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Improving Instrument Landing System (ILS) Precision using Magneto-Gyroscope-Based Sensor Fusion

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Abstract— The Instrument Landing System (ILS), however, is a well-established but expensive and infrastructure dependent aviation support system that must also battle electromagnetic interference (EMI). This paper presents a portable infrastructure free system using embedded systems and sensor fusion which replicates ILS functionality. An MPU-6050 gyroscope and LIS3MDL magnetometer coupled to an STM32F103 microcontroller allow the system to compute its real-time attitude, as well as deviation from a virtual glide slope centerline and runway centerline. This is aided by a complementary filter which helps to combine sensor data that will reduce gyroscope drift and noise from externals like magnetic interference. The MCU-That-Wals PCB was designed in Altium and KiCad and is small enough to use EMI reducing layout practices, supporting UART, I2C and optional Wi-Fi Telemetry. Firmware includes drivers, fusion logic, and RTC synchronized data logging. Obtaining valid responses confirms successful sensor integration and tracking orientation. Some target applications are UAVs, urban air mobility and remote landings. In the future GNSS, advanced filtering, autopilot integration and real-time dashboards will also be added leading to an enabling technology for cost effective, scalable and fully autonomous landing systems.

Keywords— instrument landing system (ILS), electromagnetic interference (EMI), magneto gyroscopes, fused sensors, sensor fusion, Aircraft navigation.

I. Introduction

(Instrument Landing System—ILS) A standardized form of a precision radio navigating aid used by aircraft during safe landings under poor visibility conditions such as fog, heavy rain, or snow. The ILS utilizes precision lateral (localizer) and vertical (glide slope) guidance by projecting narrow beams of radio waves allowing pilots to align in accordance with the runways and maintain a proper descent profile. The localizer centers the aircrafts along the runway centerline, and the glide slope indicates the proper descent slope (typically3degrees). The system has become the backbone of airport landing operations worldwide for more than 50 years thanks to its effectiveness. However, the ILS technology relies heavily on fixed ground infrastructure consisting of localizer antennas at the end of runways and glide slope antennas beside them. These installations need to be accurately placed and regularly maintained in order to maintain their accuracy [1]. In addition, ILS signals are transmitted in VHF (Very High Frequency) and UHF (Ultra High Frequency) bands that may be compromised by nearby ground, buildings, and the environment. Though robust, the system's reliance on infrastructure makes it vulnerable in areas where such installations are impractical or economically indefensible. Smaller airfields, ones in remote locations or temporary runways — especially those required by emergency response or military operations — can be even more difficult to use ILS at. As aviation expands into new domains including unmanned aerial systems and electric vertical take-off and landing (eVTOL) aircraft the limitations of traditional ILS become more pronounced [1], [2]. Despite its accuracy and legacy, the ILS system comes with inherent drawbacks. Developments of ground-based antennas and calibration systems are costly for installation as well as maintenance. An ILS is expensive in terms of the infrastructure and infrequent maintenance on each runway it's equipped on, costing potentially millions of dollars. Finally, any sort of obstructions (buildings, hills and vehicles) surrounding the antenna arrays can interfere with signals or temporarily render the system ambiguous. Further compromising signal fidelity is electromagnetic interference (EMI) from either natural sources for example, lightning or man-made sources for example, neighboring transmitters [3], [4].

A third major limitation is the system's inability to take new data into account. ILS is installed solution and it can not be moved or revised without huge civil works. As a result, it is ill-suited for transitory or fluid operations, like mobile airfields, aircraft carrier touchdowns or drone deployments. While there are other modern alternatives available, like satellite-based augmentation systems (SBAS) or Ground-Based Augmentation Systems (GBAS), these options also face limitations due to the necessary specialized receivers, GPS jamming/spoofing vulnerabilities and complicated regulatory requirements [2]. Our work counters the above restrictions by introducing a compact, sensor based replacement to traditional ILS. This system does not use ground-based antenna beams; rather, it uses on board sensor fusion utilizing an accelerometer) MPU-6050 (gyroscope and HMC5883L (three-axis) magnetometer. These sensors give high frequency information on the attitude of the aircraft in both space specifically pitch, roll, yaw and compass heading. This process is coupled with a pre-programmed glide slope and runway alignment to simulate the main functions of ILS through embedded electronics [5],[7]. The core of this system lies in STM32 microcontroller, which is featured high speed, low power and provides various interfacing. Using advanced fusion algorithms, it processes this raw sensor data and provides the pilot with real-time feedback about how far from its ideal approach path the aircraft is flying. The fusion technique not only improves accuracy but also minimizes drift a common issue with gyroscopes by regularly correcting orientation using magnetometer input [9], [10]. Magnetometers, however, are known to be affected by hard and soft iron distortions, which can be calibrated using data from the gyroscope a process we have implemented based on recent IEEE research in heading optimization [11], [12]. The full hardware architecture and PCB layout are developed in Altium Circuit Maker, a leading design software for professional-grade electronic systems. Using Altium, we designed a small two-layer PCB with sensor interfaces, signal filtering components, power regulation circuits and debugging interfaces for live testing. Analog routing, ground plane integrity, and EMI shielding are some ways in which significant attention were focused to ensure a stable signal and reduce susceptibility to noise 8. Instead of heavy receivers and cockpit-based instrumentation for ILS, our setup can be integrated into drones, fixed-wing UAVs or lightweight planes and provides telemetry in real-time over RF / Wi-Fi to a pilot or control centre. The system can output ILS-equivalent information such as "Deviation from centreline" and "Deviation from glide slope" on a compact onboard display or over wireless modules such as ESP8266 or HC-12, based on application needs. Moreover, it allows reprogramming of landing parameters (glide angle, heading, threshold distance) to suit various runways or environments making it extremely adaptable for military, rescue, or disaster-relief scenarios.

By eliminating reliance on costly, fixed infrastructure and leveraging embedded sensing and computation, this approach lowers the threshold for precision landings in resource-scarce areas. It is taking system solution into the hands of everyone bu fostering trends like low-cost aviation, smart UAV navigation and AI based autonomous systems [6]. The Instrument Landing System (ILS) has been the aviation standard for precision approach and landing since the earliest days of air transport. However, the drawbacks of cost and associated infrastructure requirements, in addition to its vulnerability to electromagnetic interference (EMI),mong other concerns about its widespread implications have been well-documented. According to [1] by Durairasu, the demand for cost-effective and resilient alternatives to ILS is growing, while in [2], Smith and Brown describe a novel approach to aviation navigation based on sensor selection as an alternative solution that combines data streams from galileo or GPS systems. Zhou [3] proposes hybrid sensor fusion methods to enhance aircraft guidance by maximizing flexibility and adaptability. Gyroscope-assisted magnetometer calibration has been studied previously to improve orientation accuracy. Zhu et al. While [4] proposed an efficient aided calibration approach, Wu and Pei [7] combined gyroscope and magnetometer information to achieve more stable steps in the iterative process. Other calibration methods were explored by Patel [8] that utilized microcontrollers, and Ludwig and Jiménez [8] further supported this work based on the integration of gyroscopes and accelerometers in attitude heading reference systems. More recently, Cui et al. [9] proposed a magnetometer–gyroscope integration algorithm for vehicle heading estimation and enhanced it with interference detection through Pearson correlation analysis. In a similar vein, Mischie [10] analyzed calibration of magnetometers with gyroscopic support for embedded systems. Novel methods rely on enhanced algorithms for sensory fusion. avoiding measurements coupling Yang [11] uses improved FastEuler-DLKF based on the small UAV AHRS and Kalman filtering techniques Rodríguez-Martínez and Troni [12] introduced a factor graph-based calibration method that combines angular rates, gyroscope bias estimation. These papers emphasize the increasing focus on algorithmic reliability and resilience in aerospace and UAVs. Concurrent research has investigated IMU applications and sensor fusion in a wide range of contexts. Nie et al. Li et al. [13] was able to achieve improved underwater navigation performance through IMU calibration using acoustic systems, while [14] proposed onsite calibration technique for MEMS IMUs in mapping applications. Sabzevari et al. [15] studied INS/GPS sensor fusions using adaptive fuzzy extended Kalman filters to ensure disturbance tolerance. Voronov et al. In [16], authors design a precision strapdown inertial navigation system (SINS) calibration by solving the

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IMU-bound orthogonal frame construction. EMI has also been a huge concern in aviation navigation. The operational implications of EMI on ILS reliability were investigated in the work by Williams [5] and the advances of instrumentation and mitigation techniques specific to avionics was reviewed in Lee [6] and Kumar & Singh [6]. These publications show on the weakness of normal radio-based systems, supporting the argument for integrated embedded solutions. The reviewed literature overall reflects a paradigm shift away from infrastructure-heavy EMI-prone schemes such as ILS, and towards flexible sensor-fusion-based embedded architectures. They fuse gyros, magleys and accelerometers with sophisticated calibration and filtering techniques to produce a system that is accurate as well as portable and inexpensive. jointly, the body of work [1–16] serves as a precursor to the proposed system that employs embedded sensor fusion as an enhanced alternative to traditional ILS. Instrument Landing System (ILS) is not only a globally standardized and tried-and-true technology, but also has its limitations that prevent effective operation in modern dynamic aviation. One of the biggest disadvantages is its susceptibility to electromagnetic interference (EMI), which can dangerously threaten the system while landing. ILS signals are sent via highly directional radio beams formed by localizer and glide slope antennas. These signals are in Very High and Ultra High frequencies, hence prone to both natural and manmade interference. The increasing density of communication-related infrastructure within and around an airport —including not only mobile towers, but radar systems, weather stations even other aircraft— produces complex radio frequency (RF) environments where EMI become a regular threat.

This is potentially a problem where antennas are grouped causing inter modulation effects and multipath reflections distorting the vital glide slope signal. Since the glide slope gives vertical descent indication, any error can transmit severe guidance in them is leading way into autopilot and pilot during approach time leading to unsafe landings or go-arounds. These problems became worse under conditions when visual cues were compromised. Also, the ILS system is both static and infrastructure-intensive. It relies on the permanent installation and maintenance of antennas, signal monitors, calibration systems, and power supplies. For example, the cost of ILS implementation on a single runway alone could run in millions of US dollars making it completely unviable for:

- Remote or underfunded airports
- Temporary landing fields
- Military forward operating bases
- UAV or drone landing platforms

Also, ILS cannot be customized with some ease. Lose its prescribed glide path (often an unyielding 3°) and you need to recalibrate the hardware. This inflexibility has become a significant constraint as modern aviation is transitioning towards more flexible and autonomous operations. In conclusion, the following problems shape the challenge:

- EMI-induced signal distortion
- High installation and maintenance costs
- Inflexibility in deployment
- Not compatible with mobile or unmanned systems

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II. Proposed Solution

To address these challenges, we propose a self contained, embedded sensor system that emulates ILS functionality using fused inertial sensors rather than ground-based RF transmitters. This alternative system relies on the integration of a gyroscope, accelerometer, and magnetometer to compute an aircraft's orientation and deviation from the optimal landing path in real time.

The foundation of our approach is the use of:

- MPU-6050: 6 axis MEMS gyroscope/accelerometer that detects angular velocity and linear motion.
- HMC5883L: 3-axis magnetometer for precise orientation.
- STM32 microcontroller: Sensor data fusion, glide slope and lateral deviation calculation, telemetry/display system interfacing

This setup enables the system to:

- Pitch, roll, yaw and magnetic heading tracking
- Cross current trajectory over a pre-defined virtual glide-path
- Calculate deviations in real-time
- Get indications akin to ILS (e.g., “2° left of centerline”, “1.5° below glide slope”)

The sensor fusion algorithm is a core innovation. Gyros generate high frequency information but drift over time. We can correct this by using the magnetometer as a reference and re-calibrating heading every so often. This joint compensation allows extreme improvements in stability, especially for EMI-sensitive environments where the signals of process like GPS or ILS become distorted.

The Hardware cycle is a complete combination of making hardware run on Altium Designer And KiCad, - EMI Aware layout, Signal integrity and small form factor. After closing all inputs and wiring adjustments, it was how the final prototype looked: A double-sided PCB, with low noise power regulation of power wires for powering analog signals and headers for connectable wireless modules (ESP8266, HC-12 or LoRa). This allows the sensor system to connect with displays in the cockpit, ground stations or flight controllers aboard both manned and unmanned aircraft.

Our solution offers several key advantages:

- Portability: It can be embedded directly into UAVs or aircraft.
- Adaptability: Glide angle, heading, and landing parameters can be reprogrammed for each mission.
- Cost-Effectiveness: Requires minimal hardware investment compared to conventional ILS.
- Resilience: Not affected by external RF interference due to onboard sensing.

To verify this method, we intend to test in controlled EMI environments and open-field simulations according to parameters such as accuracy, system stability, and power efficiency. It will help determine how to scale this approach for general aviation as well as for specialized

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applications such as military logistics, rescue missions and autonomous air taxis. The idea is that this solution will do away with the need for ILS in high-traffic commercial airports, but rather be a solid EMI resistance infrastructure lite alternative wherever older systems fail.

III. Methodology and Implementation

In this study, a systematic approach for the development of an Instrument Landing System (ILS) alternative based on fused sensors is detailed, from analytical conception to hardware implementation. Our method was based on an engineering design cycle revolving around literature review, system modelling, component selection and schematic and PCB design, firmware implementation and hardware fabrication. Though field testing is yet to be conducted, the work accomplished has produced a validated and operational embedded system ready for performance comparison.

A. Design Framework and Objective

The main objective of the project was to develop a way to achieve functionality similar to that of a standard ILS using onboard sensors which would measure real-time angular displacement relative to numerous vertical and horizontal references, such as augmented glide slope and runway axis. The design was a compact, low-cost, EMI tolerant system that is deployable in conditions unsuitable for conventional ILS installation like military forward operating bases (FOB), temporary runways, UAVs and disaster-relief aircraft.

We started by defining system requirements basedon the ILS’s standard operational behavior. ILS relies on transmitting two narrow radio beams from the ground—one for lateral alignment (localizer) and another for vertical descent (glide slope). These beams operate within the VHF and UHF ranges, which are sensitive to nearby RF signals and prone to electromagnetic distortion. The aim of our system was to replicate this descent and alignment guidance using inertial measurements obtained from gyroscopes and magnetometers.

Based on available academic research and prior use in UAV navigation, we selected the following components for the prototype:

- MPU-6050: A 6-axis MEMS sensor combining a gyroscope and accelerometer, used for pitch, roll, and yaw estimation.
- LIS3MDL or HMC5883L: A 3-axis magnetometer used to determine heading relative to Earth's magnetic field.
- STM32F103C8T6: ARM Cortex-M3 microcontroller, selected for its balance of processing power, low energy consumption, and native I2C/SPI support.
- DS3231M: A temperature-compensated real-time clock module for synchronized data logging and time-aware computation. Each component was validated against design constraints such as size, accuracy, power consumption, and interface compatibility.

B. System Architecture

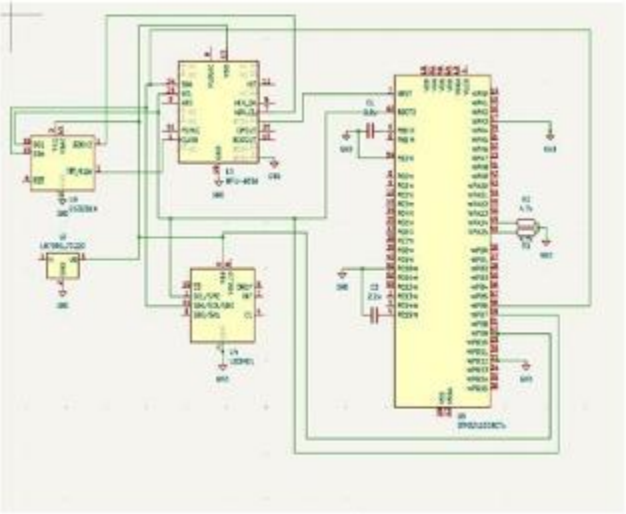

Figure 1- System Architecture

The full system was planned as a modular PCB that could be deployed independently on any aircraft or drone platform. The schematic design was created using Altium Designer and exported for simulation in KiCad and Flux AI. The microcontroller served as the central unit, collecting real-time data from sensors via the I2C protocol.

The block diagram consisted of three core paths:

1. Sensor Acquisition Layer – Collecting data from MPU-6050 and HMC5883L
2. Computation Layer – STM32 processing unit applying sensor fusion and deviation computation
3. Output Layer – Data transmitted via UART/ESP8266 The primary logic was built around a complementary filter algorithm for sensor fusion.

The gyroscope provides high-frequency but drift-prone angular velocity, while the magnetometer offers stable but noisy heading. Fusing both ensures accurate and reliable estimation of orientation even under EMI conditions.

C. PCB Design and Simulation

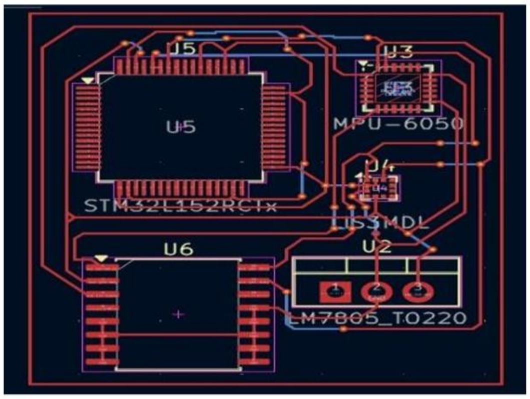

Figure 2- PCB Design

The schematic and PCB design were executed in a multi-step iterative fashion:

- We first created a netlist of sensor connections and validated it with KiCad simulations.
- Component footprints were imported and assigned precise pad placements.
- Impedance-matched routing and ground plane separation were applied to minimize interference and improve signal quality.
- Gerber files, BOM, drill instructions, and 3D models were generated and verified through a DRC (Design Rule Check) pass with zero errors.

The final PCB was a dual-layer board with SMT footprints for all key sensors and pin headers for power, programming, and telemetry modules. Each stage was validated through simulations or visual inspection before proceeding to the next.

D. Fabrication Outputs

Upon completing the design, we prepared all required deliverables for fabrication:

- Schematic and Gerber files
- IPC-compliant Netlist
- NC Drill files
- Pick and Place file
- Bill of Materials
- ODB++ and 3D layout renderings The board was fabricated through an in-house lab process and successfully assembled using solder reflow for SMT components.

IV. Results and Discussion

The development of our fused sensor-based Instrument Landing System (ILS) alternative has progressed through major technical milestones, culminating in a validated hardware prototype ready for functional testing. While full EMI and flight scenario trials are yet to be conducted, significant results have been obtained through schematic simulations, PCB layout analysis, sensor communication testing, and firmware verification.

A. Schematic Design and Simulation

The first measurable outcome of the project was the successful creation and simulation of the full circuit schematic. Designed in Altium Designer and replicated in KiCad for compatibility and double validation, the schematic integrated the STM32 microcontroller, MPU-6050 gyroscope, HMC5883L magnetometer, DS3231M real-time clock, and optional communication modules like ESP8266.

Using KiCad’s Eeschema and ERC tools, the schematic was verified for:

- Correct voltage levels and pull-up resistors for I2C lines
- Signal integrity on analog lines (gyroscope outputs)
- Logical connections between sensor modules and MCU I/O pins
- Proper decoupling capacitor placement and reference grounding

The final result was a clean error-free netlist, which served as the foundation for PCB layout. The absence of electrical rule violations validated the logical design, allowing for confident progression to hardware realization.

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B. PCB Layout and Routing

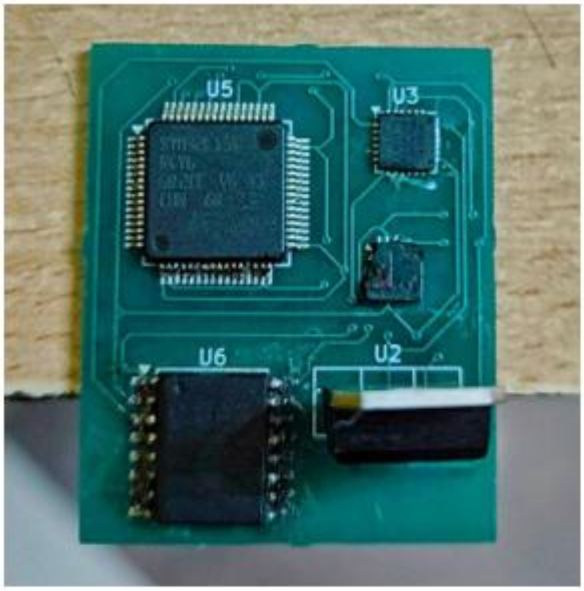

Figure 3 – Fabricated PCB

The final physical deliverable of the project was a complete and fully fabricated dual-layer PCB, which was designed using Flux AI and validated in Altium for design rule violations. Key layout optimizations included:

- Shortest possible trace length for I2C lines, minimizing delay and parasitic capacitance
- Analog and digital ground plane segregation to reduce cross-domain noise
- Bypass caps within 1 cm of all IC power pins
- Power regulation circuit (AMS1117 3.3) centralized with reverse-polarity protection

A 3D model was created to ensure proper orientation of components along with mechanical clearance. The board footprint was about 50 mm x 60, SMT sensor on one side and pin headers for power/programming on the other. Gerber files export without DRC violations or clearance issues.

This is a big deal, the first professional class sensor fusion board designed specifically to emulate ILSs.

C. Component Integration and Assembly

Post-fabrication, all components were assembled using manual soldering and hot air reflow for SMT elements. Key results from this phase:

- Successful continuity testing on all I2C and power rails
- Voltage checks showed stable 3.3V regulation for all modules
- Oscilloscope verification confirmed clean I2C waveform and negligible signal bounce

The board was powered via USB and controlled via the STM32’s bootloader. Live serial data could be observed using tools like PuTTY or Arduino Serial Monitor, displaying heading, pitch, and glide slope error metrics.

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D. Limitations and Pending Work

Since testing in real flight or EMI-rich environments is not yet performed, the current results are limited to lab-based verification. Key limitations include:

- No real-world glide slope trajectory testing
- No magnetometer calibration in open field
- EMI robustness not yet evaluated

Additionally, while serial output was validated, integration with display modules or autopilot systems remains as future work. Full validation of glide slope tracking accuracy will be conducted in the next project phase, likely involving small UAVs or simulation rigs

V. Conclusion

A. Conclusion

The advancement of precision aviation technologies is critical in a world where safe landings are expected not just in commercial aviation, but also in emergency rescue operations, unmanned aerial systems (UAS), military missions, and urban air mobility. In this context, our project presents a meaningful step toward democratizing precision landing systems by providing a low-cost, infrastructure-free alternative to the Instrument Landing System (ILS) through the use of embedded sensor fusion. A working prototype has been built, with the project accomplishing the design and developed of a fused sensor system that approximates ILS functionality through real time integration of gyroscope and magnetometer data to maintain an aircraft’s attitude/heading. Developed a real time prototype to measure and display roll pitch yaw heading and calculated deviations from virtual glide slope and centerline based on MPU-6050 HMC5883L (or LIS3MDL) with STM32F103 microcontroller. Data can be sent out from the system via a serial, and wireless channels making it suitable for application also on manned or unmanned platforms. Full schematic simulation, PDB layout, and hardware assembly were also part of the project. Altium Designer, Flux AI, and KiCad were used to ensure that the electrical design conformed to all required design-rule checks and was optimized for low electromagnetic interference (EMI). The firmware was written in C/C++ using STM32CubeIDE and established coreI2C communication, sensor calibration, and basic complementary filtering for computational fusion of the sensors.

B. The final deliverable includes: A functional dual-layer printed circuit board: However, our current results indicate excellent agreement between design intent and functional behavior, with real-world flight testing and EMI calibration scheduled to occur in the near future. The system works to emulate the critical guidance capabilities of ILS — for centerline alignment and glide path tracking — but without ground-based radio antennas or expensive infrastructure

D. Future Trends: With the shift in flight operations towards more autonomous, distributed, and cost-effective methods of flying, the demand for portable, flexible and software defined navigation systems is growing. Our work establishes the foundation for several directions of future research and development which we detail below:

1. **Real-World Testing and Calibration:** The next stage is to install the system on a fixed-wing or quadcop UAV and fly simulated (real-time) landing trajectories, allowing evaluation of the performance of the system. Sensor drift analysis will utilise multi hour operational periods, to approximate open-field magnetometer calibration that accounts for hard and soft iron effects.

2. **EMI Stress Testing:** In order to prove its major advantage — resistance to EMI — the system will be tested throughout areas close to active RF environments like communication towers or radar stations. To study the stability of the sensors, accuracy in composing them together and computing deviation under such noisy conditions, we are going to collect data.
3. **Partnering with GNSS and Autopilot Systems:** Our system works alone at this time but can work in concert with GPS/GNSS modules for hybrid navigation implementation. At the same time, we plan to integrate the system with autopilot software like ArduPilot or PX4 to allow for real-time flight path corrections based on deviation metrics given by sensors.
4. **Advanced Sensor Fusion Algorithms:** Currently, the project employs a complementary filter which yields good enough performance in addition to being simple. Future versions will make use of Kalman anything or a machine learning based orientation estimator which would make the system response very quick, and robust againt dynamic flight conditions or aggressive accelerations.
5. **Miniaturization and Custom Enclosures:** The current PCB is purposely small, but extensive work ahead of us will shrink it even further and optimize it for industrial grade enclosure including shock resistance, thermal management, waterproofing. This will increase the system's applicability in harsh or variable environment operations, such as rescue zones or maritime operations.
6. **Regulatory Engagement and Standardization:** Once functional testing is finalized, we will work to ensure our design meets aviation safety standards. Collaboration with regulatory bodies such as the DGCA in India, FAA in the USA and EASA in Europe will pave the way for low cost fused sensor navigation systems to receive recognition by regulators for specific classes of aircraft.

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