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Heterogeneous Wireless Sensor Network for Real Time Remote Monitoring of Sand Dynamics on Coastal Dunes

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Abstract. In this paper, the architecture of a heterogeneous Wireless Sensor Network (WSN) to be deployed on coastal sand dunes is described, the aim of which is to provide real time measurements of physical parameters to better define the sediment transport in connection with Aeolian processes. The WSN integrates different typologies of sensors and is provided with both local and remote connection. In particular, three different typologies of sensors are integrated in the network: a multilayer anemometric station, a sensor developed ad-hoc to measure the sand dune level and a sand collector capable of measuring the weight of trapped sand and its quantity. Each sensor node is made up at least of a ZigBee radio module that is able to transmit the data collected by the sensor at a distance of about 100 meters. While the sand level sensor and the sand collector are provided only with this transmission module, the anemometric station also integrates a microprocessor board in charge of data processing. A Gateway node provided with a GSM connection for remote data transmission and a Zigbee radio module for Local Area communication has also been developed. This node is in charge of collecting all the data packets sent by the Sensor Nodes and transmit them to a remote server through GPRS connection. A Web server has been set up to collect these packets and store them in a database. The proposed WSN can provide both a static and a dynamic framework of sand transport processes acting on coastal dunes.

1. Introduction

The term "Wireless Sensor Networks" (WSN) includes all the monitoring infrastructures made up of a set of sensing platforms, called Sensor Nodes, communicating both among them and with the outside world through radio connection [1]. Each Sensor Node is roughly made up of one or more sensors, a micro-controller, and one or more communication modules. Sensor Nodes can also be equipped with memories for data storage or with energy harvesting solutions to allow their autonomous functioning for long spans of time. Due to all these features, WSNs are a key technology to be employed for environmental monitoring, especially when real-time, remote data collection is required [2, 3, 4].

WSNs can also be a key technology to estimate the temporal evolution of sand dunes in conjunction with aeolian processes [5, 6, 7]: The solution proposed in this paper focuses on the arrangement of different typologies of sensors, interconnected among them and with the outside world through GPRS connection, to collect heterogeneous data sets that allow the definition of the dynamic processes of a sand dune.

2. Architecture of the Wireless Sensor Network

The overall architecture of the WSN is shown in Figure 1 and can be roughly subdivided in the following subsystems:

- The *Sand Level Sensor Network*, that is made up of a number of sensor nodes, arranged in a grid layout, in charge of the measurement of sand level and sand transport;
- The *Environmental Monitoring Node*, in charge of the measurement of wind direction and speed at different heights;
- The *Gateway Node*, communicating with all the other nodes of the network and in charge of data routing from the network to the remote data collection centre.
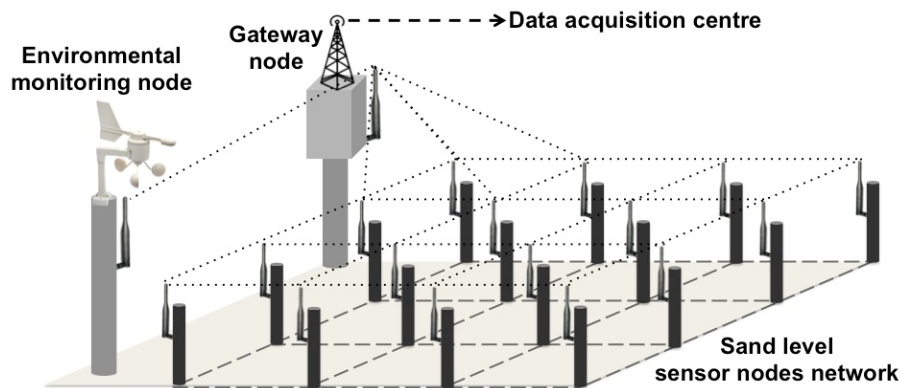

Figure 1. Architecture of the WSN

The *Sand Level Sensor Network* includes two typologies of sensor nodes: The *Sand Level Node* and the *Sand Collector Node* (see Figure 2).

The *Sand Level Node* includes an XBee Series 2 radio module in charge of local data transmission, a control logic system to optimize power consumption, a 9V battery and the sensing structure. This is made up of an array of 24 photoresistors (LDRs) mounted on a plastic tube 5 cm apart from each other (reaching a total length of 120 cm). Sunk LDRs do not sense sunlight and transmit a 0 value. Surfacing LDRs detect sunlight and transmit a higher value. By counting sunk LDRs, it is possible to measure the current level of the dune. During the data acquisition, all the values of the LDRs are sent to the Gateway node that calculates the sand level value before transmitting it to the remote data collection centre.

The *Sand Collector Node* is mainly a plastic cylinder about one-meter-high, which is able to orientate according to the wind direction. The wind-blown sand flows inside the cylinder through an opening in its side and is collected on its bottom. The plastic cylinder integrates in its upper section an XBee Series 2 radio transmission module in charge of data transmission, together with 4 1.5V batteries. A load cell is positioned on the bottom of the cylinder, connected with the battery and the transmission module by 4 wires running inside the cylinder body. The load cell measures the weight of the collected sand. This value can then be used to calculate the sand dune level.

The Environmental Monitoring Node is mainly an anemometric station integrating three anemometer/anemoscope couples positioned 40 cm, 120 cm and 200 cm from the ground. The node integrates an Arduino UNO microprocessor board that is required to calculate in real time the values of the speeds and of the directions, and an XBee Series 2 module for data transmission. While during the first tests the node was powered with a 9V battery, an energy harvesting solution based on the use of a solar panel has been set up, in order to allow the operation of the node for long spans of time.

The *Gateway Node* integrates an XBee Series 2 radio module, a GSM data transmission module and Arduino UNO board, required to manage the data reception from the various nodes and its routing to the remote data acquisition centre through GPRS connection. The Gateway Node is also provided with an energy harvesting system based on the use of a solar cell: this solution is required due to a high power consumption of the GSM module.

The Remote Data Collection centre is based on a Glassfish server provided with a Web Application that receives all the data packets transmitted by the GPRS module. These packets are then stored in a MySQL database according to the transmitting node. The Web Application also allows the visualization through Internet of the stored data.

3. Results and Discussions

The proposed architecture was tested in March, 2016 on the sand dunes located in the San Rossore regional park, Pisa, Italy. For the tests, 5 nodes WSN was set up: this included three *Sand Level Nodes*, one *Sand Collector Node* and one *Environmental Monitoring Node*. The three Sand Level Nodes were arranged in line, perpendicularly to the beach, 10 meters apart from each other. The Sand Collector Node was positioned close to the top Sand Level Node. The Environmental Monitoring Node was positioned on the top of the sand dune 5 meters apart from the top Sand Level Node. The Gateway Node was positioned close to the Environmental Monitoring Node.

Figure 2. The Sand Collector Node (on the left) and the Sand Level Node (on the right)

Figure 3. The Environmental Monitoring Node

The system was tested for a period of 24 hours. The sampling rate of the Environmental Monitoring Node was set at one sample each 20 minutes. As previously stated, wind speed and direction was calculated directly on the Arduino Uno Board and then a packet made up of the six data (three speeds and three directions) was sent to the Gateway.

Regarding the Sand Level Node, the sensor was sampled once per hour, three data packets were sent every time, each packet with the reading of 8 LDRs. The level value was calculated on the Gateway before being transmitted to the remote server.

Moreover, the Sand Collector Node was sampled once per hour. The value of the load cell was transmitted to the Gateway that calculated the sand weight before transmitting this value to the remote server.

All the data were received by the Glassfish server that stored them in the MySQL database. Each table was visible in real time directly on the beach using a Tablet PC connected to the server by the Internet.

A portion of the WSN can be seen in Figure 4. The central Sand Level Node can be seen in the foreground while the top Sand Level Node together with the Sand Collector Node can be seen in the background. The Environmental Monitoring node and the Gateway node are visible.

Figure 4. A section of the deployed WSN

4. Conclusions

The proposed WSN architecture for sand dynamics monitoring on coastal dunes was tested with success in a real time scenario, proving its effectiveness in collecting data useful to define the sand transport in conjunction with Aeolian processes. While the aim of the first tests was the proof of the technological infrastructure, further data collection experiments are expected to be performed in the next months for prolonged periods. The 24 hours span of time proved to be too short to allow the collection of a significant data set.

Moreover, as described, the first tests were performed with a small scale WSN, integrating only 5 sensor nodes. Additional nodes are being developed in order to deploy a larger network, integrating least 9 Sand Level and Sand Collector nodes. This number will allow the arrangement of the network on a grid layout for a better definition of the dynamics of a whole portion of the dune surface.

Finally, the network architecture has been designed to be easily expanded with the introduction of new typologies of Sensor Nodes. A new sensor node, able to measure the near-shore dynamics of sea currents and waves is being designed and developed. The introduction of this kind of structure in the WSN will allow the extension of the study area also to the portion of sea close to the coast for an overall definition of the sediment transport processes.

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