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The Acquisition of Sand Vibration Information in Hinterland of Desert Based on Advanced Remote Sensing System and Network Technologies

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Abstract: The deep understanding on sand and sand dunes scale can be useful to reveal the formation mechanism of the sandstorm for early sandstorm forecast. The current sandstorm observation methods are mainly based on conventional meteorological station and satellites remote sensing, which are difficult to acquire sand scale information. A wireless sensing network is implemented in the hinterland of desert, which includes ad hoc network, sensor, global positioning system (GPS) and system integration technology. The wireless network is a three-layer architecture and daisy chain topology network, which consists of control station, master robots and slave robots. Every three robots including one master robot and its two slave robots forms an ad hoc network. Master robots directly communicate with radio base station. Information will be sent to remote information center. Data sensing system including different kinds of sensors and desert robots is developed. A desert robot is designed and implemented as unmanned probing movable nodes and sensors' carrier. A new optical fiber sensor is exploited to measure vibration of sand in particular. The whole system, which is delivered to the testing field in hinterland of desert (25 km far from base station), has been proved efficient for data acquisition.
Key words: sandstorm, sand-scale information, optical fiber sensor, desert robot, wireless sensor network
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0 Introduction

Sandstorm and desertification are a great danger to not only health and property safety of human but also global environmental problem. The formation of sandstorm will be based on three basic conditions: material condition (sand source), dynamic conditions (wind), local geothermal conditions (atmospheric conditions). How does the sandstorm form under these three conditions? How can we achieve monitoring and the early sandstorm forecast effectively?

In 2007, the World Meteorological Organization (WMO) established a sandstorm warning assessment system, aiming at a global continuous observation and information acquisition of sandstorm process, finding the cause and achieving early warning of sandstorm further. The current sandstorm observation methods mainly depend on two techniques: one is groud sandstorm observation network which consists of conventional meteorological station, the other is remote sensing information network composed of satellites. The former observation method has two drawbacks. One drawback is that acquisition of the desert and desertification information is few because most of stations are set up on the edge of the desert (very few exceptions) with low spatial distribution density. The other drawback is that fixed-point observation and manual measurement suffer from power supply. The latter observation method also has a drawback of low spatial resolution and spectral resolution because it is mainly used for macro parameters after sandstorm occurrence (such as dust and sand height, vertical distribution, path, range, flux observation, etc.). Making process of sandstorm observation difficult, the major defects of the two observation methods are insufficient for observation measurements to sand source which is one of critical factors forming sandstorm.

On one hand, the statistical results of sandstorm data for 1961—2006 show that sandstorm mainly originates in hinterland of desert. On the other hand, some researchers have studied particle motion in desert[1-2] and we think there is relationship between sand vibration

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and sandstorm. The main challenge is to get the sand or sand tunes scale information in hinterland, which is helpful to understand the causes and the motion law of sandstorm for human beings. In this paper, a remote sensing system and network is presented. The whole wireless sensor network consists of desert robot nodes, mobile wireless ad hoc subnet and large scale self-adaptability network. The network achieves robot self-localization, self-navigation and multi-robot formation, furthermore, it overcomes wireless signal attenuation under the condition of strong dust and covers a large scale wireless communication. The sensing system integrates different kinds of sensors to desert robots, it takes advantages of overall and accurate monitoring geographical environment information of desert. Sensors include wind speed-direction sensor, atmospheric pressure sensor, air temperature and humidity sensor, wind and strong magnetic field sensor, sand burial quantity sensor, acceleration and ultrasonic ranging sensor. A new optical fiber sensor for measuring vibration of sand (as one small scale of sand information) is presented, which is not reported so far as we know. Compared with normal robots, the desert robot as sensors carrier has better ability of endurance, it can resist sand erosion, high temperature and strong vibration.

1 Wireless Sensing Network

The network consists of desert robot nodes, mobile wireless ad hoc subnet and large scale self-adaptability network. Figure 1 shows the network structure. It is a three-layer architecture and daisy chain topology network. Three subnets with one robot node in each are interconnected with the data center with wireless at frequency of 450 MHz, one master and two slave robots are interconnected through ZigBee. Control station is interconnected with remote information center through commercial communication network.

The robot node is a mobile and unattended sensor data acquisition system. The information collected by nodes contains the latitude/longitude, temperature, air pressure, wind direction, wind speed, local wind erosion and sand vibration. That information will be sent every 1—2 minutes. Mobile triangular structure of wireless ad hoc subnet consists of three nodes. Each of nodes is 1 km apart. Only one node of the subnet is responsible for communication through the wireless communication network with the remote data center. Large scale self-adaptability network consists of 3 wireless ad hoc networks.

Sensor data are transmitted among ad hoc subnets or base-station on the edge of the desert by using mobile wireless communication robot queue. Each robot is capable of 1 km range communication. The transmission rate is 4 800 bit/s. The sensor data collected

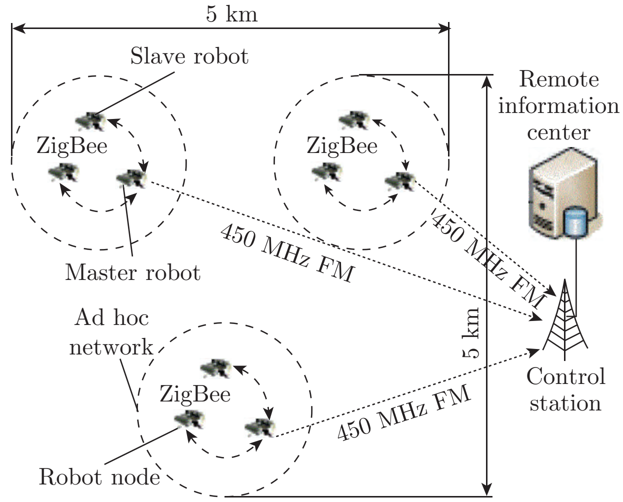

Fig. 1 The structure of wireless sensor network

by base station on edge of desert are transferred to a remote data center through commercial communication network.

Note that each robot node consists of one master robot and several slave robots. Each slave robot only subordinates to and communicates with one master robot. Each master robot directly communicates with control station. There is no communication among master robots. The control station computer is connected to the radio station on top of tower through RS485 serial ports. The radio station communicates with remote computer which is 25 km far away through 450 MHz microwave frequency modulation technology (serial communication speed of 4 800 bit/s). The master robot communicates with the slave robots through ZigBee (serial communication speed of 9 600 bit/s).

2 Optical Fiber Sensor for Measuring Sand Vibration

Lyles et al.[3] recognized that sand began to vibrate before they lifted ground as mean wind speed approached the threshold value. It is very possible that the sand collision may cause the large amounts of sand dust and then produce sandstorm. Therefore, it is important to observe the vibration characteristics of sand movement for academic value. Conventional particle research techniques mainly include laser doppler vibrometry (LDV)[4], particle dynamics analyzer (PDA)[5-6], digital particle image velocimetry (DPIV)[7-8] and high-speed multiflash photography[9-10]. These techniques have the advantage of high precision but none of them aim at sand vibration, and what's more, they are costly and bulky. There are few reports about vibration sensor for sand movement in particular so far as we know, so we develop a new optical fiber sensor to capture the micro movement. The sensor has the advantages of compact and flexible structure, small size, corrosion resistance, heat insulation and anti-electromagnetic interference, it is very suitable for micro scale measurement under the harsh sandy and dusty environment. The basic principle of measuring sand vibration movement is to observe the change of scattered light from moving sand. The setup of the sensor is shown in Fig. 2. A fiber array is used as the sensor head. The fiber array consists of eight multimode fibers which are linearly arranged. Four fibers of them are used for illuminating sand. The other four fibers with grin lens are used for collecting light scarred from sand. Note that grin lens can improve the efficiency of collecting light. The whole system consists of a light source with a wavelength of 850 nm and output power of 50 mW, a linear fiber array, two photodetectors, a data acquisition (DAQ) and personal computer (PC). Four fibers of the fiber array are connected to light source to transmit illumination light. The other four fibers with grin lens collect light scattered from sand. The outputs of those four fibers are connected to two photodetectors to eliminate the pedestal signal. DAQ converts the analogue signal to digital signal and then send signal to PC.

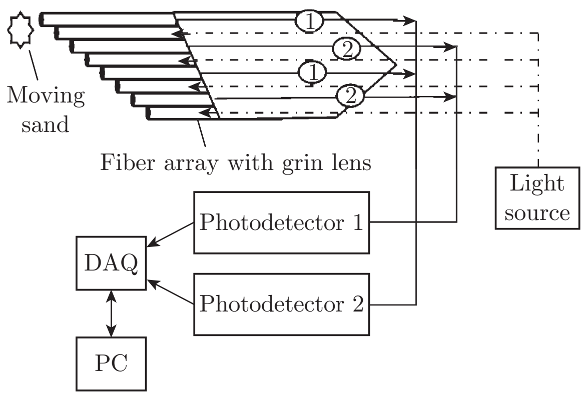

Fig. 2 The setup of the optical fiber sensor for measuring sand vibration

3 Desert Robot

Penetrating into hinterland of desert for sandstorm monitoring means that we will face a big difference in temperature between day and night, strong solar radiation, strong wind and other extreme desert weather conditions. Going deep into the hinterland of desert is the first step, however, the desert robot is our solution. Fast moving sand robot and robotic passive variable compliant legs were reported in 2009 and 2011[11-12]. Making further efforts based on sand robot, we develop a six feet desert robot. Each of its feet is C shape. According to the analysis of the actual test and the principle of bionics, the robot framework is "日" shaped structure and its shell is made of carbon fiber material and epoxy resin plate (carbon fiber conductive material, the insulated area with epoxy resin board). C-shaped leg is widened and wrapped with groove rubber layer, which obtains two advantages: ① leg elasticity is increased to reduce the impact to robot without compromise of leg strength; ② the friction between legs and sand is increased while robot subsidence is decreased. With 24 V, 15 A · h battery, the desert robot is capable of one hour continuous ground voyage, climbing the slope of 20°, reaching the speed of 100 m/h (the maximum speed of the robot in the process of testing is about 337.5 mm/s, which is 1.215 km/h) on the flat ground, and carrying a payload of 8 kg. Figure 3 shows the desert robot in laboratory.

Fig. 3 Desert robot

4 The Mobile Dust Monitoring Sensor Network and Field Test

After site investigation, we carried on field experiment in Tengger Desert, which is located on the border of Shaanxi, Inner Mongolia, and Ningxia provinces of China. The geographical position of robots and base station are shown in Fig. 4. The red dot on the right side is the base station and its geographical coordinate is (37°33′42.0″, 105°02′08.2″). The geographical coordinate of the first remote robot is (37°28′22.95″, 104°45′5.70″). The geographical coordinate of the second remote robot is (37°31′16.85″, 104°45′15.96″). The geographical coordinate of the third remote robot is (37°30′34.35″, 104°49′4.12″).

In the field test, robots were divided into three groups. Each group consisted of one master robot and two slaver robots. After communication control verification near base station, the three groups of robots were sent to hinterland of desert which was 25 km far from the base station. Communication networks covering an area of about 5 km^2 were established between each robot group and base station. Robots which carry several sensors constructed information sensing network. Communication robots and microwave bridge constructed wireless data transmission network. Robot nodes were 25 km far away from remote data center. Figure 5 shows three groups of robots testing in field.

We also tested the new optical fiber sensor in field. The head of fiber array sensor was mounted on a holder. The field test is shown in Fig. 6. The fiber array surface directly headed to sand ground where a little pit was formed from moving sand under influence of wind. The fiber array consisted of eight optical fibers. There were four optical fibers for illumination and four optical fibers for light collection. The 850 nm light was projected to moving sand by four illumination optical fibers. The reflection light was firstly collected and then transmitted into channel 1 and channel 2 by the other four fibers.

The optical power of reflected light changed when sand vibrate, which was collected by optical fiber sensor as sand vibration data. The data is coded and transmitted by wireless sensing network. Figure 7 shows data collected by the sensor.

We tried to use the change of optical power to present the sand vibration. Compared with the data of channel 1 and channel 2, optical power randomly changes as time elapses in Fig. 7, which means sand movement is complex and random.

Also, other information was collected by our sensor system and transmitted by the wireless network. Table 1 shows the sensing data collected by robots (including global positioning system (GPS)).

Fig. 4 The geographical position of robots and base station

Fig. 5 Three groups of robots testing in field

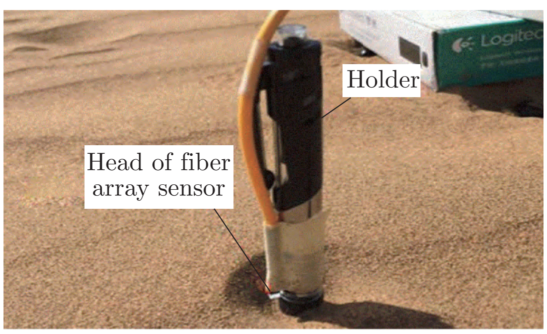

Fig. 6 Optical fiber sensor in field test

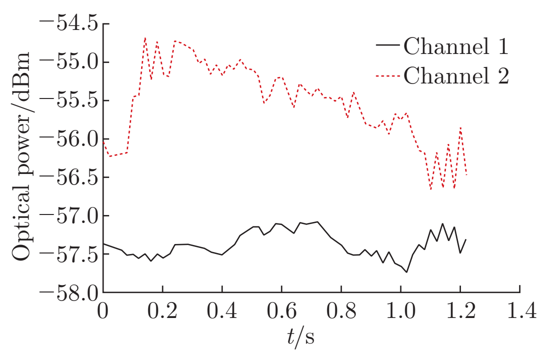

Fig. 7 Change of optical power due to sand vibration

Table 1 Sensing data collected by three group of robots

Robot No.	Sensing item					
	Temperature/°C	Pressure/kPa	Wind speed/$(m \cdot s^{-1})$	Wind direction/(°)	Wind erosion/kg	GPS
1	24.8	83.63	8.0	24.4	0.00	E104.817 N37.5000
2	24.03	82.76	4.9	27.5	0.00	E104.750 N47.4667
3	24.97	83.24	9.9	35.9	0.00	E104.750 N37.5167

5 Conclusion

It is the first report that combines optical fiber sensor, sand robot and wireless sensor network for data acquisition in hinterland of desert, which is very critical for sandstorm monitoring. The whole wireless sensor network overcomes wireless signal attenuation under the condition of strong dust and covers a large scale wireless communication. What's more, with different kinds of sensors, the sensing system can acquire overall and accurate monitoring geographical environment information of desert. A new fiber sensor for detecting sand vibration is implemented. The fiber sensor is low cost and easy to integrate with the system. The data show that sand vibration is very complex and random. A robot adapting to harsh environment in hinterland of the desert is built. The desert robot is stable as a platform carrying sensors and communication node. By using the techniques we develop, we achieve mobile and unmanned monitoring to acquire more accurate sand-scale information, furthermore, it provides technical support for the research of formation mechanism of the sandstorm. As a result, spatial scale of sandstorm observation and forecast can be reduced to small scale of source area from large scale of remote sensing.

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