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Design and Development of an Affordable ESP32-based Microdrone with Automated Landing and Kalman filtered TOF Sensing

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Abstract: The need for accessible and reasonable prices drone platforms has increased due to the expansion of UAVs (Unmanned Aerial Vehicles) in fields including agriculture, disaster management and surveillance. However most of the commercial and research drones relay on expensive flight controllers and patented ecosystem, thus limiting their adoption in educational and resource constraint environment. This paper describes the design, implementation, and testing of low-cost micro drone with an ESP32-S3 microcontroller as the core flight controller. By incorporating an MPU6050 (IMU) for attitude stabilization and a VL53L0X (TOF) laser sensor for accurate altitude measurement, the firmware expands an open-source baseline. The use of a 1-D linear Kalman filter to smooth TOF altitude data caused by propeller vibrations is a significant addition of this study. This allows for dependable automatic landing, a capability lacking in drones in this price range. The drone has a custom 3D printed X-frame, 8250 coreless motors, controlled by a motor driver circuit made of AO3400 N-channel MOSFETs, SS34 Schottky diodes, and 10kΩ gate resistors. A mobile app was developed to serve as a wireless controller communicating through Wi-Fi network hosted by ESP32 via low-latency UDP packets.
Keywords: Micro drone, ESP32-S3 microcontroller, MPU6050, VL53L0X (TOF), Kalman filter, PID control, Coreless motor, Low-cost UAV, and Automated landing.

I. INTRODUCTION

UAVs, often known as drones, have revolutionized a variety of industries, including search and rescue, logistics, agriculture, and aerial photography. By 2033, the worldwide drone industry is expected to surpass USD 182,449.6 million. Growing at a CAGR of 9.5% from 2026 to 2033 according to report done by global view research (report Id- GVR-4-68040-263-2) [1], with micro and nano drones representing a rapid growing segment due to their size, maneuverability, safety, and suitability for indoor and outdoor applications. Due to high cost of commercial flight controllers, such as Pixhawk series and DJI's proprietary systems, which are sturdy yet cost between Rs. 5,000 and Rs. 30,000 (not including motors, frames, and sensors), the entry barrier for drone development remains high despite their expansion [2]. This expense is significant for academics, students, and enthusiasts in developing countries.Furthermore the patent system restricts the customizability making them unsuitable for research applications that require deep access to flight control algorithms and sensor integration. Recent developments in system-on-chip microcontrollers have created new opportunities for the creation of inexpensive drones. The Espressif ESP32 series originally designed for IoT applications features dual-core processor, integrated Wi-Fi and Bluetooth, and sufficient GPIO and I2C/SPI interface to function as a flight controller [3]. The ESP32-S3 version is especially appealing for drones since it supports camera input and AI integration. Although there is open-source standard firmware for basic ESP32 drone flight, these projects lack sophisticated autonomous features like automated landing and accurate altitude hold. Furthermore, integrating altitude sensor in micro drone introduces noise caused by mechanical vibrations from the motors and propellors for which the simple low-pass filters are inadequate as they introduce latency that destabilizes altitude control loop. In order to overcome these obstacles, this paper presents a fully functional micro drone that uses the ESP32-S3 sense as its flight controller. The following are the main elements of this work:

- A complete low-cost drone built under Rs. 5,500 using off-the-shelf components and a 3D-printed frame.
- Integration of a VL53L0X time of flight(TOF) sensor with a 1-D linear Kalman filter to mitigate vibration induced noise.
- A discrete MOSFET-based motor driver circuit as a cost-effective alternative to integrated motor driver ICs.
- A Wi-Fi based mobile app for real-time drone control, eliminating the need for a dedicated RC transmitter.
- Development of an autonomous landing state machine that utilizes the filtered altitude data to execute safe descent profile.

The rest of this document is structured as follows: section IIreviews relevant literature; section III describes the system architecture; section IV deals with hardware design; section V explains the software and control design; section VI provides implementation details; section VII talks about experiment results; and section VIII concludes with future directions.

II. LITERATURE REVIEW

A. Platforms for Microdrones

A popular open-source microdrone platform that weighs 27g and support a variety of expansions is Bitcraze'scrazyflie 2.1 [4]. Despite its great capabilities, its price of about USD 180 (Rs. 15,000) restricts accessibility. Although the EMAX Tinyhawk line provides affordable, dependable, ready-to-fly tiny drones, it is devoid of programmability and sensor extension choices. Circuit Digest's ESP32 series drone project [5] shows that the ESP32 could be a good starting point for microdrone's flight controller. Advanced noise filtering, autonomous landing, and altitude sensing are absent from the original ESP32 architecture. This work takes the ESP-Drone as foundation and extends it significantly to bridge these gaps.

B. Altitude Stabilization and Flight Controllers

Flight controllers process sensors data and generate motor control signals.Betaflight and AdruPilot [6] are two well-known open-source flight controller firmware programs that are usually made for STM32-based board. With its 240MHz dual core Xtensa LX7 CPU and 8MB PSRAM, the ESP32-S3 has enough processing power for sophisticated filtering and real-time slight control [7]. PID control loops that operate on roll, pitch, and yawn angles obtained from IMU data are commonly used to achieve altitude stabilization [8]. Using sensor fusion method like the Mahony/Madgwick filters, the MPU6050 is still the most used IMU in inexpensive drone [9].

C. Noise Filtering and Altitude Estimation

Barometric pressure sensor (e.g., BMP280) are commonly used for altitude estimation but have a resolution of approximately ±1 meter, making them unsuitable for precise altitude hold at low altitudes [10]. Time-of-flight laser distance sensors, like the VL53L0X, provide great precision at distance of up to 1.2 meters [11]. However, in tiny drones, TOF sensors are particularly vulnerable to mechanical vibrations, resulting in noisy readings, and basic low-pass filters causes phase lag, reducing the altitude PID controller's performance. the Kalman filter is well acknowledged as an ideal state estimator capable of predicting genuine height while rejecting high frequency noise and adding little latency [12].

D. Motor driver circuit for coreless motors

Coreless motors, such as the 8250variant, are driven using N-channel MOSFETs as low-side switches in PWM controlled circuit [13]. Integrated motor drivers ICs are more expensive, but a discrete MOSFET-based solution using components such as the AO3400 provides greater flexibility and cost savings.

III. SYSTEM ARCHITECTURE

The whole system consists of three subsystems: the drone unit, the mobile controller application, and the communication link. The ESP32-S3 sense serves as the primary flight controller. It communicates via I2C with the MPU6050 and the VL53L0X (for altitude data). The processed data is sent through the PID and Kalman filter algorithm, which generate PWM signals that are routed to four discrete MOSFET motor drivers that operate the 8250 coreless motors. The ESP32-S3 also serves asa Wi-Fi access point, accepting UDP commands from a mobile application and sending telemetry.

IV. HARDWARE DESIGN

A. Frame design and 3D printing

The frame is designed in an X-configuration for symmetric thrust distribution. The wheelbase is 120mm.It was printed with PLA material (0.2mm layer height, 15% infill), which gave it a frame mass of 18 grams. A cutout on the bottom holds the downward-facing VL53LoX sensor

B. Flight controller: ESP32-S3 Sense

The ESP32-S3-WROOM-1-N8R8 was chosen because it has a dual-core 240MHz processor, 8MB PSRAM, built-in Wi-Fi, and several GPIO/PWM interfaces. Core 0 handles real-time sensor reading, Kalman filtering, and PID computation, while core 1 handles Wi-Fi communication and telemetry.

C. Inertial Measurement Unit: MPU6050

Inertial measurement unit-MPU6050 The MPU6050 combines a 3-axis accelerometer and a 3-axis gyroscope [14]. It is configured with an accelerometer range of ±4g, a gyroscope range of ±500º/s, and a sample rate of 1KHz via I2C at 400KHz.

D. Altitude sensor-VL53L0X (TOF)

The VL53L0X provides accurate distance measurement up to 1200mm regardless of target reflectance [11]. It is configured in long-range mode with a 30Hz update rate andis attached on the drone's underside looking downwards.

E. Motor Driver Circuit

Coreless motor requires unidirectional PWM-driven current, hence a low-side N-channel MOSFET switch is the most efficient topology. The AO3400 N-channel MOSFET was chosen for its low on-resistance (34mΩ @ VGS=4.5V) and gate threshold of 0.7V, resulting in reliable switching with 3.3V GPIO. The SS34 Schottky Diode was connected across each motor as a flyback diode. Its rapid reverse recovery time and low forward voltage drop (0.55V) shield the MOSFET from inductive voltage spikes. 10KΩ gate resistor: limits current during capacitive charging of the MOSFET gate. Four identical circuits are used for the four motors.

F. Motor, Propellers, and Power

8250 coreless motors operate at 3.7V with a no-load speed of ~50,000 RPM. 65mm two-blade propellers (2^X CW, 2^XCCW) balance reactive torques. A single-cell 3.7V 380mAh LiPo battery powers the system.

V. SOFTWARE AND CONTROL DESIGN

A. Firmware Architecture

The firmware utilizes the circuit digest ESP-Drone project [5] as a baseline framework for low-level IMU Communication and basic PID stabilization. This baseline was significantly modified. The following original contribution where implemented:

- Integration of the VL53LoX TOF sensor driver.
- Implementation of a 1D-linear Kalman filter.
- Development of an automated landing state machine.
- Replacement of the web interface with a UDP protocol for a mobile app.

B. Attitude Estimation

Raw MPU6050 data is fused using the Mahony filter [15], which provides stable roll and pitch estimates. The resulting quaternion is converted to Euler angle for the PID controller.

C. Altitude Estimation Using 1-D Linear KalmanFilter

The VL53L0X measurements are corrupted by high frequency noise from motor vibrations. A simple low-pass filter introduces phase lag. Therefore, a 1-D linear Kalman filter was implemented. The state velocity $X_k$consists of altitude *h* and vertical velocity *v*:

$$x_k = \begin{bmatrix} h_k \\ v_k \end{bmatrix} \quad \text{Eq. (1)}$$

The discrete state-space model is:

$$x_k = Ax_{k-1} + Bu_k + w_k \quad \text{Eq. (2)}$$

$$z_k = Hx_k + v_k \quad \text{Eq. (3)}$$

The filter operates in two steps.
Prediction:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_k \quad \text{Eq. (4)}$$

$$P_k^- = AP_{k-1}A^T + Q \quad \text{Eq. (5)}$$

Update:

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1} \quad \text{Eq. (6)}$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-) \quad \text{Eq. (7)}$$

$$P_k = (I - K_k H)P_k^- \quad \text{Eq. (8)}$$

The filter rejects vibration-induced noise while preserving a quick lag-free response by adjusting the process noise covariance Q and measurement noise covariance R.

D. PID Control

The drone employs a cascade PID control structure. The inner loop handles attitude stabilization on roll, pitch, and yaw. The outer loop manages altitude hold by applying the Kalman-filtered altitude $\hat{h}_k$. PID output is converted into individual motor PWM values that are restricted to [0,255] by the motor mixing algorithm.

E.Landing State Machine Automation

Kalman filtered altitude data is used by the automatic landing system to ensure a safe descent. Flying, descending, and touchdown are its three phases of operation.To avoid impact damage,the descent rate is gradually reduced as altitude increases. Touchdown is detected when $\hat{h}_k$< 3cm, at which point motor power is cut. Landing can be triggered by user command, Wi-Fi loss, or low battery.

F. Mobile Application & Communication

An android application was developed featuring virtual joystick. the app sends control packets at 50Hz via UDP to the drone's AP IP.

VI. IMPLEMENTATION

The 3D-printed frame was cleaned and motor press-fit into the mounts. The ESP32-S3 was mounted centrally with vibration isolating foam tape. The MPU6050 was mounted near the center of gravity. The discrete motor driver circuit was assembled on a prefboard. The extended firmware was compiled using the extended firmware was compiled using the Arduino IDE. Before flight, IMU offsets were calibrated on a level surface, and PID values were iteratively tuned during tethered test flights.

VII. RESULT AND DISCUSSION

A. System Specifications

The complete drone weight 58g with a thrust to weight ratio of 1:9:1, a flight time of ~6 minutes, and a total build cost of ~Rs 1,744.

B. Kalman Filter Performance

The Kalman filter reduces altitude variance by over 91% compare to raw data, while maintaining a phase lag of < 20ms, making it strictly superior to a low-pass filter. Variance was reduced to ±0.4 cm at a 50 cm hover.

C. Attitude Stabilization Performance

Roll stability (1σ) was ±2.1º, pitch stability (1σ) was ±2.3º, and step response rise time was 180ms.

D. Automated Landing Performance & Altitude Hold

The dronemaintained altitude with a stability of ±1.2 cm at a 50 cm setpoint when the Kalman filter altitude PID was activated.Automated landing was tested 20 times from 80 cm, achieving, a 95% success rate. The average landing time was 4.8s, with a final touchdown descent rate of 5.2 cm/s.

E. Wi-Fi Control Latency

UDP control latency averaged 18ms with a maximum of 45ms and a packet loss rate of <0.5% at a 5m range.

VIII. CONCLUSION AND FUTURE WORK

This paper presented the design and implementation of a low-cost micro drone based on ESP32-S3 sense.

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By extending an open-source baseline firmware, the project successfully integrated a VL53L0X TOF sensor and implemented a 1-D linear Kalman filter, solving the critical challenge of vibration induced altitude noise. This filtered data enabled a reliable automated landing state machine. Furthermore, a discrete MOSFET-based motor driver and a Wi-Fi mobile application kept the total build cost under Rs. 2,000. The drone achieves stable flight with attitude stability of ±2º, altitude hold accuracy of ±1.2 cm, and a 95% automated landing success rate. Future development will includes adding optical flow for horizontal positioning hold, integrating a camera for computer vision, and a magnetometer for yaw stability.

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Appendix

Component	Specification	Quantity	Unit Price (INR)	Total (INR)
Flight Controller	ESP32-S3 Sense	1	-	₹2500
	MPU6050 (6-DOF)	1	₹350	₹350
	VL53L0X (Time-of-Flight)	1	-	₹280
Motors	8250 Coreless DC Motors	4	-	₹440
Propellers	65mm Plastic Props (CW/CCW)	1 set	-	₹250

Component	Specification	Quantity	Unit Price (INR)	Total (INR)
Battery	3.7V 380mAh LiPo	1	-	₹850
Motor Drivers	AO3400 MOSFETs, SS34 Diodes	4 sets	₹10	₹40
Frame	3D Printed PLA (approx. 30g)	1	-	₹250
Miscellaneous	Prefboard, Resistors, Wires	-	₹80	₹30
Total Build Cost				₹5080