Modular Sensor Nodes for Environmental Data Monitoring

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Abstract

A framework for modular wireless sensor networks (WSN) designed to capture and monitor micro-climates in a crop field. WSN is rapidly improving in automotive industry, agricultural, industrial and environmental monitoring and many other areas. Moulder architecture minimises the software upgrade down time and enables hardware reusability. If any firmware upgrade required, preassembled and pre-programmed microcontroller module can be sent to the end user Recent developments and advances in wireless technology as well as affordability give rise to this emerging field in the realm of Precision Agriculture (PA). Vineyard monitoring is an emerging application field in PA.

Keywords: Wireless networks, modular sensor node, precision agriculture and environmental monitoring

1 Introduction

Recent advances in wireless sensor technologies have led to the development of low cost, low power, compact sensor nodes. This provides enormous opportunities in research and development of numerous application. Wireless Sensor Networks (WSN) is seen as one of the most promising contemporary technologies for bridging the physical and virtual world thus, enabling them to interact. WSN are used in both military and civilian applications including wireless data acquisition, smart buildings, target tracking, habitant monitoring, environmental contaminant detections and precision agriculture [1][2]. A WSN is composed of a number of sensor nodes, which are usually deployed in a region to observe particular phenomena in a geospatial domain. Sensor nodes are small stand-alone embedded devices that are designed to perform specified simple computation and to send and receive data. They have attached to them a number of sensors gathering data from the local environment that is being monitored.

The work described herein is an expanded version of paper presented in [3] which is realisation of a concept outlined in Eno-Humanas project [4]. It is a system for gathering (sensing) and analysing climate, atmosphere, plant and soil data. It is specifically designed for micro-climate analysis in vineyards and other agricultural/horticultural environments. Sensor nodes equipped with varieties of sensors enable environment sensing along with data processing. This research has produced and is further developing a prototyping in order to demonstrate how state-of-the-art devices could be used in precision viticulture as a management tool to improve crop yield quantity and it is assumed, crop quality.

2 Modeling the Effects of Climate Change

The WSN ability to simultaneously capture and relay real time data for analyzing the variability in climate change and its effects on plant physiology is significant for different grapevine varieties. This is because modelling the relationships between climate variability requires both data on the cause and effects recorded without any time discrepancies. Complexity in the models increases with spatial information combined with other environment related parametric variables. It is assumed that in combine with one another this variable set will correlate with grape and consequently wine quality. Gaining more insights into natural systems and their functioning including climate change involves many complex dynamic and diverse processes with nonlinear interactions that pose huge challenges to modellers [5].

A wireless network such as the one discussed herein will enable the vineyard management to decide on the kind of measures (i.e., sprinkler system, gas/ turbine heaters/ helicopter and a schedule) required for example, to prevent frost damage to the crops. Further details on the frost prediction and wireless sensor network issues could be found in [6]. Modelling macro-micro climate change effects has begun in this project with the use of WSN data obtained from vineyards located in three continents. This enables observations of the variability in global climate change across the continents using prediction model values provided by NASA and other institutions. The models and results will be used in a comparative analysis on climate change effects on viticulture, especially its variability and its influence on grapevine “cultivars“ or varieties and wine quality, such as aroma, colour and mouth feel as climate change effects on viticulture is described to be dramatic and varying across the globe significantly.

3 Wireless Technology

WSN is one of most significant technologies in decades eliminates connectors, provides safe/flexible connectivity, improves resources sharing, easy installation and mobility. The other advantage is that these systems require a low micro power levels, thus it can last for longer period of time [7].

Two major protocols are used in wireless networking, IEE 802.15.4 and ZigBee stack. The ZigBee network stack sits on top of IEEE 802.15.4 standard Medium Access Control (MAC) and Physical (PHY) layers (refer to Figure 1). MAC and PHY layers define the RF and communication components between other devices. ZigBee stack contains the network layer, an application layer and security service provider (SSP) [8].

These protocols have their own limitations and advantages. The main limitation for the both protocols is low data rate (narrower bandwidth). Therefore these protocols are suitable for low data transmission applications.

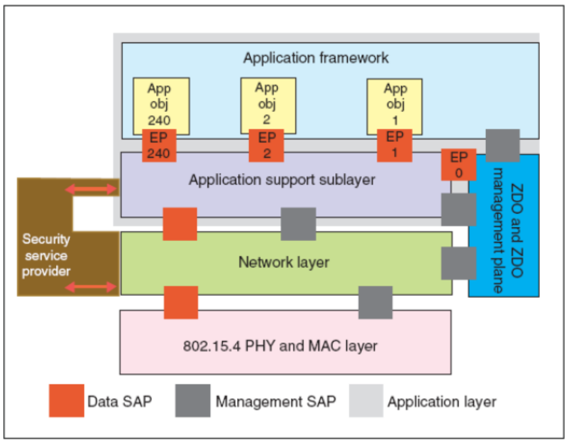

Figure 1: ZigBee stack layer adapted from [9]

As the data rate is increased the power consumption, cost and complexity of the system increases geometrically. Since sensor nodes are often located in remote locations, power consumption needs to be minimal, preferably battery operation for end of product life. Moreover sensor data does not require wide band-width and therefore ZigBee protocol is suitable for small sensor networks.

3.1 Wireless Network Topologies

Three main network topologies used in wireless net-working are point-to-point, star and mesh networks (refer to Figure 2). Each of these topologies has their own advantages and disadvantages in different applications. Their main difference is the use and behaviour of network components.

Point-to-point is the simplest topology and mostly used to replace single communication cable. Point-to-point network can work adequately, when two end points are located close to each other [8].

Star topology is also known as a point-to-multipoint wireless system. This system is usually based on IEEE 802.11 or Bluetooth communication standards. This system has one main base station, which controls the communication with all the other end nodes. The reliability of this network depends on the quality of the RF link between the coordinator and each of the end nodes. The main problem with this system in industrial applications is the difficulty finding a suitable place for the central controller in order to communicate with each end node.

Mesh topology is also sometimes called a peer-to-peer system. This system is an ad hoc multi-hop system. Mesh networks are based on the ZigBee protocol, which means each node can be used to send and receive data. In this manner, network consists of multiple redundant communication paths, which can be used in event of node failure. Therefore, data will reach its destination reliably, via the intermediate nodes (refer Figure 2).

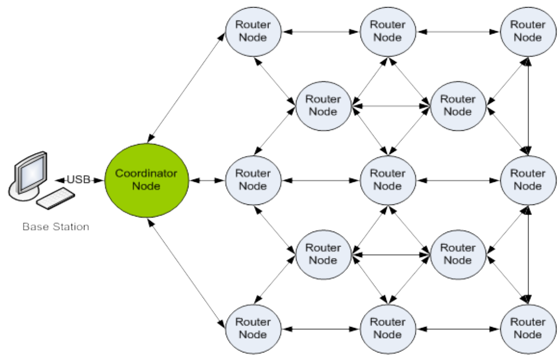

Figure 2: A mesh network topology applied in a vineyard monitoring application

The mesh network has three important properties: Self-Configuring, Self-Healing and Scalability. A ZigBee mesh network configures itself automatically. The network identifies new nodes and automatically includes them in the network. Moreover, if one node fails the network re-routes the message through an alternative path. According to the ZibBee mesh network standards, it can support up to 65,536 network nodes (clients) [8].

4 The WSN Architecture

The proposed WSN system [10] consists of sensor nodes located in critical locations within vineyards for collecting weather, atmospheric and environmental data as well as plant related data such as leaf wetness and sap flow. Figure 3 shows the system architecture consists of three layers namely, mote layer, server layer and application layer.

Mote layer: This layer consists of all the wireless sensor nodes and a Base Station (BS). Each node has one or more sensors plugged into the hardware device with a transmitter, power supply (usually a small battery) and microcontroller. The nodes are distributed over an area of interest uniquely arranged as required provided the distance between the sensor devices does not exceed the maximum communication range. Therefore, energy optimized routing becomes essential. Data transmission from sensor nodes to the BS depends on application maybe continuous, event driven, query-driven or hybrid. In continuous approach, data is transmitted to the BS periodically according to predetermined intervals. In query and event driven models, data is transmitted when an event takes place or query is generated from the BS. The Hybrid model uses combinations of these approaches to transmit data from sensor nodes to the BS. Various types of routing protocols such as data-centric, hieratical and location-based protocols are available [9].

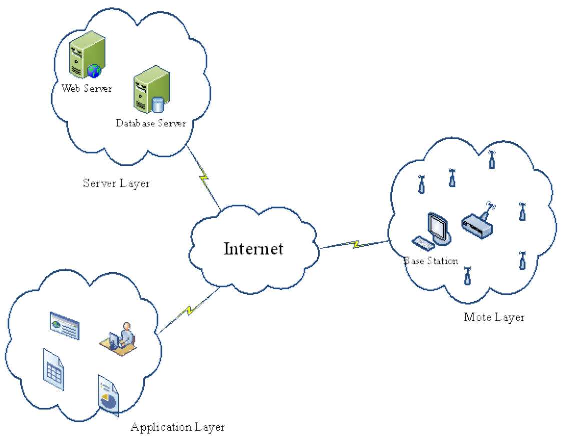

Figure 3: A schematic view of WSN architecture

Server layer: Data are sent to the data server from the BS through the internet. Two main tasks performed by data server are to:

1) obtain and process data from the BS.

2) populate database with WSN data and enabling the application layer to access WSN data.

The server layer also deals with on-time data delivery from the BS and generates alarm when an undesirable event takes place.

Application layer: This layer allows users of the system have remote access to WSN data using web browsers. This provides a powerful tool to visualize real-time WSN data and compare data from various nodes. In addition, the BS can be accessed remotely to modify sensor nodes' configurations.

4.1 Modular Sensor Architecture

During the past few years modular sensor node architecture shown to be popular due to increasing demand on more energy efficient micro processors, accurate and sensitive sensor developments, improved wireless radios and improvement of wireless software architecture for efficient data management [12].

Modularity design imposes greater flexibility for the end product. Same node can be utilised for different applications equipped with required sensor modules. This is highly desirable when each sensor node collecting microclimate, atmospheric and plant data within different vineyards requires different sets of sensors.

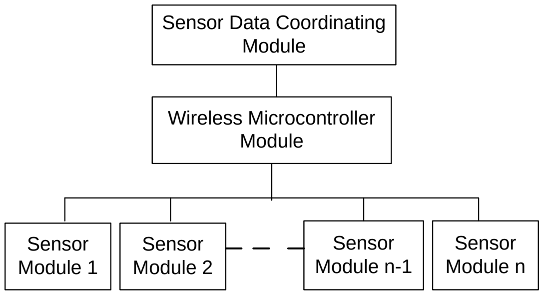

Figure 4: Components of proposed modular sensor architecture

Figure 4 illustrates the building blocks of the proposed modular sensor design. The wireless microcontroller module controls the whole data communication aspect, while sensor data coordinating microcontroller module, collects and calibrates the data. It is possible to introduce various type of sensor modules required by application.

4.2 Proposed Modular Design

This design allows for including up to 16 different sensor modules and two controller modules. Some sensors such as soil moisture and leaf wetness are externally exposed pluggable modules and others are embedded into sensor cards. There are two levels of controller modules, board level controller and communication level controller. ATmega1281 microcontroller is used for board level communication. This powerful microcontroller consists of 16 Analogue to Digital Conversion (ADC) channels and 4 UART ports. This microcontroller can operate up to 16MHz at 5VDC.

The main aim of this board level controller unit is to maintain the interfacing between different sensor modules and transfer the processed data to the communication level controller module via RS232 communication port. The power management of the sensor modules is monitored by ATmega1281 microcontroller. The power management is archived by shutting down the all the sensor when they are not in service. The service time will be defined by either pre allocated time interval or request from the main coordinator unit. When the units are run on pre-allocated mode, microcontroller extracts the reading from the sensor module in defined intervals. The second mode is interactive process between coordinator and router nodes. The coordinator nodes can request data from each individual router node, in any random order according to the user inputs.

The main purpose of the communication level controller is to maintain the ZigBee mesh network and transmit the data to the coordinator node. The Taxes Instrument CC2431 wireless microcontroller is used to create the mesh network. The main advantage of this microcontroller is that it has built in radio transceiver, which operates at free commercial 2.4GHz frequency band. It also has a very good communication rage of 100m in open area.

4.2.1 Wireless Nodes

There are two types of sensor nodes, which are used in this application, router and coordinator nodes namely. The main purpose of the router node is to send the sensor data to the coordinator node. Once data is received the coordinator node transfers the data to the computer via USB interface. The router node will hop the data to the main coordinator node via adjacent nodes. Each router node will have list of neighbouring node ID table. If for any reason hopping through a neighbouring node fails, node will go through the list of IDs to send the data to the next closest node.

4.2.2 Sensor Module

Each sensor module consist with its own card, as shown in Figure 5. The main advantage of this design is that all the sensor modules are interchangeable. Each sensor card has it unique 8-bit ID number. Therefore when the card is plugged into any slot main microcontroller will identify the ID number and set the calibration setting for the specific card. This modular design will support the expansion of new sensor module and also sensing unit can be optimised for any specific application.

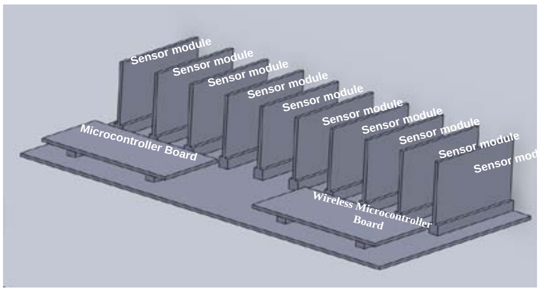

Figure 5: Modular board with plug-in sensor cards

4.2.3 Microcontroller Modules

Moulder design minimises the software upgrade down time. If any firmware upgrade required, preassembled and pre-programmed microcontroller module can be sent to the end user. Then user can replace the pre-programmed module with the existing module. This module can be sent back to the workshop for firmware upgrade. More powerful controller module maybe introduced, with minimum hardware changes.

5 Implementations

To achieve objectives described in Eno-Humanas project [4], a WSN prototype was designed and developed for gathering and monitoring environmental data within vineyards. Both hardware and software were designed and built by researchers at Auckland University Technology (AUT).

5.1 Hardware design

For both WSN hardware components (i.e. coordinator node and router node) one wireless plug-in module is used. The plug-in board is based on CC2431 wireless micro controller. This microcontroller has on chip 2.4GH wireless radio, 128KB in-system programmable flash and hardware based location awareness. Sensor nodes used are small low-cost with two microcontroller described (refer to Section 4.2) which have their own built-in micro-processor. These nodes can automatically set up an ad hoc wireless communication network with other motes that are within range (up to100 m).

Nodes are battery powered allowing wireless communication capabilities and supported by power solar cells. Solar energy is stored in rechargeable (secondary) batteries. This is essential in this application where maintenance operations such as battery changing are impractical. Sensors may be configured to send data to the BS in following manners:

Periodically: sensor node sends data according to predetermined intervals.

Event-based: sensor node stars sending data when a specific requirement is met. For instance, there may be no need for sending data to the BS unless temperature drops below a certain threshold in frost prediction task.

In this study, data are sent to the BS periodically at varies intervals for different sensors. In addition, an ultra light minicomputer with wireless communication capability is used to receive sensed data from sensor nodes. The BS also can be accessed remotely via internet to upload sensor data to the main off-site server.

5.1.1 USB coordinator node

The coordinator is used to collect the information from the network and transfer the data into the computer via USB port. This board is powered through the computer USB power supply. Once data is received from the network, sensor data is transferred to the RS232 to USB converter. The converter sends the RS232 data to the computer via USB port (refer to Figure 6).

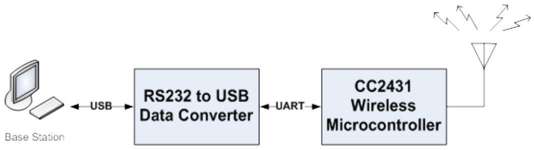

Figure 6: Base station with coordinator node

Every time new node is connected to the network, coordinator will identify the node and issues the new node with an IEEE address. During the communication between these nodes, coordinator identifies each node with the IEEE address.

5.1.2 Sensing router node

The router node can be divided into two main modules; sensor module and wireless module as shown in Figure 4. The CC2431 controller module collects the sensor readings via Analogue to Digital Converters (ADC) and transmits the data to the USB coordinator dongle via mesh network. The sensor unit is powered via 4x1.5V AA battery pack. Due to limitation on flash memory, raw data is sent to the BS without any processing. The BS converts ADC reading into appropriate values by using conversion factors.

The sensor modules can accommodate up to sixteen different environmental sensors including pressure, leaf wetness, sunlight, humidity, temperature, CO, CO_2, O_3 , soil moisture and soil temperature.

Figure 7: Graphical user interface for displaying WSN data

A graphical user interface designed to manage sensor nodes communication, data logging and server upload. It also provides a dashboard for displaying sensor readings and derived parameters such ad dew point (refer to Figure 7). Historical data displayed in grid and graphical formats which can be customized to provide better visualisation of logged data.

Sensor modules can be added/removed as required. Data that are collected at predetermined intervals or at specific times are transmitted through the network elements to a main computer or controller

5.2 Live Web Monitoring

A web application was developed enabling users to interactively access the WSN data over the internet. It allows live monitoring and visualization of climate, atmosphere, plants and soil data from each vineyard (refer to Figure 8).

Figure 8: Live web monitoring of Awarua vineyard's environmental data (www.geo-informatics.org)

6 Discussion

Generally speaking most of commercial wireless sensor node architectures follow a similar design involving a single microcontroller and a number of connected components. Alternative architectures for wireless sensor nodes such as modular architecture proposed herein offers a range of benefits including energy conservation, hardware reuse and real-time performance.

Power and resource management are two main issues that needed to be taken into consideration. In this implementation, one way to achieve this is to incorporate a low level controller that facilitates for more sensors and computational power. The higher level controller will handle the ZigBee mesh networking, and request the data from the low level controller. The main task for the low level controller is to collect data from the sensors and process the data for suitable format and send it the high level controller on demand. The low level controller will be responsible for the sensor power management.

7 Conclusions and Future Work

The paper investigated the recent advances in remote wireless sensor devices, and how WSN of these devices could be combined with the internet and used in vineyard operations, such as management decision making, by monitoring weather, atmospheric, environmental conditions and plant physiology, and also for online display of climate information at larger scales, such as regionally within a state and cities in the Asia Pacific Region.

Power management need to be improved by introducing more intelligent and efficient algorithms to reduce unnecessary up-time and redundant data transmissions.

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