Enabling Relative Localization for Nanodrone Swarm Platooning

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Abstract—Nanodrone swarm consisting of multiple lightweight and low-cost nanodrones can perform severe tasks in a challenging environment. Therefore, it is important to predict the relative position of the nanodrones in the swarm for safe platooning. To this end, we present Tagroup, a system that can sense the relative position of the nanodrone swarm with commodity passive RFID tags. Specifically, we attach one commercial-of-the-shelf RFID tag to the nanodrone in the swarm. Then, we can estimate the relative position of the RFID-tagged nanodrones in the swarm by profiling the spatial-temporal phase readings from the RFID tag. To demonstrate it, we fly two nanodrones and estimate their relative positions with the spatial-temporal phase profile.

Index Terms—Relative Localization, Commodity Passive RFIDs, Nanodrone Swarm Platooning

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) become popular for performing tasks in severe environments. For example, the UAVs have been used to rescue lives [1], delivery packages [2], enhance the performance of critical wireless communication infrastructure [3], [4], [5], and even proliferate the entertainment [6], [7], [8]. These UAVs are usually instrumented with different kinds of sensors for sensing, navigation, and platooning [9], [10]. However, these bulky and power-hungry sensors will hinder the development and deployment of drones to perform tasks in a cluttered environment, especially, considering the lightweight and small nanodrones that can only fit in our palm as shown in Fig. 1. These nanodrones are as small as 22x22x20 mm [11], [12], which can traverse through small, tight, and narrow spaces such as plant canopies and crevices in the forests or disaster sites to perform tasks. Since one nanodrone is limited in performing the tasks efficiently due to its size and hardware, multiple nanodrones can be used to have a swarm as shown in Fig. 2 for performing the tasks. As the nanodrone in the swarm will move synchronously in all three translational movement degrees of freedom, it is important to formulate an accurate geometry of swarm pattern for safe and accurate platooning [13].

To sense the relative position of nanodrones in the swarm, we can simply use cameras or LiDAR sensors. However, these advanced sensors are expensive and cannot be resilient to dynamic environments such as non-line-of-sight and dark environments (e.g., fogging). Someone may wonder if we can use wireless signals (e.g., WiFi, sound) to sense these nanodrones. Actually, we cannot leverage these existing RF-based sensing techniques for nanodrone localization, as we cannot instrument these bulky and power-hungry devices on the nanodrone, and it is difficult to localize each individual nanodrones in the cluttered environment.

With the development of low-power backscatter communication and sensing, Radio Frequency IDentification (RFID) has proliferated for indoor localization [14], [15] and gesture recognition [16], [17] due to their battery-free, low-cost, and small form-factor. Therefore, we believe commodity passive RFIDs are a good fit to proliferate nanodrone swarm applications. However, we cannot simply leverage the existing RFID-based sensing techniques [15], [14], [18], [19] for relative localization in the nanodrone swarm without hardware modifications of the RFID reader.

In this paper, we propose Tagroup, a system that can accurately sense the relative position of the nanodrones in the swarm, using commodity passive RFID tags. To do so, we attach a commodity passive RFID tag to each of nanodrones in the swarm. Then, the relative position of the nanodrones in the swarm is sensed through the spatial-temporal phase profile of the backscattered signals from the RFID-tagged nanodrone. The key idea of our design is to use the linear relationship between the phase readings and the distance between the tagged nanodrone and the reader. The relative position of the nanodrones will be estimated in the 3D space along the x, y, and z-axis. Specifically, we will extract the trough zone in the phase profile due to the nanodrone’s movements. Then, we can use the time ordering of the trough zone’s lowest point for nanodrone’s relative position estimation.

Contributions. Tagroup’s contributions are three-fold as follows:

- First, Tagroup is the first system that will localize the relative position of the nanodrones in the swarm using

Fig. 1: The nanodrone with size of 70x48x35mm, fitting in the palm.

Fig. 2: Example of nanodrone swarm with four nanodrones flying in the 3D space.
II. **Tagroup’s Design**

To find the relative position of nanodrones in the swarm, we can use the linear relationship between the phase of backscattered signals and the reader-tag distance as follows:

\[ \theta = \left( \frac{2\pi \cdot 2d}{\lambda} + \mu \right) \mod 2\pi \]  

(1)

where \( \theta \) is the phase of backscattered signals, \( \lambda \) is the wavelength, \( d \) is the distance between reader and tag and \( \mu \) indicates the phase shift due to the noise. As illustrated in the introduction section, the phase profile will exhibit a trough zone when the RFID-tagged nanodrone moves from left to right in front of the reader’s antenna. Therefore, the relative position of two nanodrones along the x-axis can be estimated based on the time when the lowest point of the trough zone has been achieved. To demonstrate this, we do the simulation in Python to exploit this linear relationship and trough zone in the spatial-temporal phase profile. Specifically, when the RFID-tagged nanodrone flies in front of the reader’s antenna as shown in Fig. 3, we can see there is a trough zone in the phase profile as shown in Fig. 4. Note, the phase readings are wrapped up. Therefore, we can estimate the relative position of nanodrones in the swarm using the trough zone. We can use the time ordering of the trough zone’s lowest point to predict the relative position along the x-axis. However, we cannot use the trough zone’s lowest point to predict the relative position of nanodrones with the same x-axis flying along the y-axis, as the trough zone’s lowest point will be achieved at the same time due to the same x-axis of nanodrones. We observe that the phase value of the trough zone’s lowest point will be different when nanodrones with the same x-axis fly along the y-axis. Therefore, we will leverage the phase value of the trough zone’s lowest point to predict the nanodrone’s relative position. To predict the nanodrone’s relative position along the z-axis, we can simply estimate the time ordering of the trough zone’s lowest point when the swarm flies along the z-axis.

III. **Experimental Evaluation**

In this section, we present the experimental evaluation of Tagroup.

A. **Evaluation**

**Hardware.** We use commodity passive RFID tags which can be purchased from the market at a price of 5 cents per...
we plot the phase profile of RFID-tagged nanodrone 1 and 2 closer to the reader’s antenna in comparison to nanodrone 2. If nanodrone 1 is at the right of nanodrone 2. So, nanodrone 1 is the reader’s antenna along the x-axis as shown in Fig. 5, where to demonstrate our idea. The nanodrone 1 and 2 flies in front of motions with a nanodrone swarm consisting of two nanodrones

B. Results

As shown in Fig. 6, we can see two trough zones in the phase profiles of nanodrone 1 and 2. Moreover, the lowest point of the trough in the phase profile from nanodrone 1 will be at the left of the lowest point of the trough in the phase profile from nanodrone 2. This is because nanodrone 1 is closer to the reader’s antenna in comparison to the nanodrone 2. Therefore, we can predict the relative position of nanodrone 1 and 2 based on the time ordering of the lowest point of the trough in their phase profiles.

Relative localization along the y-axis. After we figure out the relative position of two nanodrones along the x-axis, the problem becomes how we can predict the relative position of nanodrones in the swarm along the y-axis. To do so, we put two nanodrones in front of the reader’s antenna with the same x coordinates and different y coordinates (e.g., the y coordinate of nanodrone 2 is smaller than nanodrone 1) as shown in Fig. 7, where two nanodrones will move along the x-axis. Obviously, nanodrone 2 is closer to the reader’s antenna. Then, we plot the phase readings of two nanodrones over time as shown in Fig. 8. Since two nanodrones have the same x coordinates, we cannot predict their relative positions based on the time ordering of the trough’s lowest point in the phase profile. As we can see, the lowest point of trough from the phase profiles of nanodrone 1 and 2 will be achieved simultaneously. However, we can see that the lowest point of the trough in the phase profile from nanodrone 2 is smaller than the lowest point of the trough in the phase profile from nanodrone 1. This is because nanodrone 2 is closer to the reader’s antenna. Mathematically, in this scenario, the phase-changing rate over time can be expressed in the following equation:

\[ R_p = \frac{d\theta}{dt} = \frac{4\pi}{\lambda} \sqrt{\left(\alpha t + v x_0\right)^2 + y_0^2} \]  

where \( v \) is the moving speed of the RFID-tagged object, \( \lambda \) is the signal wavelength and \((x_0, y_0)\) indicates the coordinates of the object. As we can see, the smaller coordinate indicates the larger phase-changing rate, which is in accord with our above observation in the experiment. Therefore, we can predict the relative position of nanodrones along the y-axis based on the value of the trough’s lowest point (or phase-changing rate) in the phase profile. To predict the relative position of the nanodrones along the z-axis, we can simply compare the time ordering of the trough zone’s lowest point when the swarm flies along the z-axis during platooning.

IV. Related work

Nanodrone swarm can leverage multiple nanodrones’ capabilities to improve the overall system’s resilience and accelerate the task performing in aerial photography, topography and delivery [23], [24]. To maximum embrace the nanodrone swarm’s capability, it is important to recognize the relative position of nanodrones in the swarm. The straightforward idea is to use vision or infrared sensors to sense the relative position of drone swarm [25], [26]. However, these vision or infrared sensors are constrained by the line-of-sight perception.
Recent studies [27], [10] mount the motion sensors on the robot to sense the relative position among the drones in the swarm. However, it is impossible to instrument these bulky and power-hungry sensors on the nanodrone with Size, Weight and Power (SWaP) constraints. In contrast, Tagroup uses low-cost, battery-free, ubiquitous and small form-factor RFID tags to sense the relative position among the nanodrones in the swarm by profiling the spatial-temporal phase readings from backscattered signals.

V. CONCLUSION

In this paper, we propose Tagroup, a system that can sense the relative position of the nano drones in the swarm, using the commodity passive RFID tags. To do so, we attach commodity passive RFID tags on each nano drone, such that the relative position of the nano drones in the swarm can be estimated through the time ordering of the trough’s lowest point in the spatial and temporal phase profile. We believe Tagroup can proliferate the human-drone interaction, dazzling drone shows for the entertainment industry, and safe drone swarm platooning.

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