PESTICIDE DRIFT CONTROL WITH WIRELESS SENSOR NETWORKS

I. M. Santos, and C. E. Cugnasca

School of Engineering
University of São Paulo
São Paulo - Brazil

ABSTRACT

Precision Agriculture is an agricultural practice that uses technology based on the principle of variability. The geographically referenced data implement the process of agricultural automation so as to dose fertilizers and pesticides. The efficient application of low cost pesticides without contamination the environment is an agricultural production challenge. The main effect to be avoided during application is pesticide drift. To minimize it is important to know the environmental conditions, such as wind, temperature, and humidity at the moment of application. This article discusses and proposes the use of Wireless Sensor Networks in a support and control system for pesticide application. A Wireless Sensor Network is a special kind of ad hoc network, consisting of several sensors that collect and process information from the environment which it is distributed. These sensors are use to record different data types, such as temperature, humidity, wind speed and direction. Three uses of the application of sensor networks in precision agriculture are investigated. In the first case, the sensor network evaluates environmental data at the time of application to determine suitable environmental conditions for application. The system monitors throughout the application and in addition emits an alert when the environment is unfavorable for the application. The second use evaluates the wind speed and direction to suggest corrections in the path of a tractor or aircraft. It is expected that this alteration in the path results in applying the defensive solely in the appropriate area. The last use of the sensor network that will be discussed here analyzing crop dusting quality by evaluating the deposition of pesticide over the crop. The use of sensor networks in precision agriculture has become an important management tool. Wireless Sensor Networks can be used in crop dusting, in order to minimize and control pesticide drift, and the contamination of soil and waterways, improving effective application.

Keywords: wireless sensor network, precision agriculture, pesticide drift, crop dusting, automation, embed network.

INTRODUCTION

The indiscriminate use of natural resources has caused environmental damage and the depletion of productive capacity in agriculture. Among the advances in technology, Precision Agriculture (PA) is the main mechanism for the rational use of natural resources in agricultural crops. PA aims to improve the utilization of inputs and productivity, reducing costs and environmental impact (Zhang et al., 2002; Adrian et al., 2005).

The efficient pesticides application, with low cost, and without contaminating the environment is an agricultural production challenge. The main effect to avoid during application is pesticide drift. To minimize pesticide drift it is important to know the environmental conditions, such as wind, temperature and humidity at the moment of application. In addition, the equipment used in the crop dusting process needs to be set correctly (Chaim, 2009; Cunha et al., 2003; Hewitt, 2000).

New technologies such as the introduction of monitoring through Wireless Sensor Networks (WSN) (Kwong et al., 2009; Qial et al., 2005) have been introduced in the farming field. This technology minimizes pesticide drift which is a crop dusting problem.

WSN is a special type of ad hoc network, composed of a sensor with the capacity to collect and to process information autonomously in a certain area (Akyildiz et al., 2002; Tubaishat and Madria, 2003; Gajbhiye and Mahajan, 2008). This type of network is useful for a wide range of applications, such as environmental monitoring, precision agriculture, industrial processes, embedded systems, surveillance systems, among others (Estin et al., 2001; Pottie and Kaiser, 2000; Estrin et al., 1999).

The application of WSN in agriculture monitoring involves continuous monitoring and observation of a crop area in order to evaluate changes in that environment. The performance of monitoring systems can be improved by new technologies or improvements in sensor networks, routing protocols and embedded systems.

The crop area is monitored more efficiently with the integration of two technologies: embedded networks in agricultural vehicles and WSN for crop monitoring. These vehicles function as a mobile gateway; using the ISO 11783 (ISOBUS) standard (Darr and Hudson, 2004). This standard specifies a serial data network for control and communications for agricultural tractors and implements. The sensor data are collected directly by the onboard computer of the vehicle, at the moment it enters the signal area of the sensor network.

In crop dusting process, the environmental conditions are considered to play an important factor in the quality and effectiveness of process. Bad environmental conditions can cause pesticide drift, resulting in a waste of product, money, inefficient dusting, and environmental pollution (air, soil and water).

Pesticide drift is the horizontal movement of droplets of pesticide before they reach either the soil or plants (Chaim, 2009). Although this drift always occurs, it should be avoided as much as possible. It becomes intolerable when the distance traveled by the droplets is large enough to leave the target crop area under treatment. When the pesticide drifts leave the area they can cause damage to neighboring crops, cities, people, animals, lakes or rivers (Hewitt, 2000).

The main factors that affect the occurrence of pesticide drift are: the drop size (diameter) and weight, wind direction and intensity, temperature, environment humidity, and the drops launch height.

Of these factors there are two main factors to directly control pesticide drift. The first is the weight of the drops, determined by setting the spray nozzles in installed dust equipment. The temperature can have an indirect effect to the weight of the drops. High temperatures tend to promote evaporation; the drops become smaller and more susceptible to drift. Another side effect is the heating of the soil that produces updrafts hindering the immediate deposition of drops. In addition, the thermal inversion phenomenon, high temperatures at high altitudes, affects the drops dissipation into the atmosphere enabling long distance travel. Low relative humidity also reduces the drop diameter by evaporation. Complete evaporation can occur when the drops are already fine, polluting the air and causing deficiency in the spray procedure, because the drops do not reach their target.

The second factor affecting the pesticide drift is the height of the crop dusting equipment, which is especially true in case of airplane dusting. On the one hand, if spraying occurs at a high altitude then the drops are more time exposed to the drift effect, such as the wind, and evaporation. On the other hand, if the crop dusting occurs in a low altitude then the turbulence caused by the vehicle motion tends also to generate pesticide drift. As such the wind velocity and direction influence drift control.

A drop cannot move against wind, therefore planning of the application should take into account the wind direction and is fundamental to control pesticide drift. Having the wind in a favorable direction can ensure the security of sensitive areas, such as streams, lakes, rivers, and villages. Usually, the pesticide drift is proportional to the wind speed.

We propose a system based on WSN, after looking carefully at the presented technologies and aspects that affect the crop dusting monitoring, which considers three functionalities: the evaluation of environmental conditions, the alteration of the crop dusting path, and the evaluation of crop dusting efficiency.

The aim is to gain greater efficiency in the crop dusting process, with lower occurrence of pesticide drift and, consequently, lower product waste and environment contamination around the crop.

The following sections discuss the use of WSN in the crop dusting process, discussing the three functionalities; the main technical challenges to implement WSN in pesticide drift monitoring, proposing three strategies to meet those challenges; and, finally, close the work with comments about the advantages, expectations and challenges of this approach.

USE OF WIRELESS SENSOR NETWORK IN PESTICIDE DRIFT CONTROL

The use of WSNs for crop dusting, specifically for mapping pesticide drift, brings the advantage of a more precise monitoring of environmental conditions through their sensors. The waste of pesticide is expected to be reduced, consequently reducing production cost and improving the production process by treating solely the target area. Moreover, the use of sensor networks should minimize the risk of contamination of regions near the target crop.

We can develop strategies in the crop dusting process that minimize the occurrence of pesticide drift when we consider the ability of WSNs to monitor environmental parameters, such as temperature, humidity and wind. It is expected that the system assist farmer by automating the process and providing a decision support system.

As mentioned before, three functionalities for WSN in the context of crop dusting are considered: the evaluation of environmental conditions, support in crop dusting route definition, and evaluating the efficiency of spraying. Each of these features are discussed as follows.

a) The evaluation of environmental conditions

The first application of WSN is to monitor and to evaluate the environmental conditions. This monitoring happens constantly, before and during spraying.

The WSN will work as a decision support system, checking whether environmental conditions are favorable for dusting. For example, if the environmental temperature is over the limit, as determined by experts, then the farmer will be informed by the system about this. Another example is that if during the pesticide application the system detects wind gusts, it will warn the operator that he should stop the spraying.

The flowchart shown in Figure 1 demonstrates the decision support system logic based on WSN monitoring.

b) Support in crop dusting route definition

Another function of the decision support system is assisting in the path definition, especially for aerial crop dusting. In this context, the WSN will monitor wind conditions and make changes in the vehicle path, providing uniform spraying over the target area and avoiding spraying outside that area.

The alteration in the vehicle path should be timely, allowing the operator to change his actions. Figure 2 shows an example of such a path change for an airplane. In this simulation the WSN is monitoring the environmental conditions of the targeted crop area. When wind variations occurs during spraying, the sensor network detects the change and interacts with the airplane embedded system, suggesting an alteration of the path.

c) Evaluation of the spraying efficiency

The use of WSN allows evaluating the crop dusting process through a so called leaf wetness sensor. These sensors are able to verify the moisture deposited over the crop leaf (Bregaglio et al., 2011). After spraying the deposited pesticide can be checked by the leaf wetness sensor, thus measuring the success of the dusting in the target area.

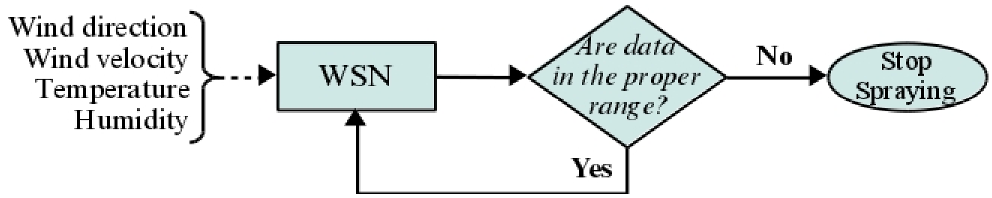

Fig. 1. Flowchart of the decision support system.

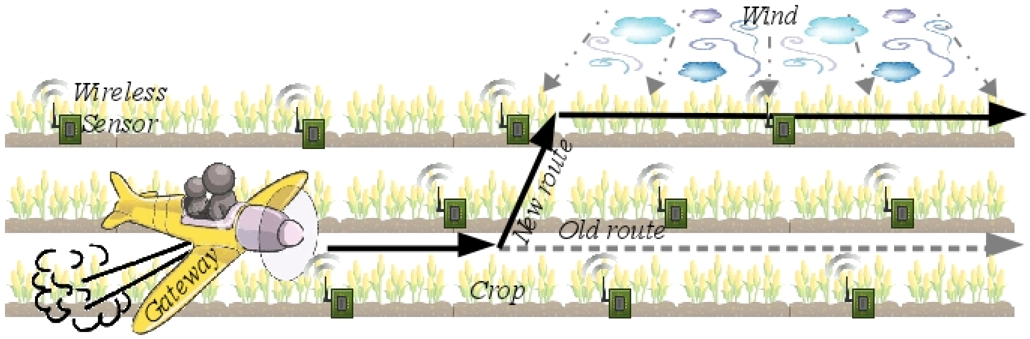

Fig. 2. Mobile gateway route changing based on WSN monitoring.

This data is then used in the optimization of the system and the development of algorithms using artificial intelligence or combinatorial optimization to provide better solutions in different conditions. Furthermore, the data is used to evaluate the WSN as a decision and support crop dusting system under current conditions.

Thus, the use of WSN for monitoring pesticide drift brings advantages and new strategies for PA. Further improvements are expected, however there are theoretical and technical challenges for WSN in relation to crop dusting decision support systems. The next section discusses some of these challenges.

CHALLENGES AND STRATEGIES FOR IMPLEMENTING WIRELESS SENSOR NETWORKS IN PESTICIDE DRIFT MONITORING

The use of WSN for pesticide drift monitoring poses some challenges. The main one is the data routing problem. The speed of the crop dusting vehicle, with the embedded gateway node, is determinant in this process. If the vehicle motion is slow, as in the case of tractor, the problem is almost nonexistent because the sensor has ample time to transfer its data to the gateway. Therefore, if the vehicle moves at high speed, such as an airplane, than the routing and transmission of the data is considerable more difficult.

This work proposes three strategies to face this technical challenge of the interaction between WSN and a crop dusting vehicle (mobile gateway): the gateway route representation in WSN, the organization of network nodes into clusters, and the data routing protocol based on interception.

a) Gateway route representation in Wireless Sensor Network

The first strategy is the representation of the mobile node route on the WSN. For all sensors to be able to transmit their data to the mobile node they should be aware of the optimal path to the mobile gateway in order to effectively use the available bandwidth in the network.

Pre-processing will be necessary to implement the route representation on the sensor network. This pre-processing is to represent the mobile gateway route path over the crop area and send this information to the sensor network.

For the whole path of the mobile gateway nodes near to the path will be identified and selected. These selected nodes are so called reference nodes. Proximate sensors to these reference nodes in turn will refer to these sensors in

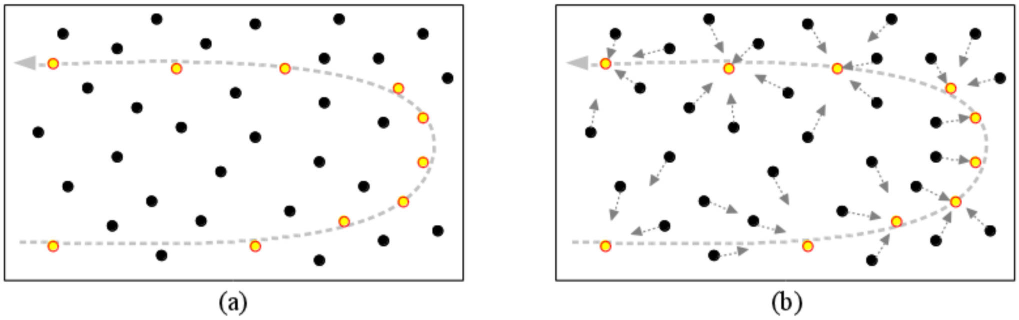

Fig. 3. The representation of the mobile gateway path. a) Path definition and reference nodes determination; b) Organization of remaining sensor nodes.

order to contact the mobile gateway as illustrated in Figure 3. Figure 3(a) shows a previously determined path and the selected reference nodes, giving priority to those nodes that are closer to the mobile gateway path. After the selection of the reference nodes the remaining nodes organize themselves in relation to these reference nodes (Figure 3(b)) since they now have indirect knowledge of the planned mobile gateway path.

b) Organization of the network nodes into clusters

The strategy of grouping the sensor network nodes into clusters aims to organize the sensors hierarchically and yield energy savings (Vladic and Xia, 2006).

A WSN organized in clusters is shown in Figure 4. Each sensor node belongs to a specific cluster and each cluster has selected a “cluster head”, which are highlighted in the figure.

In the context of this work, the set of selected nodes functioning as cluster heads the same set of nodes selected as reference nodes, which were established in the mobile gateway route representation process. Consequently, there are as many clusters as reference nodes. In each cluster the remaining nodes forward their data to cluster head before the data is ultimately transmitted to the mobile gateway.

c) Data routing based on interception

Data collected by the sensors, in particular data regarding to weather conditions, need to be delivered to the mobile gateway during its passage. This

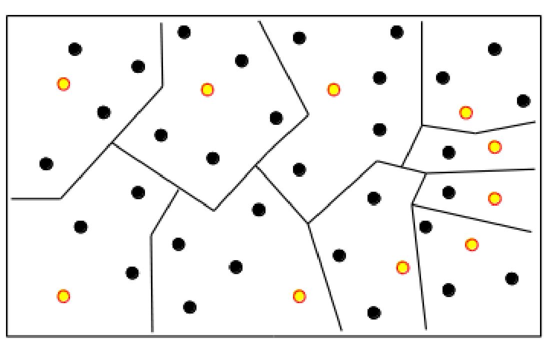

Fig. 4. WSN organized into clusters with its cluster head highlighted.

delivery of data becomes complex when the mobile gateway is moving at high speed. Selecting reference nodes close to the determined path solely based on their proximity to the path is not enough. To solve this problem of high speed mobility, as in the case of embedded gateways on crop dusting airplanes, we propose the use of arrangement in cluster and data routing based on interception (Oliveira et al., 2010).

Data routing based on interception consists out of monitoring the gateway movement in relation to the sensors. At the time the gateway approaches the sensor nodes calculate the speed and direction of the gateway and report this to their neighboring sensors.

Using this information the data of the sensors is then routed to reference nodes further ahead in the path where the mobile gateway.

Figure 5 shows an example of routing sensor data using this strategy. When the mobile gateway enters the monitored area, at time t_1, the sensor network determines its approach. The sensor nodes calculate the gateway speed and send their recorded data to the next referenced node in gateway route in t_2 time where it is transmitted to the mobile gateway.

The proposed approach presents some challenges. The first challenge is determining an adequate number of reference nodes proximate to the expected gateway path. Choosing a low number of reference nodes causes overhead, due to increased amount of data transferred for the routing protocol, and leads to an increased chance of failures in the data delivery process, because for instance in practice the realized path may not coincide with the estimated path. A large number of referenced nodes on the other hand can make the interception of the gateway more difficult, because a chosen node can be out of the estimated path. In addition, the increase of referenced nodes increases the total energy expenditure of the WSN as more data will be transferred between nodes. It becomes clear that it is important to select an optimal number of nodes, balancing energy requirement, transmission loss and routing complexity.

A second challenge is related to the choosing of the cluster head. At different moments of time a different cluster head can be chosen for the same cluster. This change is cluster head is needed to reduce power consumption of the node and extend the sensor network life as a whole. However, for the purpose of this work, the cluster head is mainly chosen based on his proximity to the mobile gateway path and thus its gateway function. Alternatively, the system can define new and different paths for the mobile gateway to optimally use the stored energy in the sensors and thus the network. However, this strategy possible conflicts with the interest of the end user and therefore reduces the usability of alternative routes.

Ultimately, the main challenge is the data routing problem. Although the

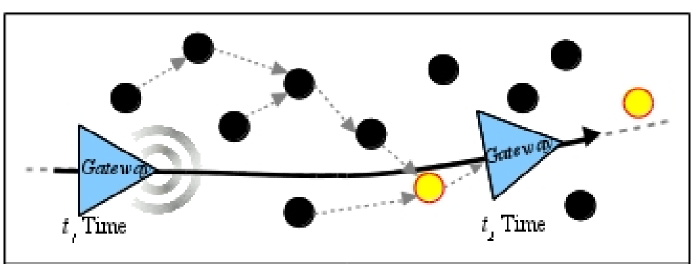

Fig. 5. Data routing using the interception strategy.

interception strategy has been demonstrated to work by computational simulations, the path has always been a linear path. This work proposes an interception routing protocol that allows any path using the combined data of the sensor network and planned path. Further planned research is to verify the presented approach, using computer simulations, in the context of crop dusting.

CONCLUSIONS

Precision Agriculture (PA) is the agricultural practice that uses information technology based on the variability of the crop and climate environment. With the recorded data of the crop area, we can develop an agricultural automation that allows dosing fertilizers and pesticides dynamically, among other things.

The use of WSN in agriculture can perform an important role in many activities such as climate and environmental monitoring, detection or prevention of pests and diseases, automation of irrigation systems, soil analysis, and generation of yield maps. Specially, WSN can be used in monitoring and mapping of the pesticide drift problem, caused in crop dusting process.

The use of WSNs in this context can amplify crop dusting efficiency, minimizing product wastage, farmers' financial loss and especially reduce the contamination probability of neighboring areas, such as pasture, other crops, communities and river or lakes.

This work proposed the use of WSNs for three pesticide drift monitoring functions. The first consists of a decision system, which evaluates the climatic data and determines whether the environmental conditions are favorable to crop dusting. The second function is to assist the operator during spraying. In this case, the WSN evaluates the wind data (direction and speed) and suggests corrections on the crop dusting vehicle route. This function aims to optimize the dusting process and to minimize the contamination of neighboring areas. Finally, the WSN is able to evaluate the efficiency of crop dusting, checking the product deposition over the crop leaves. These data can be used as feedback to the system, developing algorithms to optimize its own operation.

The utilization of WSN in pesticide drift monitoring poses some technical challenges. This work proposed three approaches to solve these challenges: gateway route representation in WSN, organization of network nodes into clusters, and data routing based on interception. These strategies aim to use WSN in crop dusting not for only slow vehicles, but also for faster vehicles, such as airplanes.

The sequence of this work is to verify the quality of these solutions by computational simulation. In the representation of the gateway mobile route, it is necessary to establish standards for defining the number of reference nodes and their redefinition. Also, we should check the full functionality of the system, especially considering the routing data protocol.

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