EverCopter: Continuous and Adaptive Over-the-Air Sensing with Detachable Wired Flying Objects

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Abstract
The paper proposes EverCopter, which provides continuous and adaptive over-the-air sensing with detachable wired flying objects. While a major advantage of sensing systems with battery-operated MAVs is a wide sensing coverage, sensing time is limited due to its limited amount of energy. We propose dynamically rechargeable flying objects, called EverCopter. EverCopter achieves both long sensing time and wide sensing coverage by the following two characteristics. First, multiple EverCopters can be tied in a row by power supply cables. Since the root EverCopter in a row is connected to DC power supply on the ground, each EverCopter can fly without battery. This makes their sensing time forever, unless the power supply on the ground fails. Second, the leaf EverCopter can detach itself from the row in order to enjoy wider sensing coverage. An EverCopter, while it is detached, runs with its own battery-supplied energy. When the remaining energy becomes low, it flies back to the row to recharge the battery.

Author Keywords
Flying objects; MAV; wired flying; over-the-air sensing

ACM Classification Keywords
H.5.1 [INFORMATION INTERFACES AND PRESENTATION]: Multimedia Information Systems.

General Terms

Design, Algorithms, Reliability, Management

Introduction

Networked MAVs such as AR.Drone [1] have a big possibility for wider area of sensing and actuation. By using MAVs with camera and various sensors, we can monitor our surroundings from the sky without disturbed by various obstacles on the ground. There are also many challenges and visions to leverage MAVs for supporting our life [2, 5]. MAVs can provide over-the-air sensing. Though previous sensor network can monitor various environmental change, it's target is basically near the ground or floor. Over-the-air sensing can enhance the sensing area by using environmental sensors and cameras from the sky. However, there is one essential issue for MAVs - the limitation of flying time. Since MAVs are running with battery, it can fly only for short time. For example, battery life of AR.Drone with live video streaming lasts only for 10 minutes. To realize continuous, stable, and thus widely covered field sensing, flying time should last longer such as couple of hours/days. Therefore, mechanisms to balance between mobility of MAVs and their life time should be investigated for more sophisticated over-the-air sensing.

EverCopter

To achieve this goal, we propose *EverCopter*, dynamically rechargeable flying objects for continuous and adaptive over-the-air sensing (the concept is shown in Figure 1).

Dynamic Flying Mode Change

It achieves the aforementioned goal by the following two-fold. First, an EverCopter transits between *wired* and *wireless* modes. The wired mode means that the EverCopter is flying and recharging its battery, connected to another via a power supply cable. Multiple EverCopters can be tied in a row, and the root one is connected to the DC power supply on the ground. The wireless mode, on the other hand, means that the EverCopter is flying by itself, detached from others. It can fly as long and wide as the battery lasts. Second, the mode transition is dynamic in that an EverCopter can detach itself from, and attach itself to another while they are flying. An EverCopter in the wireless mode can fly away from the others to finish its sensing task in a specified sensing area, and then fly back to refill its energy. By reiterating this mode transition without touching down on the ground, EverCopter's can continue sensing for a long time. Overview of two modes is presented in Figure 2. In the continuous sensing mode, EverCopter continues to sense field by cooperating all of wired MAVs for a long time. Thus, for example, continues mode can be used for security camera application which is required to be operated all the time. On the other hand, in the adaptive sensing mode, EverCopter makes a flying object to fly freely by removing limitation of wired. This mode is used for sensing tasks which require wider range of mobility power but can be achieved within short time.

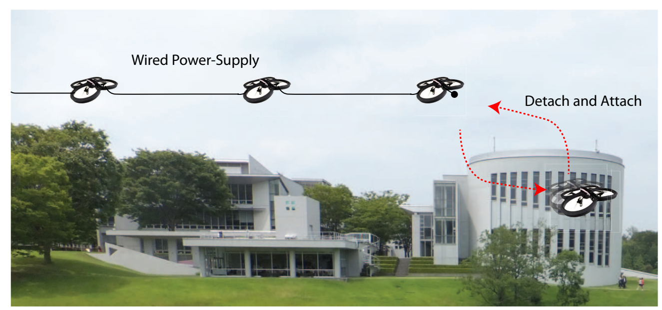

Figure 1: EverCopter: continuous sensing by wired flying objects and adaptive sensing by detaching flying objects.

Research Challenges
To create EverCopter, we have to answer the following two questions: (1) how to control the MAVs automatically to keep the power cable in the sky, and (2) how to control the MAVs automatically to detach/re-attach from/to the cable. In addition to these questions, we also have to design hardware for carrying a stable electric current to multiple MAVs. In the next section, we present our first design and prototype implementation.

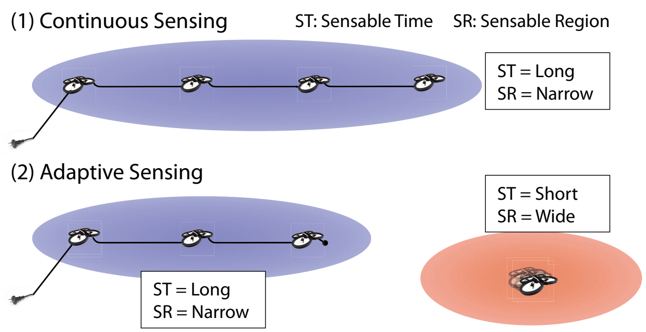

Figure 2: Two modes of EverCopter: continuous monitoring and adaptive monitoring.

Design Prototype and Implementation

Flying Control Techniques
To realize EverCopter, a flying control technique for cooperating multiple MAVs is necessary. We designed following two control techniques: 1) wired flying technique and 2) re-attachment flying technique. We denote set of MAVs for EverCopter as E. E contains each flying object as $E = \{E_1, E_2..., En\}$. E_1 is the first flying object, thus E_n means the last flying object which connected to the power source.

Wired flying technique, which enables MAVs to fly with wired power cables, controls MAVs based on each MAVs' location. When E_1 starts to fly, other E_2 to E_n remains on the ground. If E_1 flies enough away of cable length between E_1 and E_2, E_2 starts to fly toward direction of E_1. E_3 to E_{n-1} periodically fly according to the rule. Since E_n is connected to power source, the flyable area of EverCopter depends total length of cables which connects E_1 to E_{n-1}. Re-attachment flying technique enables detached E_1 to re-attach E_2's power cable. Firstly, detached E_1 flies back to the same location of E_2 and then land on the ground. E_2 drop down the cable to E_1 by recognizing E_1's detailed location, and E_2 tries to attach cable to E_1 by controlling it's attitude.

Hardware and Software
We implemented a prototype of EverCopter by using AR.Drone. Hardware prototype is shown in figure 3. As hardware implementation, we converted AR.Drone to be operated with power-supply cables. Each AR.Drone mounts GPS sensors and power-management controller in the space originally for it's battery. In addition, plugins for power-cable is attached at the front and back of AR.Drone. AR.Drone as first flying object has magnet-based detachable power plugin at the back. AR.Drone as second flying object has magnet-based power-plug and take-up roll to roll the cable. We also implemented stable power supplier which transmits electric power by monitoring each MAVs' voltage. As software, we implemented flying control techniques by leveraging a GPS unit and camera. Every AR.Drone is connected to WiFi and controlled by a single computer. Especially for re-attachment flying technique, we implement software to detect the detail of location for the 1st flying object by using computer vision technique and control the take-up roll to attach the power-cable.

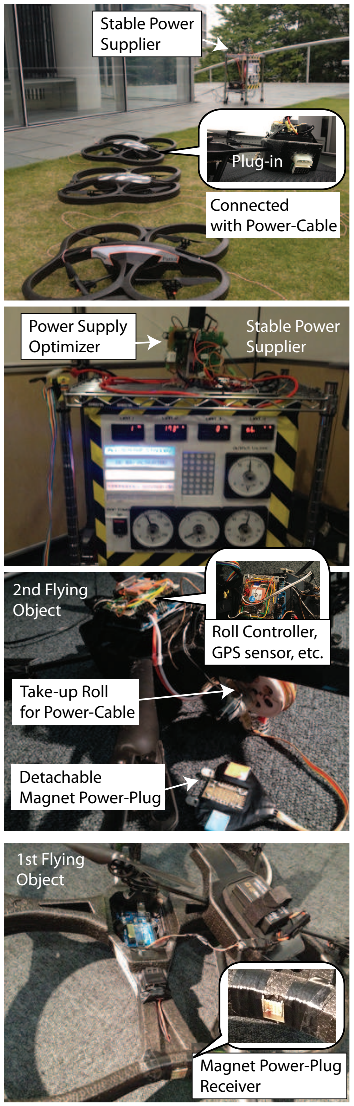

Figure 3: Hardware implementation of EverCopter.

Related Work

The challenges to augment helicopters by attaching extra equipment have been done at various sides [6, 7]. Though these works attach slung load or suspend loads to their helicopters, their objectives are not to augment helicopter's functionality but to fly helicopters stably. The concept of sensing environment by using MAV (Miniature Aerial Vehicles) is used in many fields. Flying Eye [2] is the product which provides video images from MAV and Higuchi et al. [5] use MAV for dynamic camera work. But they have not attacked about the problem of battery and flying range. Swieringa et al. [8] proposes automatic battery swapping system for small-scale helicopters. Battery swapping is another interesting approach, however, the difference between the approach and our approach is that EverCopter provides fully continuous flying time. Avoiding obstacles is the major problem in the robotic research field and many researchers challenged to solve this problem [9, 3, 4]. Whether the robots are flying or not, avoiding obstacles algorithm can be applied to EverCopter. As a future work, we apply these algorithms to EverCopter and make an obstacle adaptive flying algorithm.

Conclusion

In this paper, we proposed EverCopter, detachable wired flying object for continuous and adaptive over-the-air sensing. EverCopter provides future direction of sensing with MAVs by balancing flying time and flying area. For future work, we will sophisticate our implementation and evaluate our system with actual environment.

Acknowledgements

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