A Mobile WSN Sink Node Using Unmanned Aerial Vehicles: Design And Experiment

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***Abstract*—In this paper, we construct a new type of mobile wireless data sinking platform for data collection based on unmanned aerial vehicle (UAV) technology, which aims to address the increasing demand for wireless sensor network (WSN) distribution in different monitoring areas and enlarge the coverage for various application scenarios. A wireless environmental monitoring system is firstly studied, and then wireless communication capacity and data collection experiments are performed. The communication capacity test results show that when the RF modules operate with a transmission power above 1 dBm and a communication distance below 100 m, the UAV wireless sink node can maintain a high quality communication data link. Additionally, an outdoor data collection experiment is performed using this UAV platform within a mountainous area. In this outdoor experiment, the data analysis results show that the validity rate of the environmental data that is obtained from the WSN cluster head node on the ground is higher than 92%, and most of the missing data results from WSN communication failures. This experiment proves the feasibility of introducing UAV as a sink node in a clustering WSN. The overall contributions of this paper can provide guidance for building a UAV cooperative WSN system in future.**

***Index Terms*—Mobile Wireless Sensor Networks, Unmanned aerial vehicles, Sink platform, Data analysis**

I. INTRODUCTION

Due to advantages of having no wiring, a flexible topology and a low cost, WSN has been applied to a wide range of fields including environmental monitoring, intelligent transportation, agricultural situation acquisition, and animal tracking and positioning [1-3]. The working WSN nodes are usually stationary as this type of node is restricted by its working environment, and the node monitoring range is also largely limited. As WSN is being continuously developed and mobile robots are being added to the network, vehicle engineering technologies such as wireless mobile nodes can further extend the WSN monitoring scope and improve the flexibility of the wireless network layout [4-7].

Relating research to combine Mobile Wireless Sensor Networks with practical requirements has been done both in China and in other countries. Young-Duk Kim et al. [8] have built an environment monitoring system with a mobile WSN based on wheeled robots and a TinyOS platform, and have proposed a multi-channel Medium Access Control protocol. Kwong et al. [9] have built a mobile WSN platform for monitoring livestock movement characteristics of free-range animals and have analyzed the optimization of wireless data transmission performance. The above studies have improved the performance and application scope of this domain, through adding mobile nodes to WSN. However, there are disadvantages that prevent ideal movement tracks from being built as the moving range is small and there is a poor environmental adaptability for mobile nodes.

Unmanned Aerial Vehicle (UAV) technology is an effective, high-speed platform that has been widely used in national defense security, agriculture, forestry and animal husbandry, logistics transportation, and other fields [10-11]. Introduction of this technology into wireless networks is a new hot spot in current MWSN studies. Imad Jawhar et al. [12] have proposed UAV platforms including the linear WSN data framework, which includes an unmanned aerial vehicle, a relay node, a perception and gathering node, and a multi-hop network for data transmission. The have also performed simulation tests to verify the feasibility of this framework. Dac-Tu Ho et al. [13] have used the particle swarm algorithm to optimize the UAV WSN track point, based on the hierarchical network protocol Low Energy Adaptive Clustering Hierarchy (LEACH). The network parameters such as the life cycle and flying time are studied in a simulation test.

Most of the current existing research on WSN UAV is based mainly on path planning and design of the framework, rather than research into combining UAV with wireless networks. In this paper, the ZigBee protocol stack is used based on the characteristics of MWSN and UAV technology, to build a new type of mobile wireless platform that can be used for a wide range of monitoring applications and improve the network coverage area. Based on the convergence platform, the UAV platform can be used for actual WSN environment monitoring data network tests to verify the feasibility of the UAV gathering platform to provide a basis for UAV wireless networks that can be widely used in future.

The structure is organized as follows: Section 2 presents the platform design of an unmanned aerial vehicle. Section 3 presents the experimental materials and methods and tests are given in Section 4. Finally, Section 5 concludes the paper and suggests further work.

II. PLATFORM DESIGN OF UNMANNED AERIAL VEHICLE

As shown in Fig. 1, this paper proposes a UAV WSN gathering platform that consists of the following components: an unmanned aerial vehicle body (including a controller), a ZigBee module, a GPS module, an image acquisition module, a sensor module and a power supply. The flight of the unmanned aerial vehicle module is the main consideration as it carries the overall platform. The wireless module gathers the ground WSN data, and the data is stored in the storage unit. The GPS coordinates within the GPS module acquire the UAV location information. The image acquisition module collects the images during UAV flight. The sensor module acquires the status parameters of UAV during the flight process.

III. EXPERIMENTAL METHODS AND MATERIALS

A. *Experimental materials and equipment*

The platform built for this research adopts a single screw after push type fixed-wing carrier as shown in Fig. 2. The fuselage materials are foamed polypropylene (EPP) with a wingspan of 172 cm, a captain of 112 cm, and a 40 cm tail plane. The communication module components are: a CC2530 wireless module from TI Company with a carrier frequency of 2.4 GHz, a 3 dBi omni-directional sucker antenna and a Heaven and Earth fly remote control with eight channels. The power system uses the New West Company 2217 - KV1100 40A brushless motor, a brushless electronic governor, a 12 V power dc power supply, and 7g double propellers with a length of 254 mm. The other special test equipment includes an APM2.5 CJMCU - 109 current sensor, an ANTAI faith APS3005D manostat, an ANTAI ADS1112CAL 7-inch screen oscilloscope with a 1G sampling rate, a 110 m ~ 200 m digital oscilloscope, a tripod, a tablet, a tape measure and a load.

B. *Experimental design*

A communication network experiment was performed to obtain the static and dynamic communication reliability of the constructed gathering platform. The parameters were as shown in table 1. The height was below 150 m, the step length was 5m; the transmission power between nodes was 4.5 dBm and 1 dBm, the communication rate was 250 KBPS, the height of the ground node was 1 m and the node omni-directional antenna gain was 3 dBi. Using the communication height as the test factor, 1000 data points were sent in a row for each communication height, and repeated three times and the average taken. The received signal strength index (RSSI) and the average packet loss rate (PLR) of the wireless communication nodes was thus obtained between the gathering platform, when receiving the signal to measure the communication reliability of the platform.

After completion of the static experiment, the feasibility and the platform communication reliability during flight was obtained by performing a UAV wireless node network experiment. A cluster of WSNs were formed in a ground fruit farm, and the UAV platform was used three times to wirelessly collect different volumes of data. The success rate parameters were then obtained for the network communication platform in order to dynamically evaluate the reliability performance.

IV. PRACTICAL COMMUNICATION NETWORK TESTS ON UAV PLATFORM OUTDOOR

A. *Communication test*

Fig. 3 is obtained by software analysis, and shows the relationship and fitting curve between different communication distances, RSSI and PLR.

Fig. 3 shows that the transmission power of the UAV wireless collection platform is 4.5 dBm and within the communication distance range of 150 m, the node can establish effective communication with the ground when the RSSI is greater than -90 dBm and the PLR is less than 20%. The transmission power is 1 dBm when its corresponding RSSI and PLR are less than -95 dBm and 30% respectively. The test results show that the UAV WSN collection platform within the scope of the communication distance is 120 m as long as a transmission power is chosen that has greater than 1 dBm link quality in order to meet requirements. In order to ensure reliable communication, the node flight height of all nodes should be chosen to be below 100 m to ensure a high quality of communication.

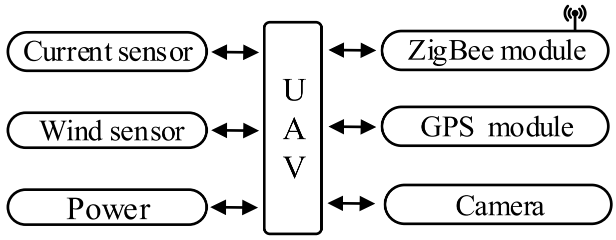

Figure 1. Structural diagram of UAV platform

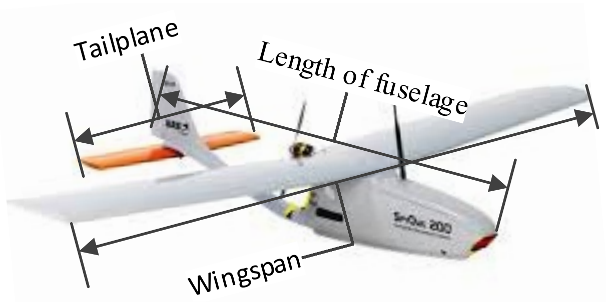

Figure 2. The key geometric parameters of the UAV

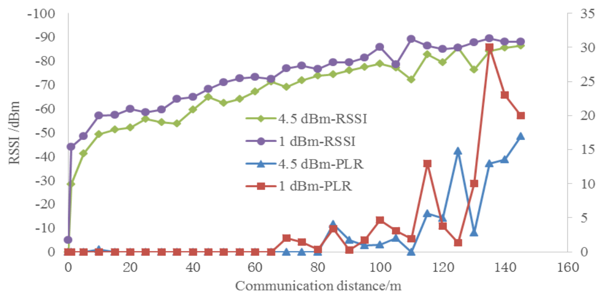

Figure 3. RSSI、PLR in different communication distance

TABLE I.
UAV WSN PLATFORM PARAMETERS

Impact factors	Height /*m*	Transmission power / *dBm*	Communication rate / *kbps*
Values	0~150 (/5*m*)	1, 4.5	250

B. *Network test*

Upon completion of the communications test, multiple hops are set up within heterogeneous clusters of WSN within groves, to collect orchard parameters such as temperature and humidity, light intensity and wind speed. This wireless network includes a collection node and an ordinary node. As shown in Fig. 4, the entire experimental system includes a UAV wireless platform, a ground station and the WSN. The dotted line in the overall flight path shown in Fig. 4 indicates that the UAV gathers from the clearing platform, establishes communication within WSN over the WSN, and completes the whole network data collection. In this experiment, the flight height of UAV is less than 100 m, and the flight time is approximately 30 minutes after reaching WSN UAV, where the airspace and the cluster head nodes establish communication links, cluster the environmental monitoring data, retrieve the cache in the pseudo code to describe the communication process, such as the communication process adopted error retransmission and interference retreat mechanism in table 2. The altitude change curve is shown in Fig. 5.

From Fig. 5 it can be seen that once the desired height is reached, the UAV flies in cruise state. The experimental data analysis shows that the height control of the variance is 7.3 and the mean square error is 2.7, indicating that the UAV meets design requirements when the flight control system has a flying height error below 3 m and a relative altitude error of less than 3%.

In the experiment, the fixed-wing UAV is controlled by the manipulators and the UAV climbs to 100 m after 96 s. At this point, the onboard flight control system (APM) 2.5 and the WSN data acquisition subsystem are launched, the UAV is flying along its designated route while constantly attempting to contact the ground WSN nodes at the same time. There is a high risk for fixed-wing UAV controlled landing. In this experiment, after the data acquisition is completed, the UAV is returned to the landing field by the flight control system of the flight control hand remote for closing the heading, height, the throttle adjustment function, and keeping the balance function, drones in the manipulators, flight control using a coordinated control method for smooth landing to reduce the difficulty of control.

Fig. 6 shows the UAV wireless converged network packet acquisition test platform. The acquisition success rate of the three packets is more than 92%, meeting application requirements. The actual number of packets is less than theoretical predicted which has been analyzed and is caused by packet loss due to WSN communication interference, as the lost packets have no successful transmission from the WSN child nodes to the cluster head nodes.

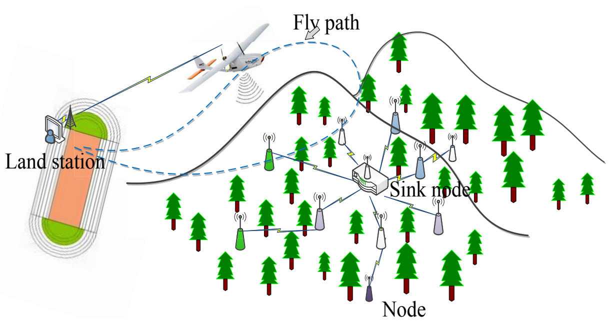

Figure 4. Outdoor practical tests

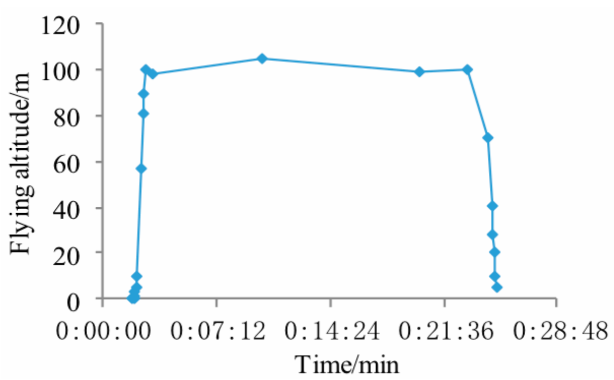

Figure 5. Flight level curves of UAV

C. *Environmental monitoring data analysis*

Regional data (temperature, humidity, light intensity, wind speed) is monitored by the UAV for six hours between 13:30 to 19:30 and the results of the analysis are shown in Fig. 7 and 8.

TABLE II.
THE COMMUNICATION PROCESS OF UAV WITH GROUND WSN PLATFORM

```
Receive Data From WSN()
Try broadcasting UAV beacon packets
if beacon packets were ACKed for 3 then
    Start querying data from ground WSN
    sink node with RTS CTS and ACK strat-
    egy
    if CRC error then
        Re-transmit current packet
    if CRC error > 5 then
        Wait for 10s and retry
    else
        Prepare for next packet
    if no ACK from ground WSN node for 10
rounds then
        Restart from sending UAV beacons
```

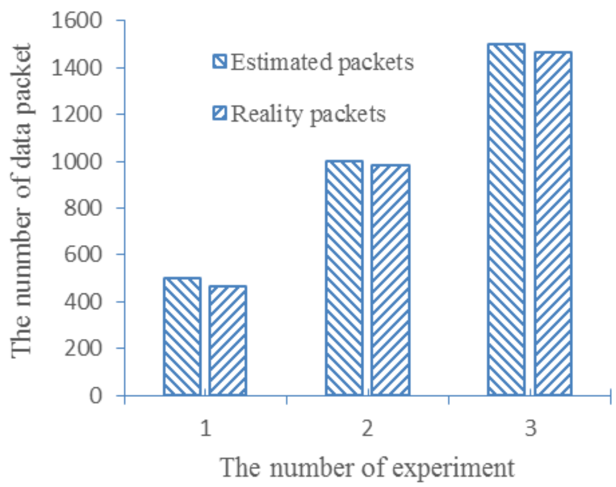

Figure 6. Data acquisition test

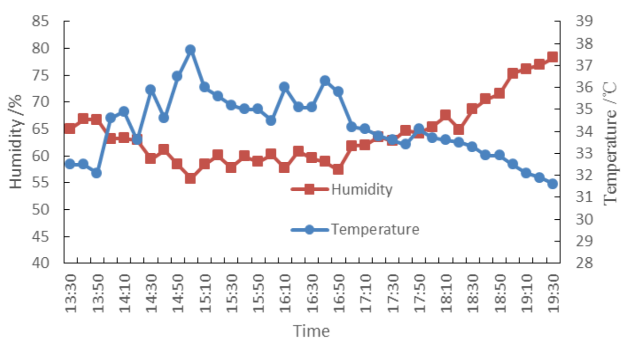

Figure 7. Temperature and humidity change curves of the monitoring area

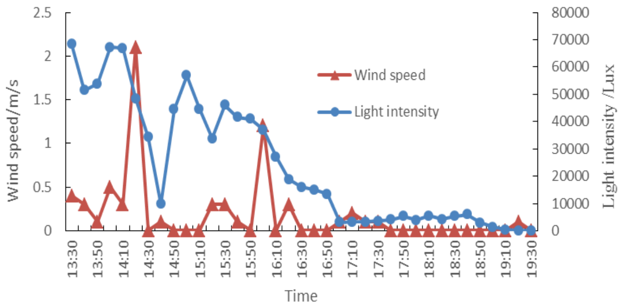

Figure 8. Monitoring area - light intensity and wind speed curve

Fig. 7 shows the temperature changes, which displays a downward trend after first rising, and peaks appear at 15:00. At the same time, the humidity shows a change trend that is in contrast to the temperature change. Figure 8 shows that the light intensity curve has an overall downward trend, with an obvious correlation to the temperature changes. The overall change in the monitoring period wind speed curve is smooth with no obvious change.

V. CONCLUSION AND DISCUSSION

In areas without GPRS or 3G mobile communication network coverage, UAV can be distributed through different locations of a network to monitor data. Therefore a UAV-WSN platform can effectively expand the monitoring area and its scope. This contribution of this paper is to build a wireless collection platform based on UAV. The platform was used to test tension, rotational speed and the wind field. It can be concluded that for data collection and analysis, this platform provides necessary support for a wide range of future applications. At the same time, the platform communication network performance is tested, the static and dynamic reliability of the communication using the platform is verified. Finally, a practical application test is performed using an MWSN which illustrates the feasibility of the platform.

Due to experiment's environmental limit, this experiment did not test a wide range of network authentication and other environmental factors. Future research can be performed according to the specific application of WSN UAVs, and determine the UAV combination of WSN in flight and more precise mathematical models by constructing different types of UAV and different network modes.

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