Simulation of Cooperative Positioning Flight Ad-hoc Network

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Abstract. Cooperative positioning method is necessary for multiple rotor-winged drone swarm applications for airborne satellite navigation receiver has less usability in urban canyon, which could be achieved by drones’ FANET (flight ad-hoc network): each drone broadcast and receive wireless signals containing measurement information with its neighbour drones, then calculate the relative position results or absolute results when some drone could positioning by satellite navigation receiver, to reduce the communication demand all drones distributed to multi-subnet dynamically. A simulation of the cooperative positioning process was shown, which achieves the continuous relative positioning result in denial environment.

Keywords: Drone swarm; Denial area; Cooperative positioning; FANET; Simulation.

1. Introduction
The multiple rotor-winged drone swarm develop rapidly in civil applications in past few years for it has great efficiency than manual work, such as delivered packages, automatic faming, light show and power inspection \cite{1-3}. In order to achieve the purpose of those applications, visual perception and relative positioning methods are needed in most tasks. Most civil drones used a GNSS (Global Navigation Satellite System) receiver chipset integrated in control module and single element antenna to achieve absolute positioning for their cost, load and size limitation. Some specialized application drones used RTK (Real Time Kinematic) technique (add information service and communication cost) to improve positioning accuracy for cooperative safety \cite{4-5}.

The GNSS receivers need at least four visible satellites’ signal simultaneously while in denial environment, mostly in urban canyon, would worked discontinuously and even lose effectiveness:
- Signal-sheltered: Nowadays large city has more and more high-voltage installations which would shelter the navigation signals, only few high elevation signals could be received.
- Multipath: Besides the direct signals, the receiver would receive a great number of multipath signals reflexed by building surface, which could cause error and signal attenuation.
- Jamming: It has so many L-band transmitters for different purposes in urban area even uncontrolled jammer, which could deny the signal receive process intentionally or accidentally.

Some methods improving positioning applicability were analysed such as outdoor pseudolites, high-power WiFi and mobile communication network, which are workable but need a building cycle and considerable expenditure in large city. A discussed method is positioning by relative ranging in the FANET composed only of drones, which is similar to sensor network: during ranging and communication process each point could achieve the FANET ranging result matrix; then calculated the relative positioning results even there has no absolute position point, the relative positioning results has less used for determine “where are the drones” but could be used for determine “where are
the drone partners”; and if there have four or more drones could achieve their absolute position, all the
drones could get absolute positions by space datum registration process [6].

![Diagram showing GNSS signals and environment]

a) GNSS-denial environment in canyon  b) Cooperative positioning by relative ranging

**Figure 1.** Low-cost airborne GNSS receiver has risk in urban canyon, and positioning by FANET could be a backup method.

The cooperative positioning FANET has many advantages such as

- Low-cost relative to complex integrated navigation: The cooperation positioning accuracy and continuity mainly depend on ranging signal character and drones’ spatial distribution, which means it could achieve suitable performance without high quantity sensors.
- Convenient in rapid changed applied area: The cooperative process has no need of external source so it could be convenient used in new city area, and building around rapid changed area.
- Decentralized implementation: Whichever one or few drones broken the FANET could continue providing the relative positioning for it has no need of absolute position point.

2. **Cooperative Positioning in Band-limited FANET**

A key technology of the Co-positioning FANET is how to design such a ranging and communication signal among the flight drones. For it is hard to use a multi-frequency signal for differential carrier-phase measurement in a band-limited FANET, the ranging accuracy (not considered dynamic error) is mainly based on received power and PRN correlation character by early-later phase detector in receiver, which means the communication data span must be an integral multiple of PRN cycle, in other words, accuracy ranging means low data transfer speed.

For example, a 2MHz frequency spectrum bandwidth FANET signal with 1023-gold PRN supports continues ranging would only supports most 2MHz/2/1023=1kbps data speed.

On the other hand, for all the drones are free flight to suit different situation, not flying in formation, the distance between pair drones is always changed, as a result, ranging at different time among the swarm would cause a dynamic error. Reducing the dynamic error need reduce the FANET ranging cycle and high-frequency inertia compensation data exchange, which has considerable demand of communication speed when capacity increase.

Another example, assume the compensation data altogether 20bit per point, each pair points ranging result need 30bit, in a 10 points FANET need 30bit×90+20bit×10=2900bit per ranging cycle. Hence, it is impractical to design a combined signal to satisfied huge capacity drones’ cooperation positioning in band-limited FANET.

As a compromise, the FANET would adaptively separate to several subnet: all the drones in same subnet would exchange information and calculate relative position to reduce exchange information, ensure ranging accuracy and reduce the need of PRN length; this might lose accuracy than all-points-ranging network but exchange the ranging cycle benefit, which means a MEMS-INS is also could be used for inertia compensation, even without any compensation data.
Figure 2. Band-limited FANET should separate to multi-subnet pattern.

The common drones between subnets act as different relative space datum’s registration points.

3. Simulation of Co-positioning in FANET

3.1. Simulation Architecture

To achieve a more credible simulation result, a hardware test combined simulation architecture was designed as below. It has three main parts: first is the initial process includes manual parameters input and primary simulation scene form, determine how the drones flight at first and where they go; second part is the hardware test data statistics, two airborne modules were connected by RF cable and the ranging & inertia compensation data results were recorded by computer; third part is the calculate process includes network structure form, cooperative control and cooperative positioning.

Figure 3. Simulation architecture for cooperative positioning FANET.
A denial condition process is added to this simulation for assessment how the communication status affect cooperative positioning result: assume there has a mobile jammer near the swarm at a random position, then calculated the denial distance by its transmitting power and the upper limit of FANET signal’s interference to credit ratio, and simply assume drones within the distance could exchange information normally.

Some main parameters setting in this simulation is showed in the table.

**Table 1.** Parameters setting in simulation.

| Parameter          | Min Value | Max Value |
|--------------------|-----------|-----------|
| drones’ distance   | 20m       | 2Km       |
| network capacity   | 20        | 100       |
| subnet capacity    | 1         | 10        |
| flight speed       | 0         | 10m/s     |

### 3.2. Simulation Results

The test simulation scene is described as below: a drones swarm composed of 50 points were dispersed randomly in a vertical plane, perform a cooperative deliver packages task that avoiding ground obstacles by visual sensors and flying across points of a circle. The primary state of all points and dynamic path planning result are showed in figure.

![Primary state of simulation](image1)

![Drones’ path planning result](image2)

**Figure 4.** Primary spatial distribution (blue), goal (red) and path planning.

All the drones execute a common bionic control procedure that decide local path planning by current velocity, neighbour points’ distance and velocity, and target position, so they could run in decentralized pattern. The intermediate state shows that the swarm planning results present both individual and group imprinting characters.

![Form a common direction of motion](image3)

![Split into two directions with individual goals](image4)

**Figure 5.** A group imprinting phenomenon in cooperative path planning.
Finally, the 50 points’ FANET cooperative relative positioning result are achieved in this simulation. It is showed that the relative positioning error has a downward trend for all drones gradual flying in similar velocity at the end period of task so dynamic error of ranging process would be reduced, and by specific designed FANET signal and calculate method, the relative positioning error maintain less than 1m.

![Figure 6. FANET cooperative relative positioning result.](image)

4. Conclusion
Cooperative positioning by FANET could act as a backup method in GNSS denial area, which achieves suitable relative positioning result by specific designed ranging & communication signal. The simulation presents an outstanding performance, which validates the cooperative method could improve positioning continuity.

References
[1] B. C. Min, C. H. Cho, K. M. Choi, et al 2009 Development of a micro quad-rotor UAV for monitoring an indoor environment. Springer Berlin Heidelberg.
[2] P. Gabrlik, A. Jelinek, P. Janata 2016 Precise multi-sensor georeferencing system for micro UAVs, IFAC PapersOnLine, p 170-175.
[3] P. Gabrlik 2015 The use of direct georeferencing in aerial photogrammetry with micro UAV, IFAC PapersOnLine, p 380-385.
[4] Rabah, Basioyun, Ghanem, et al 2018 Using RTK and VRS in direct geo-referencing of the UAV imagery, NRIAG Journal of Astronomy and Geophysics, p 220-226.
[5] L. Bin, X. Jiangtao, F. Bangsheng, et al 2019 A covariance shaping filtering method for tightly-coupled MIMU/GNSS of UAV, Aircraft Engineering and Aerospace Technology p 1257-1267.
[6] Chenglong He, Baoguo Yu and Qingwu Yi 2020 A Cooperative Positioning Method for Micro UAVs in Challenge Environment. 3rd IEEE International Conference on Unmanned Systems (ICUS).