Computers and Electronics in Agriculture 119 (2015) 19–32

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Design of a low-cost Wireless Sensor Network with UAV mobile node for agricultural applications

Jose Polo *, Gemma Hornero, Coen Duijneveld, Alberto García, Oscar Casas

Instrumentation, Sensor and Interfaces Group, Universitat Politècnica de Catalunya, BarcelonaTech, Spain

ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 15 September 2015
Accepted 26 September 2015
Available online 22 October 2015

Keywords:
WSN
UAV
Low-cost system
Agriculture

ABSTRACT

The aim of the present paper is to propose an agricultural environment monitoring server system utilizing a low-cost Wireless Sensor Network (WSN). Several sensor nodes are scattered in fields several kilometres in size, and we propose collection of the information stored in the nodes by a mobile node, or mule. To cover long distances in a short period of time, we use an unmanned aerial vehicle (UAV), which retrieves the data stored in the ground nodes. In addition, the UAV may be used to acquire additional information and to perform actions. Its elevated position allows observation of the field with a perspective that is useful for detecting changes affecting crops, such as pests, diseases, significant changes in soil moisture, drought or floods.

1. Introduction

Sensors are being introduced into almost every aspect of life. Agriculture is one such domain where sensors and their networks are successfully used to reap numerous benefits (Aqeel-ur-Rehman et al., 2014). The sensors can provide risk assessment information, for example, by alerting farmers at the onset of frost damage and providing better microclimate awareness. In precision agriculture, sensor networks enable an enhanced understanding of the changes in the crops to determine the optimum point for harvesting. They can improve the handling and management of water resources for irrigation, and they help to optimize fertilizer use and to increase crop performance (López Riquelme et al., 2009).

In a sensor network, the nodes must collect several measures of various parameters, such as temperature, humidity, and salinity, and they must transmit these measures, usually, to a central control. In field applications, due to the large distances, transmission must generally take place using a wireless network.

Wireless technologies have been under rapid development during recent years. The types of wireless technologies being developed range from simple IrDA, which uses infrared light for short-range, point-to-point communications, to wireless personal area networks (WPANs) for short-range, point-to-multipoint communications, such as Bluetooth and ZigBee, to mid-range, multi-hop wireless local area networks (WLANs), to long-distance cellular phone systems, such as GSM/GPRS and CDMA (Wang et al., 2006) networks.

The first application of a Wireless Sensor Network (WSN) in a greenhouse was reported in 2003. It was a monitoring and control system developed by means of Bluetooth (Liu and Ying, 2003). For applications where higher data rates are important, Bluetooth clearly has the advantage because it can support a wider range of traffic types than ZigBee. However, ZigBee is designed for devices with low power consumption and has a range of approximately 10 m to 100 m (ZigBee Specification FAQ).

Most crop fields are extensive, with a size of up to several kilometres. In this type of field, the distance between nodes needed to cover the whole area can be large. Hence, it is necessary to use radio extenders, to use other wireless protocols or to increase the power of transmission, thereby increasing the energy consumption (Ruiz-Garcia et al., 2009). To avoid this increase in the energy consumption, the nodes can be located sufficiently close to one other, which requires an increase in the number of nodes.

We propose the use of a sensor network for extensive fields where the nodes are not capable of communicating amongst themselves directly, and a mobile node is used to collect the data from the static nodes. The mobile node moves from one node to another node. If the mobile node is installed in an aerial vehicle, it can access any position, no matter its location or distance; its travel speed is sufficient to reach distant points in short periods of time, and it is a low cost system.

For monitoring plants in fields, in addition to the variables taken by the ground nodes, it is very helpful to have other

* Corresponding author.
E-mail address: jose.polo@upc.edu (J. Polo).

http://dx.doi.org/10.1016/j.compag.2015.09.024
0168-1699/

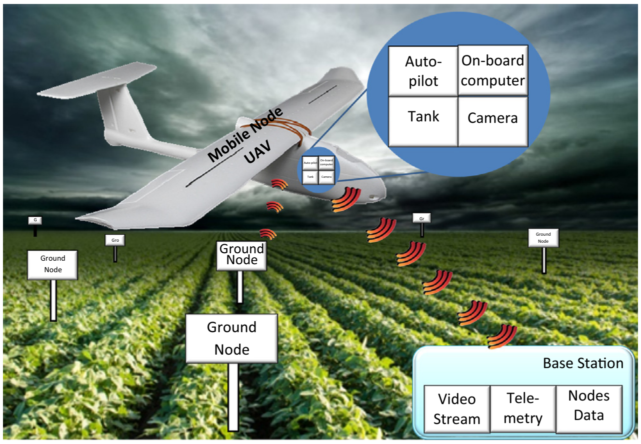

Fig. 1. System architecture.

measures affecting large areas of the field. Aerial images can be used to detect water accumulation on plant surfaces or on the ground. The appearance of crops or the colour of plants often changes when they suffer from a disease or a pest. These images can be obtained using satellites or manned aircraft, but they are expensive. Alternatively, a camera carried by an aerial vehicle can acquire those images. Using infrared imaging, it is possible to measure moisture on crops (Stafford et al., 1989) or soil (Ayalew and Ward, 2000; Hassan-Esfahani et al., 2014; Hea et al., 2007; Yin et al., 2013).

Another important point to highlight is that an aerial vehicle can be used to act on the environment, which is an important advantage. For example, if a disease or pest is detected, pesticides or insecticides can be used to fight them. The vehicle is able to transport these substances and release them at a particular point when necessary.

Finally, to improve the vehicle's manageability and usability, it would be very helpful if it could fly autonomously or could be guided manually.

Therefore, the aim of this work is to create a network of sensors that can be applied in agricultural operations with extensive fields. Using several low-cost sensor nodes scattered throughout the field and a low-cost mobile sensor node, not only can the data from the ground nodes be recovered but global measures of the crops can also be obtained from the sensors carried by the UAV, including video measures (using a image sensor), and the UAV can act if necessary. The mobile node sends all the collected information to a base station wirelessly. Fig. 1 shows architecture of the developed system.

2. Materials and methods

When fields are very extensive, the nodes of the network are too far apart to communicate amongst themselves. A mobile node, or mule, is carried by the aerial vehicle, and to include the above features, it must meet several requirements:

- The distance to overcome can be several kilometres. To achieve good autonomy, a low consumption system is necessary. The vehicle must be able to cover distances of up to 10 km or to operate in fields of approximately 100 ha.
- The vehicle will fly above the nodes at a certain distance. The communication range must be sufficient to enable the mobile node to communicate with the sensor nodes dispersed on the ground and to collect the data stored in them.
- To detect situations of disease or pests in crops, the images should be of high quality. The vehicle must send a live video stream with sufficiently high quality to show changes in crops and store the video for later processing.
- If a disease or pest is detected, the application of a substance to counteract them can be useful. The vehicle must be able to transport these substances and launch them in the required positions.
- To obtain a system that is not too expensive, the total cost must be kept as low as possible, within a budget of $1000.

The candidate vehicle that has the desired features and meets the requirements is a UAV. During the past several years, these devices have become more and more popular, and their applications are growing continuously.

A UAV is defined as an aircraft that does not carry a human operator, is operated remotely using various levels of automated functions, and is normally recoverable. There are different types of UAVs, and they can be classified in different ways, including by who is operating it, the flight type, the size, the payload, and the level of automation. One way to classify UAVs is by the flight type, which is primarily either rotorcraft or fixed wing but is occasionally another, such as balloon, kite, or ducted fan technology. Rotorcrafts (Fig. 2 left), which usually have two to eight rotor propellers, have the advantages of hovering to collect imagery and taking off and landing vertically (VTOL or vertical take-off and landing); however, they deplete batteries quickly because much of their energy is dedicated to vertical lift, and thus they are limited in time aloft to typically less than 30 min. Japan, for example, is a pioneer in the application of rotorcraft UAVs to agriculture. For 30 years, environmental parameters have been monitored by remotely controlled helicopters, called "aero-robots" (Lee, 2014).

Fixed wing UAVs (Fig. 2 right) can fly longer distances for longer times, usually 45 min to several hours, making them more effective for collecting imagery over a wide area, but they need space for takeoff and landing and cannot hover (HTOL or horizontal take-off and landing). They are capable of moving at higher speeds carrying heavier payloads with lower energy consumption, and they have great autonomy, but they cannot execute VTOL manoeuvres or high-precision movements.

This type of vehicle is currently used for several applications such as for agriculture, the film and broadcast industries, pollution measurements, surveillance, communications relays and so on (Bento, 2008; Benett, 2014).

Considering the amount of equipment that needs to be carried and the energy requirements to extend the range to the required distance, a good option for our agriculture network is to use a fixed-wing architecture.

The fixed-wing UAVs have swept back wings, and the tip aerofoils have a greatly reduced incidence compared with the aerofoils of the inner wing. This ensures that as the aircraft nose rises, the wing's centre of lift moves towards the rear, thus returning the aircraft to its original attitude. The performance of these aircraft suffers because of the reduced effective tail-arm in both the pitch and yaw axes, although the rearward sweep of the wing does add to the directional stability (Austin, 2010).

The developed vehicle is divided into two main parts: (1) the plane itself, which is composed of several subsystems that are needed to fly properly, and (2) the payload, which consists of several subsystems to achieve the desired features.

The plane architecture contains the following subsystems:

- Airframe: it is the body of the whole system. It carries all of the other subsystems and allows the plane to fly by generating lift.