DSENSE: Mobile Wireless Charging and Sensing by Drones

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1. EXECUTIVE SUMMARY

In this project, we propose DSENSE, a mobile wireless charging and sensing platform using drones to alleviate the pain of energy delivery and data gathering in traditional wireless rechargeable sensor networks (WRSN). DSENSE combines the new technology of drone platform with the wireless charging technology based on electromagnetic radiation with the intention of powering the sensor nodes deployed in remote locations (e.g., embedded in walls, in soil), retrieving and forwarding sensor data packets to the cloud. This kind of mobile charging and sensing method executed by drones is demonstrated to be effective and efficient–DSENSE successfully drives WRSN-based monitoring services in both a high-rise building and a large farmland. Compared with traditional human operation, not only monitoring time but also the whole system costs has decreased a lot, which brings a new opportunity to the environmental monitoring field.

2. GENERAL DESCRIPTION

WRSN are used in a wide range of applications from large scale terrestrial habitat monitoring to structure health detection because of their ability to measure a multitude of environmental variables with high frequency over long periods of time. In some practical applications, sensors are deployed in remote and dangerous locations provide unprecedented amounts of data, powering these sensors and uploading the sensor data to cloud server remain challenges. A lot of research has been focused on the increase of sensor's lifetime such as adding other infrastructure (e.g. solar panels or wind generator) or periodic maintenance to batteries. Such kinds of method would no doubt cost a large mount of manpower and material resources , and some sensor nodes are deployed in peculiar locations(e.g. embedded in structure or located in primeval forests) which human can't reach or very dangerous to reach. Although sensors in a WRSN can be replenished by mobile wireless chargers over distance, challenging issues remain in many aspects. For example, stable wireless charging is hardly achievable in remote locations, and harvested energy on sensor nodes is usually insufficient to establish an ad hoc network with multi-hop communications [1].

In this project, we developed DSENSE to address the problems of using the drone platform equipped with 915MHz RF energy transmitter to charge sensor nodes in hard-to-access locations. The maximum charging distance is about 10m and maximum charging power is 3W, DSENSE also enables charging of sensors through concrete, wood and some other metalloid materials. A trajectory file with node locations is generated and pre-downloaded to the drone. Nevertheless, users can also take over the control at any time through the 433MHz MavLink.

In this project, we applied DSENSE in high-rise building structure health detection and large farmland environmental monitoring. The real-time sensor data is shown in the cloud server, and all the flight parameters of drone platform can be observed through ground station. A short video featuring the motivation, system description and field experiments is available online at https://www.youtube.com/watch?v=pmQw2rhAur4.

3. SYSTEM DESIGN

DSENSE mainly consists of three parts: energy transfer system, programmable drone platform and a cloud server. The system architecture is shown in Figure 1. The hardware facility is shown in Figure 2.

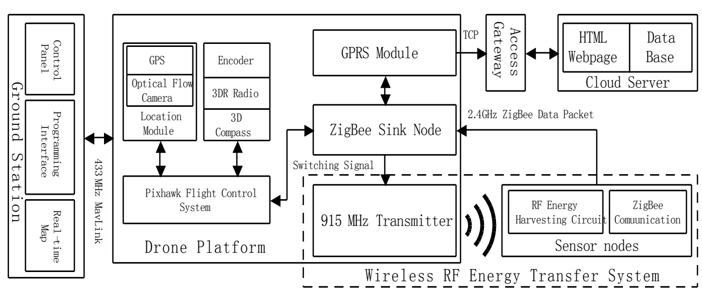

Figure 1: System architecture

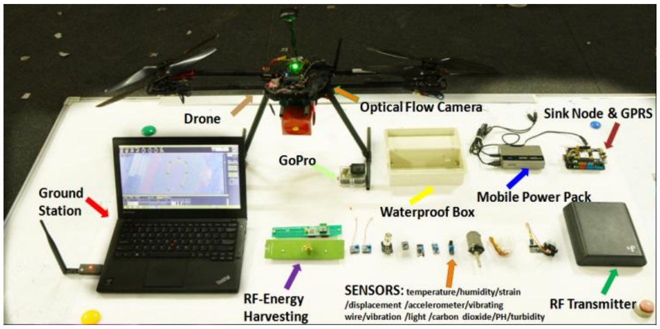

Figure 2: Hardware facility

3.1 Energy Transfer System

The wireless charging technology based on the RF energy transmission especially is a hot topic nowadays. There are three main ways to implement the RF-energy transferring: electromagnetic resonance, electromagnetic radiation and electromagnetic induction. The electromagnetic resonance method requires larger coils, which does not meet the practical need of the wireless rechargeable sensor nodes. The energy transmission of the electromagnetic induction is carried through the electromagnetic coupling between two coils which has been applied in Paper [2]. In this method, the distance between the coils is very short, therefore the drone must be very close to the sensor nodes, which requires the drone of high location accuracy and endangers the drone itself. Compared with magnetic induction, far field radiation-based charging achieves longer ranges and a high degree of freedom [3].In order to charge the sensor nodes, firstly the RF transmitter produces steady and reliable electromagnetic waves that will be harvested by the energy harvesting antenna of the sensor nodes and then converted into continuous DC pulse. Secondly this pulse will be converted into the DC voltage through the chopper circuit. DSENSE transfer the 915MHz electromagnetic frequency that, being tested, is of the highest energy transmission efficiency. The experiments in the demo have shown that DSENSE charging-energy conversion efficiency can reach 74.1%, the maximum charging distance is about 10m, and DSENSE also enables charging of sensors through concrete, wood, glass and other metalloid materials. DSENSE wireless charging system is mainly composed of the RF transmitter and the wireless rechargeable sensor nodes.

The hardware design of the wireless rechargeable sensor node is mainly divided into four modules: the energy harvesting antenna, the energy conversion, the sensors and the module of microprocessor and ZigBee communication. The energy harvesting antenna, adopting the Patch antenna of 915MHz central frequency, is used to harvest and convert the electromagnetic waves into the high-voltage pulses. The RF-DC energy conversion chip, connected with transceiver antenna after impedance matching, is used to convert the high frequency high voltage pulse s produced by the antenna into the stable DC voltage and store it into the super capacitor. According to the practical applications, varieties of analog output sensors with ultralow power dissipation have been designed for DSENSE, which can perceive and collect the environmental information. The module of microprocessor and ZigBee communication module adopts the CC2530 chip, with an 8051 inner core and the good performance of a leading RF transceiver, is used to process and send the sensor data to the sink node through the antenna.

The launching power of the RF transmitter can be adjusted according to the practical need. The direction of electromagnetic wave is concentrated and the energy transmission efficiency is high. This RF transmitter contains an oscillator, power amplifier, power and antenna. The VCO adopts the narrowed voltage-controlled oscillator chip of 915MHz central frequency and is used to produce steady and reliable signals of 915MHz. The power amplifier adopts the RF triode circuit of high power and is used to amplify the original signals. The module of power is composed of the lithium battery of high capacity, the relevant level changer and the filter circuit, and is used to supply power to the whole RF transmitter. The module of antenna, adopting the right hand circular polarization RFID Patch antenna of 915MHz central frequency, features large coverage, high energy concentration and less energy consuming of the space scattering. After collecting the sensor data, the power supply RF transmitter will be shut off the automatically to prevent energy loss.

3.2 Drone Platform

The drone platform of Dsense adopts four- rotor aircraft. A trajectory file with node locations is generated and pre-downloaded to the drone, including GPS of searching fixed-location, high timing hover, automatic returning, obstacle-avoiding and so on. The flying system of Dsense adopts the open source platform of Pixhawk that the firmware can be set according to practical flying requirement. This platform is equipped with gyroscope, accelerometer, magnetic gauge, barometer and other flight requisite sensors. In addition, to improve the flight and hovering stability, an optical flow camera with a duplicate image detection algorithm are proposed to assist GPS and improve the location accuracy to eliminate the mistakes of the barometer in the low altitude. Besides the requisite hardware, the RF transmitter and the sink node are fixed on the drone, too. After reaching the location of sensor node, the drone hovers and launches the RF transmitter to charge. Once the sensor data is collected, the drone stops hovering and carries on the next flight plan. The whole drone platform is controlled by a real-time ground station that can communicate with the drone through MavLink protocol of 433MHz at any time. The instant GPS, the altitude, the speed, and other flight parameters of the drone can be seen clearly in the control panel.

3.3 Cloud Server

Once power transfer process is completed, the sensor data is transmitted to a sink node placed on the drone through ZigBee protocol, and then is forwarded to a certain access gateway using TCP/IP protocol after being analyzed and processed. The sensor data is finally stored in a cloud database, a visual graphical interface (Figure 3) which features historical data processing, query, retrieval, statistics and waveform drawing is also available on webpage at the same time.

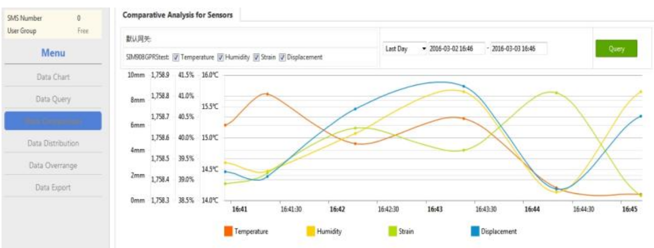

Figure 3: Cloud visual graphical interface

4. IMPLEMENTATION

We fully implemented DSENSE on a Pixhawk open-source drone platform and conducted field experiments in two different scenarios (see Figure 4). In the first experiment, rechargeable sensor nodes were deployed onside walls of each floor of a 12-floor, 38m-height dormitory building to monitor the temperature, humidity, strain and displacement etc. In addition, we deployed seven sensor nodes in a large farmland in the north of Hangzhou to monitor soil temperature, moisture and illumination of crops. With a trajectory file downloaded, the drone flew to sensor nodes, one after another, charged them and retrieved the data. Received data was also displayed on a cloud webpage, together with all flight information of the drone. After a long period field testing, continuous improvements have been made to achieve better performance. Besides structure and farmland monitoring mentioned above, we have been conducting DSENSE on bridge damage detection and wild water quality monitoring, which obtained great progress to a certain so far. We firmly believe that DSENSE will one day replace traditional environmental monitoring method and have a huge application market.

Figure 4: Field experiments

5. REFERENCES

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