Abstract
Vertiport Design with Integrated Visual Markers for Vision-Aided Navigation

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Innovative Air Mobility (IAM) promises to transform urban transportation by enabling high-frequency, short-range flights of electric vertical take-off and landing (eVTOL) vehicles. While the concept is compelling, the safety of IAM operations requires the availability of a navigation solution that is both highly accurate and robust under the entire flight phases. In particular, the take-off and landing phases at the Final Approach and Take-off (FATO) area is a safety-critical zone in which positional errors of even a few decimeters can lead to catastrophic collisions. Therefore, European Union Aviation Safety Agency (EASA) has defined stringent “safety-volume” constraints for the FATO that must be respected when planning the flight routes at FATO areas.

Conventional Global Navigation Satellite System (GNSS) receivers, while sufficient for the majority of the en-route phase, become increasingly unreliable as a vehicle descends to the vertiport. Near-ground propagation is plagued by signal blockage from surrounding structures, rapid variations in satellite geometry, and severe multipath reflections from the concrete and metal surfaces that dominate urban vertiport environments. These impairments can degrade GNSS-only position estimates to the order that is far beyond the tolerances prescribed by EASA for the safety volume. Consequently, a single-sensor GNSS solution cannot guarantee the required level of situational awareness during the most critical portions of the flight.

Therefore, a multi-sensor navigation architecture has been proposed in [2]. By fusing GNSS measurements with inertial navigation system (INS) data, barometric altitude, and vision-based cues, the overall estimator can maintain continuity and accuracy even when one or more sensors are degraded. Within this framework, vision-aided navigation offers a particularly attractive capability because it can provide high-resolution pose information that is independent of satellite geometry. Furthermore, vision-aided system can perform using inexpensive, passive visual markers located on the vertiport.

The present work concentrates on the vision-aided component of the multi-sensor stack, specifically on the use of fiducial markers as a source of pose estimation. Building on the methodology introduced in [3], we detect the four corner points of each marker in the on-board camera image, solve the perspective-n-point (PnP) problem, and recover the vehicle’s three-dimensional position and attitude relative to the marker’s reference frame. When the three-dimensional coordinates of the marker corners are

pre-registered to a global datum (e.g., a local East-North-Up frame tied to the vertiport's geodetic location), the resulting pose estimate is an absolute navigation solution that can be directly fed to the flight-guidance controller.

To assess the practical benefits of augmenting the EASA-prescribed vertiport layout with dedicated fiducial markers, we have designed a series of marker configurations that complement the existing "V-pattern" markings. The configurations explore variations in marker size, spacing, and orientation, with the aim of maximizing visibility from typical approach trajectories. Each layout is evaluated against two criteria: (i) the geometric dilution of precision (GDOP) of the visual pose solution across a dense grid of approach points, and (ii) the robustness of the solution under adverse weather conditions (fog, rain, and low-sun glare).
All experiments are conducted in a high-fidelity virtual environment built on the Unreal Engine platform and interfaced with Microsoft's AirSim (ProjectAirSim) toolkit. This simulation framework provides photorealistic rendering of the vertiport, realistic atmospheric scattering models, and a physics-based camera sensor that reproduces the noise characteristics of commercial machine-vision cameras.

Keywords: Innovative Air Mobility, vertiport, safety volume, multi-sensor navigation, vision-aided navigation, fiducial markers, AprilTag, simulation, Unreal Engine, AirSim.

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Biography
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Young-Hee Lee is an academic researcher at the Institute of Communications and Navigation of the German Aerospace Center (DLR) and a lecturer at the Technical University of Munich. She received her BS and MS in Aerospace Engineering from Korea Advanced Institute of Science and Technology (KAIST) in South Korea, and successfully completed her Ph.D. work on collaborative SLAM for multi-agent systems using visual and range measurements at the Technical University of Munich in 2023.