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The use of unmanned aerial vehicles and wireless sensor networks for spraying pesticides

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ABSTRACT

The application of pesticides and fertilizers in agricultural areas is of crucial importance for crop yields. The use of aircrafts is becoming increasingly common in carrying out this task mainly because of their speed and effectiveness in the spraying operation. However, some factors may reduce the yield, or even cause damage (e.g., crop areas not covered in the spraying process, overlapping spraying of crop areas, applying pesticides on the outer edge of the crop). Weather conditions, such as the intensity and direction of the wind while spraying, add further complexity to the problem of maintaining control. In this paper, we describe an architecture to address the problem of self-adjustment of the UAV routes when spraying chemicals in a crop field. We propose and evaluate an algorithm to adjust the UAV route to changes in wind intensity and direction. The algorithm to adapt the path runs in the UAV and its input is the feedback obtained from the wireless sensor network (WSN) deployed in the crop field. Moreover, we evaluate the impact of the number of communication messages between the UAV and the WSN. The results show that the use of the feedback information from the sensors to make adjustments to the routes could significantly reduce the waste of pesticides and fertilizers.

1. Introduction

Unmanned aerial vehicles (UAVs) have become cheaper because many control functions can now be implemented in software rather than having to depend on expensive hardware. This has allowed single or multiple UAVs to be employed for real-world applications. The UAVs very often require a means of communication so that they can communicate with on-land computers, sensors or other UAVs. As most of the research with UAVs is still in its initial stages, there are a number of open questions that need solving, like mapping and localization schemes [33], route planning [29], coordination and task allocation [30,28] and communication issues [6], among others.

In this paper, we propose an architecture based on unmanned aerial vehicles that can be employed to implement a control loop for agricultural applications where UAVs are responsible for spraying chemicals on crops. The process of applying the chemicals is controlled by means of the feedback from the wireless sensor network which is deployed at ground level on the crop field. Furthermore, we evaluate an algorithm to adjust the UAV route to changes in the wind (intensity and direction) and the impact caused by the number of messages exchanged between the UAV and the WSN. The information retrieved by the WSN allows the UAV to confine its spraying of chemicals to strictly designated areas. Since there are sudden and frequent changes in environmental conditions, the control loop must be able to react as quickly as possible.

The information retrieved by means of the WSN provides the UAV with knowledge of the position and amount of chemicals detected by every sensor of the crop field. However, after the application of the chemicals by the UAV, some areas of the crop may not have a sufficient amount of chemicals; the reason for this is the high speed of the UAV and even though the controls allow the UAV to adjust to sudden random changes of wind as quickly as

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possible, this might not be enough to maintain a perfect lane. As a result, what happens is that we might have some clusters without the correct amount of chemicals being dispersed. Hence, in this paper we also show how to build a chemical concentration map using the data provided by the WSN. The purpose of this is to show clusters where there is an insufficient application of chemicals and the map might be used to perform new UAV applications in designated areas. We show how to build these maps using Instance-Based Algorithms [2] and Density-Based Algorithms [20].

This paper is an extended version of a previous study [10]. It aims to describe the methodology that is employed in a more thorough way, conduct new experiments and discuss the new obtained results. Furthermore, we describe how a chemical concentration mapping can be carried out by using the data obtained from the WSN and we present evaluations with real hardware, where we measure the communication time between the UAV and a ground sensor employing XBee-PRO Series 2.

This paper is structured as follows: in Section 2 we discuss related work on mobile ad hoc network routing protocols and cooperative sensing. Section 3 outlines the proposed method, by describing the proposed system architecture and the details of its development. Section 4 describes the evaluation of all the conducted experiments, the first for the UAV route adjustment, the second for building the chemicals concentration maps (clusters) and the third for the evaluations employing real hardware. The final section concludes the paper and offers some future perspectives.

2. Related work

2.1. Routing protocols

Mobile ad hoc network (MANET) routing protocols can be divided into a few main groups: (i) flat proactive routing, (ii) on-demand reactive routing, (iii) hybrid schemes, (iv) geographical routing and (v) opportunistic routing. Proactive (table-driven) ad hoc routing protocols maintain their routing information independently of communication needs. Status update messages are sent periodically or when the network topology has changed. Thus, a source node gets a routing path immediately if it needs one. This results in low latency and makes them suitable for real-time traffic. When they use proactive routing protocols, nodes proactively update their network state and maintain a route regardless of whether data traffic exists or not. The main drawback of these routing protocols is the high overhead they need to keep the network topology information up-to-date. All the nodes require a consistent view of the network topology.

Reactive (on-demand) routing only establishes routes if they are required. This saves energy and bandwidth during periods of inactivity. It should be noted that a significant delay may occur as a result of the on-demand route discovery. Compared to proactive ad hoc routing protocols, one advantage of reactive routing protocols is the lower overhead control. Furthermore, reactive routing protocols have better scalability than proactive routing protocols in MANETs. One drawback is that reactive routing protocols may experience long delays for route discovery before they can forward a data packet. Reactive protocols perform well in light-load networks.

Geographical routing protocols assume that a source knows its position and can determine the position of the destination. Moreover, each node knows its neighbors' positions. In comparison with flooding-based approaches, geographical routing has a reduced overhead for route discovery. Geographical routing protocols only require neighbor information containing their location to route packets and do not need to maintain per-destination information. Most geographical routing protocols use greedy forwarding as the main method to select the next hop. In order to avoid dead-ends in the routing path, face-routing has been proposed to route around a void.

Opportunistic routing [7,35,27] assumes that an end-to-end communication path may frequently be disrupted or may not exist in a MANET at any time. The routing mechanism forwards the message towards the destination on a hop-by-hop basis and the next hops are selected according to protocol-specific characteristics. This means that it is not essential to have a stable end-to-end connection from the data source to the destination. The packets are forwarded even though the topology is continuously changing.

2.2. Cooperative sensing

Wireless Sensor Networks are networks composed of several wireless nodes. These nodes are often deployed near or inside environments or phenomena with the aim of sensing/obtaining information about it. The information is then routed to a command center, where the data can be examined and appropriate action can be taken [9]. According to [3], those nodes are small embedded systems with the three following components: (i) mote, that is the main component of the sensor node, it is able of communicate wirelessly and should be programmable. Traditionally they are composed of a microcontroller, a radio and an energy source; (ii) a set of sensors, whose objective is to sense the environment and collect data (i.e., temperature, humidity); and (iii) data interface, that can be a USB or a serial port, used to connect the mote to a computer so that it can be programmed. Some motes allow this by means of the wireless interface.

One major issue when dealing with WSN is the limited source of energy, which is normally provided by batteries. Although the batteries can be changed, this can be dangerous for human beings as the sensor nodes might be installed in hazardous environments (i.e., volcanoes, chemical/nuclear affected areas). Furthermore, changing batteries is expensive (and requires both human and financial resources). Some techniques can be employed to increase the lifetime of the nodes. The first of these is the on–off behavior, i.e., the sensor nodes turn off some components to save energy. The best component to turn off is the radio, because it is the component which uses most energy [24]. This procedure makes the sensor node unreachable for some time, so the communication protocols used by the WSN must be aware of it. The second technique seeks to enhance the lifetime of the WSN by using limited radios (low power and bandwidth) because it requires less energy. As a result, the nodes can only communicate with the nearest neighbors. Hence, to send any information from the WSN to a base-station, the message must be routed via several nodes. This method is called multi-hop communication.

The cooperation of several types of nodes in a WSN application, including static and mobile nodes, can be seen in the work by Erman et al. [14]. They have established a platform of heterogeneous wireless sensor nodes with the objective of sensing and monitoring fires in buildings. They propose to deploy nodes inside a building where each node is capable of detecting the temperature of the room. When a fire is detected by the WSN, an UAV is called to fly near the fire and to deploy more sensors, and thus gather more information. When the fire-fighters arrive in the building, they wear a so-called Body Area Network so that they can receive the information from the nodes and also collect information required for the protection of the fire-fighters, such as body temperature and concentration of CO_2 near their mask.

Another project that relies on the cooperation of different types of nodes can be seen in the work by Valente et al. [31], where it is proposed the deployment of sensors in several vineyards to collect information about factors such as temperature and humidity.