Distributed UAV-swarm-based real-time geomatic data collection under dynamically changing resolution requirements

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Miguel Almeida (miguel.almeida@neclab.eu),
Hanno Hildmann (hanno.hildmann@uc3m.es),
Gürkan Solmaz (gurkan.solmaz@neclab.eu),

Cloud Services and Smart Things Group
Social Solutions Research Division

NEC Laboratories Europe (NLE)
Application scenarios

- **Continuous blanket surveillance** (ensuring un-interrupted area coverage) can be useful for a number of different applications
  - Finding missing child in a crowd
  - Bio-security (herd health monitoring)
  - Crowd surveillance (finding suspicious people in an event)

- We propose the usage of swarms of semi-autonomously operating aerial devices for this problem

- The swarm can be tasked to provide continuous and complete coverage of an area

- Specific (sometimes dynamically changing) resolution requirements may be imposed in real time on the generated data-feeds
Problem

- An area that requires surveillance
  - e.g. missing child

- A minimum resolution constraint
  - Needed by the video analysis software

- We may want to increase the resolution
  - Analytics software requirements for specific areas
Problem (2)

- It is possible to use more drones than needed (i.e., 10-drone swarm instead of 7)

- The altitudes of the drones determine the area they cover and thus the resolution of the provided footage

- Drones may provide a higher resolution than needed (i.e., surveillance drones have some redundancy)

Figure: Coverage change by altitude
Homogenous minimum resolution requirements

Minimum resolution requirements: ☐ (in the entire area)
Actual minimum resolution requirements

Minimum resolution requirements: □
Improvements by altitude changes

Figure: Coverage change by altitude

Algorithm improvements

Minimum resolution requirements: □ (in the entire area)

Figure: Homogeneous coverage

Minimum resolution requirements: □

Figure: Optimized coverage
The **swarm surveillance algorithms** enable cooperatively executing tasks where one device is not enough.

Devices in collective sensing tasks can adjust the quality or the scope of their sensory focus:
- E.g., Providing **video coverage for an area**

This enables a swarm of devices to operate on two levels:
- The entire swarm provides **blanket coverage** over an area
- The **individual devices significantly improve the measurements** for specific points/areas
Surveillance algorithm – Pseudocode

1. Randomly pick a drone A

2. Randomly pick an area $\alpha$ belonging to the group of areas that are the furthest away from A

3. Randomly pick a drone B who is in the vicinity of $\alpha$

4. Evaluate the aggregate resolution of $[AB]$ and the penalty of $[AB]$

5. “Trade” $\alpha$ from A to B

6. Evaluate the $agg\_res'$ of $[AB]$ and the $penalty'$ of $[AB]$ after the trade

7. Stochastic decision with $agg\_res$, $agg\_res'$, penalty and penalty'
System architecture

Figure 1: Overview of the system architecture

- **Control station**: Computer to control the swarm from
- **Computing Platform**: Raspberry Pi
- **Autopilot Hardware**: Pixhawk
- **Mobile Platform Hardware**: ESCs, Motors, Servos, etc.

Figure 2: Detailed System architecture
Development & testing

Development

- We developed / built our own drones for testing purposes incl. the control software
- We implemented a simulation test bed that facilitates the creation of hybrid swarms
- Test bed consists of physical drones as well as additional simulated drones using the same software as the real ones

Testing and Validation

- We implemented the swarming algorithm for drones and successfully conducted field tests using a hybrid swarm of 25 surveillance drones.

Performance Evaluation

- Simulated and real world deployment tests showed the approach to perform well and consistently converged towards good configurations.
Performance evaluation - I

Setup

- Automatically added requirements at
  - Iteration 2000
  - Iteration 4000
  - Iteration 6000
  - Iteration 8000

Performance

- The swarm starts at high altitude and with random coverage allocation. The performance quickly improves as the swarm settles to lower altitudes

- New resolution requirements result in service violation, which is quickly (within thousands of exchanges) overcome.

- Even under these requirements the swarm continues to improve the overall performance
Evaluation

- We recorded the altitudes of all drones over the course of the test and plotted them as frequency distribution (showing which number of drones operated at which altitude, over time). 10 distinct altitudes were possible (while airborne), these were aggregated into 5 categories.

Performance

- The swarm starts with all drones at the highest altitude (see previous slide)

- As the swarm optimizes the allocation it quickly drops from very high to high and then to medium, with the optimization performance slowing down as the drones collectively lower their altitude.

- With the introduction of the first requirement (iteration 2000) there is a peak, but then the swarm operates with almost all drones at optimal altitude, and only very few changes.
Advantages of the approach

Specific advantages of the approach

The approach relies on the use of a swarm. Normally, the use of multiple devices adds complexity and overhead, while our approach improves with the swarm size. (This does of course not apply to the communication overhead, as n devices require n connections.)

The members of a swarm effectively partition the problem space by sharing the responsibilities among themselves and thereby achieve (a) fast and good local optimization, as well as (b) reliable performance quality (a drone will perform its task pretty much unaffected by the size of the swarm, since it is only communicating with its immediate neighbours).

Intended application areas

The use of the application is primarily focusing on dynamic scenarios (i.e. where there is a clear need to cover an entire area at the same time). However, our simulation framework and hybrid swarm can be applied to other scenarios where this capability is not a requirement but a bonus. The ability to provide multiple mobile sensing / mapping devices combined with the capability of using automated data processing software to interact with the devices might provide a benefit to applications in the area of Geomatics as well.

We hope that the exerts at this conference have suggestions, criticism or advise for us.