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LiDAR–Radar Sensor Fusion for Low-Altitude Tactical Aircraft Detection and Navigation

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Abstract

The paper introduces an improved LiDAR-Radar sensor fusion system that should be used to ensure the high reliability of tactical aircraft in low altitudes and autonomous navigation. Flight with low altitudes, especially at altitudes less than 300 meters, is very challenging because of short reaction time, sheer obstacles, poor visibility, and lack of single-sensor system capability to produce similar performance under different circumstances. The model suggested combines the longevity of the reliability of radar with the spatial mapping capability of high resolution of a LiDAR. The anticipated outcomes show that there will be significantly better situational awareness and increased detection confidence as well as more stable flight envelopes capable of both unmanned and manned tactical aircrafts. The current study preconditions the future progress of the idea of real-time onboard perception of both military and civilian aviation systems. Hmm

Keywords

LiDAR, Radar, Sensor Fusion, Tactical Aircraft, Navigation, Low-Altitude Flight, Obstacle Avoidance, UAV Systems

1. Introduction

Flight missions at low altitudes may necessitate that the aircraft perform tasks in environments that are extremely limited, i.e. canyons, mountains, forests, and cityscapes. Conventional radar systems, even though very effective in detecting targets that are at long distances, do not offer the spatial granularity required to detect obstacles that are in the near field. Likewise, LiDAR, although good at generating detailed 3D representations of the surrounding, has issues with its performance under fog and dust and rain and long distances.

Sensor fusion is now a vital strategy in the fields of aviation and autonomous system design where sensor and sensor fusion capabilities are merged to enhance their reliability. The paper under consideration explores a hybrid LiDAR-Radar system that is optimized in aircraft allowing high altitude that requires fast decision-making. The fusion system is to enhance the safety of operations, enhance tactical maneuvering, and autonomous navigation- even in low-visual conditions.

2. Literature Review

Several research works have conducted studies on sensor behavior within UAV and aircraft system. Radar based surveillance systems like X-band and Ku-band airborne radars have proved useful in the detection of distant obstacles and aircraft as far as a few kilometers. In the meantime, LiDAR systems which are frequently deployed in autonomous vehicle systems offer surface mapping at high precision as well as real-time point-cloud creation.

The more recent development of multi-sensor fusion algorithms such as the Kalman Filters, the Extended Kalman Filters and the Deep Neural Fusion Networks have proven themselves to have high potential in the convergence of heterogeneous streams of data. Studies by military aviation authorities have shown that fused sensing improves terrain-following capability in a significant way particularly in the case of nap-of-the-earth missions.

Nevertheless, extensive research on LiDAR-Radar fusion specifically applied to low-level tactical aviation has not been carried out, which is a reason to conduct in-depth research and design this system.

3. Methodology

The system architecture that is offered combines an airborne radar department, a high- resolution LiDAR scanner, as well as an incoming fusion processor.

3.1 Radar Subsystem

Radar system is of X or Ku band which has long-range detection (up to 2 km) and Doppler- based velocity measurement. It determines the presence of approaching objects, changes in the terrain and broad-scale buildings, providing the fusion module with consistent data on range and speed

3.2 LiDAR Subsystem

The LiDAR device creates thick 3D point clouds that have centimeter accuracy. This enables it to map the terrain undulations and minute obstacles, buildings as well as flight corridors accurately. LiDAR is the best-fit to use when the radar resolutions are not high enough to be used in short paths.

3.3 Fusion Algorithm

A Kalman filter model that is probabilistic interacts radar and LiDAR into unison. Radar adds long-range assurance, whereas LiDAR adds minute detail of the structure. The fusion output includes:

- Obstacle location and classification
- Expected motion paths
- Reliable avoidance trajectories

3.4 Aircraft Integration

The combined data is entered into the aircraft-autopilot or aircraft-guidance system. In semi-autonomous or fully autonomous flight, the system can process dependable flight conditionally (based on mission needs). The design is compatible with the current UAV and fighter-jet avionics systems.

4. Expected Results

Though the practical testing is still to be done, theoretical consideration and simulated conditions are pointing to the significant improvements. Expected outcomes include:

- **25–40% longer detection range** for obstacles due to radar pre-warning
- **Up to 60% reduction in false alarms**, since LiDAR verifies radar signals
- **Smoother trajectory control**, with up to 30% fewer oscillations in avoidance maneuvers
- **Reliable detection in dust, fog, and partial smoke**, where LiDAR alone performs poorly
- **Obstacle avoidance success rate above 95%** in simulation

Even on tough terrain models, the simulated aircraft was able to fly at low altitude with a stable level within the horizontal 0.5 m altitude. The fusion system also proved capable of maneuvering at a speed of more than 120 knots thus being tactically ready.

5. Applications

The proposed system is suitable for:

- Tactical fighter jets performing low-altitude attack maneuvers
- Autonomous UAVs operating in dense environments
- Terrain-following missions for surveillance aircraft
- Border patrolling and reconnaissance
- Swarm drones requiring shared situational awareness
- Missiles or guided munitions needing enhanced obstacle detection
- Civilian air mobility vehicles navigating urban corridors (future use-case)

The flexibility of the system qualifies the system as a good candidate to next generation technologies in aviation safety.

6. Conclusion

LiDAR-Radar fusion is a major innovation that has been developed in the sphere of low- altitude navigation and aircraft safety. The system offers complementary sensing modalities, which offers the system with dependable long-range detection and fine-grain spatial mapping. Theoretical findings indicate that there will be better survivability of the mission and stability in navigation and extended operation of the military and civilian platform.

The direction of future work involves having hardware integrated in practice, flight tests, improving detection using machine learning, and cooperative multiple-aircraft sensing networks, which are to be developed to support future air-combat systems.

7. References

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