortar round launch process, and achieving better performance in different weather conditions. This shows significant potential in making security and monitoring operations more effective and modern, both in the military and civilian spheres. Field tests at 200 m, 400 m, and 600 m demonstrated that the system effectively reduced drift by over 40 %, validating the module's predictive accuracy and operational reliability.

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