Satellite Drone Navigation System (SDNS)

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1 Introduction

We chose to tackle the Millog and Milrem Challenge Track 2 with the objective of improving GNSS-agnostic positioning for UGVs.

2 Problem

GNSS denied environments introduce difficulties for accurate autonomous navigation for unmanned ground vehicles (UGV). Although UGV platforms include state-of-the-art sensor suites and sensor fusion, sensor noise and therefore position drift is inevitable without repeated absolute position anchors. This can be especially problematic when carrying out longer distance missions with a defined waypoint. This problem is further exacerbated when missions are executed consecutively.

An example is casualty evacuation operations, where the distance to the patient is often greater than 200 m. Depending on terrain, magnetic interference, and on-board sensors, the drift in assumed location could prolong or endanger the mission.

A potential solution that has seen some implementation is having a module that allows to deploy a tethered drone from the UGV[1]. This grants a wide optical view over the area, helping locate and navigate the vehicle through complicated terrain. However, it only allows for relative positioning from the drone reference frame. It does not stop the absolute positioning drift, so the drone itself does not know where it is in the wider local area.

In conclusion, a GNSS alternative is needed rapidly to provide accurate and reliable absolute positioning in a jammed environment.

3 Our Team

Deniel Must
Satellite Communications Engineer

Augustinas Rukas
Satellite Systems Engineer

Tuomas Erola
Rocket Scientist

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Data Analyst

We are a team of enthusiastic students in the field of Space Science and Technology. We have founded and continue to lead Aalto Space Association with the central aim of increasing interest in space-related activities. We are also working on various space technology projects at Aalto University, from Finland's next student satellite project, to a student-run rocketry team.[2]

4 Solution - Satellite-aided drone-UGV teaming for navigation

4.1 Satellites as an absolute reference

The need for an absolute reference frame for position anchoring naturally lead us to explore space-based capabilities. However, modern crises are defined by electric warfare (EW), which invalidates traditional systems such as GNSS or TX/RX positioning. Pre-fetched satellite images provide absolute referencing of surrounding terrain, but it is extremely difficult to correlate ground-based observations from the on-board camera and satellite imagery.

Therefore, our solution expands on the tethered drone concept. The drone acts as an intermediary and provides a point-of-view from above, which can be matched to a wider satellite image of the local mission area (chosen based on the drifted position estimate) that is stored on the UGV. This way, we can accurately estimate the position of the drone based on its observations. Then, the UGV can be located in the drone's image and its absolute coordinates can be calculated relative to the known drone position. Finally, since the drone is connected via an fiber optical cable, it cannot be jammed, and all of the computing can be done in the UGV.

4.2 Technological Feasibility

4.2.1 Operations In Various Conditions

Operation during a clear day

During a clear day we capitalize on the benefits of the optical camera and use it's data in our image recognition model to pinpoint the UGV location. We would install a small lightweight camera on our tethered drone.

Operation during night

During the night, optical instruments cannot be relied upon considering the lack of resolution and image quality (mainly because of graininess)[3]. Hence, we employ synthetic aperture radars (SARs). SAR can be used in night-time environments to produce sufficiently crisp images for our image recognition model. This is more involved in the case of smaller more commercial drones, however, its feasibility was already explored and it is very much doable. [4]

Operation in environments where the canopy is covered

In situations when the canopy is covered SAR radars are able to see through[5], for example clouds and leaves of trees, which enables us to locate the UGV even in impossible conditions.

4.2.2 Requirements

The first requirement that must be met is high enough resolution for both synthetic aperature radar (SAR) and optical satellite imagery. To match aerial drone imagery with a pre-fetched map, the satellite image must resolve terrain features such as roads, forest boundaries, or building outlines visible to the drone's camera. Assuming the UGV operates with a 1–3 m tolerance for absolute positioning, a ground sample distance of 0.3 m ensures sufficient precision for feature-based alignment. A 30 cm ground sample distance corresponds to ± 0.30 m positional uncertainty per pixel, which is acceptable for our navigation tasks.

From public sources, ICEYE offers up to 25 cm-resolution SAR imagery.[6] 30 cm-resolution optical imagery is offered Airbus Pleiades Neo[7]. Therefore, current commercial satellite data already provides the necessary spatial resolution for accurate drone-to-map registration.

The recency of satellite imagery is another important aspect, since the frontline terrain can change rapidly under, for example, artillery bombardment. Although it is possible to have renewed images of a target area every Low-Earth-Orbit period of around 90 minutes (with a dedicated satellite constellation, the time further decreases), this depends heavily on the arrangements made with the provider and the global location of the mission. We also must consider that, in a jammed environment, the UGV might not have the capability to download updates, but doing it daily, at a minimum, is very feasible both for UGVs and satellites.

5 Image Recognition Model

The image recognition model is designed to perform real-time comparison between satellite images and live drone footage to accurately determine the location of the UGV. This section describes the underlying algorithm implemented in the demo available on the project GitHub repository.

5.1 Algorithm

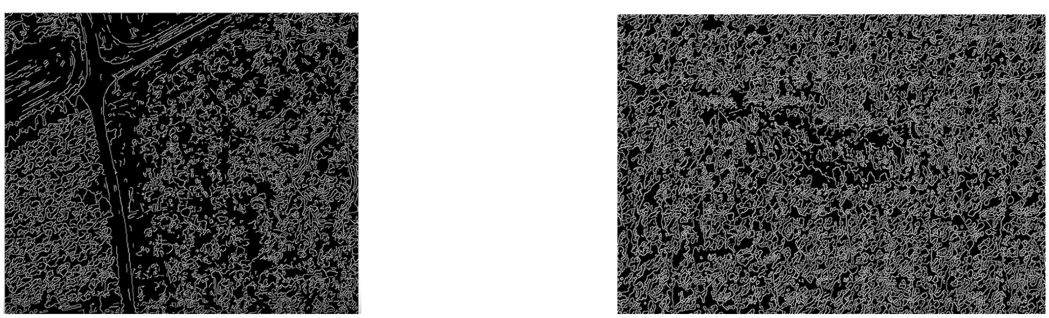
The satellite image encompasses the entire area in which the UGV is expected to operate during the mission. The scene-matching process is based on feature detection and matching algorithm. Since the drone image represents a sub-frame of the larger satellite scene, a region of interest (ROI) is first identified to restrict feature extraction to relevant areas. The ROI is determined by comparing Canny [8] edges across the subframes of varying sizes. Once the ROI is established, keypoints and descriptors are extracted using the ORB [9] algorithm. These features are then matched to those in the satellite image using a brute-force matcher. To achieve precise alignment and ensure robustness against outliers, the algorithm applies the RANSAC [10] method to estimate the true position of the drone frame within the satellite image.

5.2 Results

The results demonstrates a proof of concept for the proposed localization method. The algorithm was able to identify the correct regions of the satellite imagery that corresponds to the drone's view, validating the feasibility of using visual feature matching for UGV localization. To further develop should focus on improving robustness to environmental variations, such as structural damage or landscape changes, and enhancing the ROI detection performance in challenging areas like dense forests.

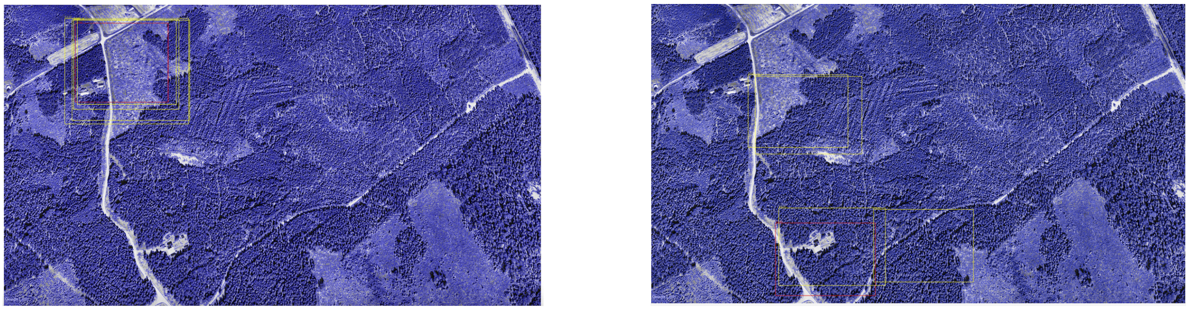
(a) Satellite image (b) Drone 1 (c) Drone 2

Figure 1: Satellite image of the operation environment and two simulated drone images.



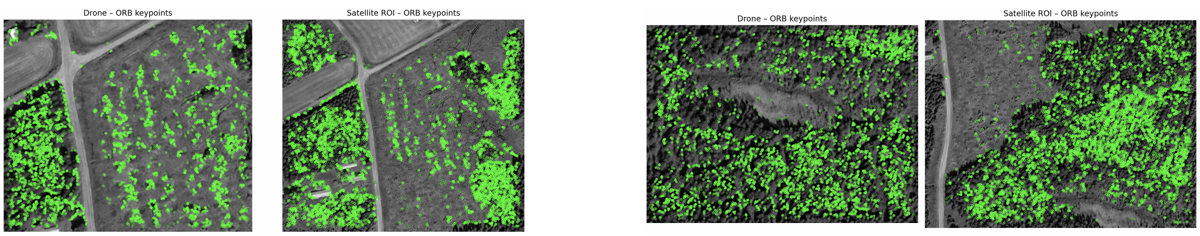
(a) Drone 1 (b) Drone 2

Figure 2: Canny edge detection for Drone 1 and Drone 2 images.



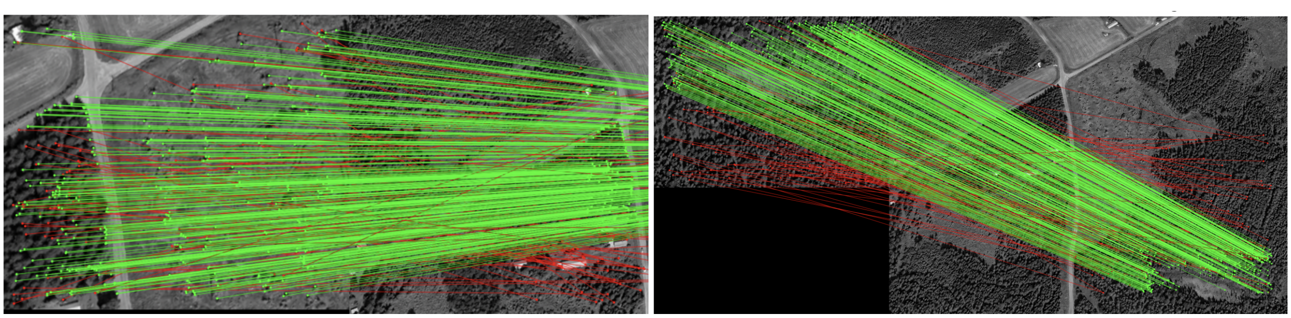
(a) Drone 1 ROI (b) Drone 2 ROI

Figure 3: Regions of interest (ROI) detected from the two drone images.



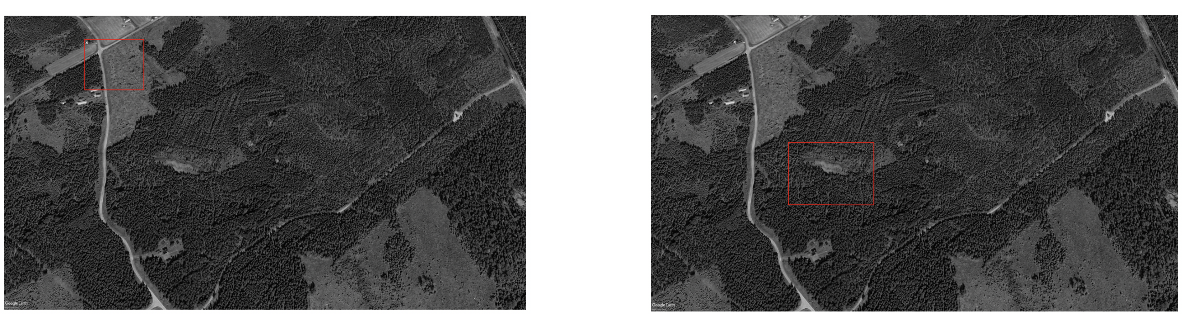
(a) Drone 1 ORB (b) Drone 2 ORB

Figure 4: ORB features.



(a) Drone 1 matches (b) Drone 2 matches

Figure 5: BF-matches. Green lines represent correct matches while red lines represent outliers



(a) Drone 1 result (b) Drone 2 result

Figure 6: The detected area of the drone image is represented as a red square.

6 Next Steps and Scalability

Once our system is implemented, it will allow for other sub-technologies to function. The solution for accurate location under EW will be of great benefit to the common war fighter. We have many ideas our technology enables:

Operational Uses

- **Share location with the team.** The UAV–UGV broadcasts its current position to the swarm so other vehicles and drones can coordinate safely.
- **Local locator for soldiers.** Nearby soldiers can better gauge their position based on the swarm's position.
- **Find and mark from above.** The drone's camera or radar can spot points of interest (e.g., targets, obstacles) and place clear pins on the map with coordinates.
- **Improve other drones.** Existing drones can use the same map alignment to reduce drift and keep their video and map views lined up.
- **Multimodal Data.** Using drones with dual (SAR + Optical) cameras and fusing the matching outputs for better positioning.

7 Conclusion

We presented the Satellite Drone Navigation System (SDNS): a satellite-aided UAV–UGV teaming approach that restores *absolute* positioning in GNSS-denied environments. A fiber-optic tethered UAV acquires imagery that is referenced onboard basemaps created with satellites. Our proof-of-concept (ROI selection, ORB feature matching, and RANSAC) successfully localized simulated drone views within the satellite scene, indicating feasibility with commercially available $\sim$25–30 cm data. The resulting common operating picture improves navigation safety, coordination with other assets, and enables extensions such as blue-force mapping and cueing.

References

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