Wireless Sensor Networks for Swift Bird Farms Monitoring

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Abstract—**This paper provides an in-depth study of Wireless Sensor Network (WSN) application to monitor and control the swift habitat. A set of system is designed and developed which includes the node's hardware, GUI software, sensor network, and interconnectivity for remote data access and management. System architecture is proposed to address the requirements for habitat monitoring. The application driven designed, provides and identifies important areas of work in data sampling, communications and networking. In this monitoring system, a sensor node (MTS400), IRIS and Micaz radio transceivers, and a USB interfaced gateway base station of Crossbow (Xbow) Technology WSN are employed. The Graphical User Interface (GUI) is written using a Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) along with Xbow Technology drivers provided by National Instrument. This monitoring system is capable of collecting data and presents it in both tables and waveform charts for further analysis. This system is also able to send notification messages by e-mail, whenever changes on the swift habitat at remote sites (swift farms) occur, via the Internet connectivity. Other functions that have been implemented in this system are the database system for record and management purposes; remote access through the internet using LogMeIn software. Finally, this research draws a conclusion that a wireless sensor network for monitoring swift habitat can be effectively used to monitor and manage swift farming industry in Sarawak.**

I. Introduction

The swift farming industry has the potential to grow into a multi-billion dollar industry due to the industry's relatively profitable risk-return profile as well as a continuously growing demand for edible birds' nests by wealthy countries. There is also a discernable world-wide trend pursued by international home grown pharmaceutical and herbal products companies in using edible birds' nests as base materials for producing natural and organic health supplement products. Malaysia is currently the 3rd largest producer (7%) of edible birds' nest in the world behind Thailand (20%) and Indonesia (60%) with estimated annual weight value of approximately 160 tons for the world consumption in 2006. The total consumption value of edible birds' nest throughout the world in 2006 is estimated in the vicinity of USD1.5 to USD4 billion. The main markets are Hong Kong (50%), China (8%), Taiwan (4%), Macau (3%), Japan, and South Korea. Their demand will continue to grow at double-digit rates for the next 2 decades and this delicacy is catching quickly in the United States [1].

Breeding the swift is not an easy task. The birds itself are very sensitive to human being and require special care to produce a high quality nest and productivity. About more than 1500 swift farms in Sarawak, Borneo has been setup but none of the farms has real time monitoring. These farms are mostly equipped with electrical equipments including humidifier, audio system and timers, thermometer and humidity tester. The temperature and humidity of the farms are monitored manually only once in every four to six weeks due to the remote access and sensitivity of swift habitat. Sudden extreme change of temperature and humidity could cause the swifts to migrate to other places. Farmers used audio system with special sound alternately to attract female and male swift and this is done manually at a farm. Manual monitoring and controlling of equipments in the farms will frighten the swifts away. All the above problems could negatively affect the production of birds' nests and hence result in a great lost to the investors of the swift farms.

The application of wireless sensor network for swift farms monitoring claims to be enormous potential benefits for scientific communities and society as a whole. This application will enable long-term data collection, monitoring and managing remotely. Interconnectivity with the physical environment at a swift farm will allow each sensor to provide localized measurements and detailed information that is hard to obtain through traditional method.

This paper develops specific monitoring applications for swift habitats. It presents a collection of requirements, constraint and guidelines that serves as a basis for general sensor architecture for many such applications. This includes identifying the current problems and pro-

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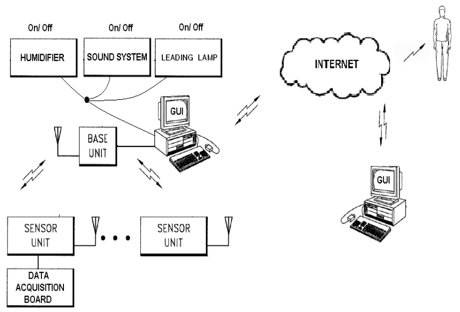

Figure 1. Swift farm monitoring system design

poses a solution. It describes the main components of the sensor network for such application – the hardware and sensor platforms, network services and communications. The remainder of the paper is organized as follows. Section II identifies the system requirements for swift farms monitoring application. Section III discusses the system architecture of tiered sensors that interconnect the main system components from localized collections of sensors node to the remotely monitoring. Section IV presents the system development, procedures and considerations on the hardware and software design. Section V describes the results from the initial deployment of the sensor nodes. This will be followed with discussion on this application-driven design exercise to identify important directions for further investigation and improvement. Section VI provides concluding remarks.

II. System requirements

Swift colonies are known for their sensitivity to human disturbance. Repeated disturbance will lead to migration to other places and caused low productivity to the farmers. Swift farmers have strove to design their swift farms with high technology equipments such as controlling light intensities, humidity levels, air flow standards, heat standards, odors and smells, and swift flight-paths in order to mimic swift cave environments. Once a swift farm has been completely constructed, a continuous vocalization of swift chirps and mating sounds are played every day using audio systems installed in order to attract and make the farm their new home. Research published by L. N. Ambu in [2], suggested that one of the ecological behaviors of birds is that they will return to where they were hatched as long as the conditions of the farm is fit for their habitat.

Sensor networks represent a significant advance over traditional methods for monitoring. Sensors can be deployed inside the farm and is substantially more economical method for monitoring, controlling and conducting long term studies. Fig. 1 shows the proposed swift farm monitoring system. The system requirements in developing a wireless sensor network for monitoring the swift habitat are as follows:

1) Internet Access
   The sensor networks at the swift farm must be accessible via the Internet. This is an essential aspect of habitat monitoring application that supports remote interactions with in-situ networks.
2) Sensors
   The deployed sensors must be able to sense light, measure temperature and relative humidity.
3) Networking
   The base station at the swift farm needs sufficient resources to host Internet connectivity and database systems. Due to few swift farms within several meters away, the second tier of wireless networking is required to provide the connectivity.
4) Remote Management
   The remoteness of the site and sensitivity of the swift requires the ability to monitor and manage sensor networks remotely over the internet connectivity.
5) Remote Control
   For our particular application, the ability to control the electrical equipments such as humidifier, audio system, lighting or heater is an essential set of useful function.
6) Data Archiving
   Database is essential for record purposes and analysis for automated controlling.

III. System Architectures

The system architecture for habitat monitoring based on tiered architecture is proposed by A. Mainwaring [4]. Similarly, the system architecture has been implemented in swift habitat monitoring applications. The systems core architecture components include sensor nodes, sensor network gateway, network base station, relational database, Internet connectivity and a user interface. In this Wireless Sensor Network Monitoring System, the lowest level consists of sensor nodes which are connected to a processor/radio board. The radio communication deployed in this system is an IEEE 802.15.4 compliant radio frequency (RF) transceiver designed for low power and low-voltage wireless applications. It uses radio that employs Offset Quadrature Phase Shift Keying (OQPSK) with half sine pulse shaping. The 802.15.4 radio includes a Digital Direct Sequence Spread Spectrum (DSSS) baseband modem providing a spreading gain of 9dB and data rate of 250kbps. The radio is highly integrated for wireless communication

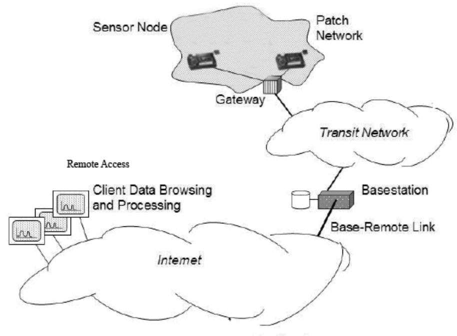

Figure 2. System architecture for habitat monitoring

in the 2.4GHz unlicensed ISM band. It complies with worldwide regulations covered by European Telecommunications Standards Institute (ETSI) EN 300 328 and EN 300 440 class 2 (Europe), Federal Communications Commission (FCC) Code of Federal Regulations (CFR) 47 Part 15 (US) and Association of Radio Industries and Businesses (ARIB) Standard (STD) -T66 (Japan).

The sensor nodes transmit data through the sensor patch to the sensor network gateway. The gateway is responsible for transmitting data from the sensor patch through a local transit network to the base station that provides wide area network (WAN) connectivity, database services and data logging. This operation is known at the second layer of the architecture. The base station communicates with host through a serial bus at 57,600 bps. The incoming and outgoing packets are framed using a Point to Point Protocol - High Level Data Link Control protocol (PPP-HDLC protocol). The data is displayed to farmers through a graphical user interface (GUI) that is written using Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW). This final layer of architecture is known as the custom client software (Client Tier). This custom client software is not only capable of displaying data received, but also able to send out e-notification and replicated e-monitoring data to the system operator/owner in required situations. In order to control the electrical equipments in the swift farm, a controlling system employing parallel port is also developed for this monitoring application.

Finally, for farmers to be able to perform remote access and controlling the network through internet connectivity, a remote access product that uses a proprietary remote desktop protocol that is transmitted via Secure Sockets Layer (SSL) is employed. An SSL certificate is created for remote desktop and is used for cryptographically secure communications between remote desktop and accessing computer using remote access product (LogMeIn). The system architecture for habitat monitoring is shown in Figure 2.

IV. System Developments

The implementation of the system consisted of hardware and software development.

A. Hardware Development

The hardware deployed in this project includes the sensor board, data acquisition board and processor/radio board.

1) Environmental Sensor Board: The environmental sensor board MTS400, developed by UC Berkeley and Intel Research Labs, offers five basic environmental sensing parameters. This energy-efficient digital device provides extended battery life and performance with low maintenance field-deployed sensor nodes. This versatile sensor board is intended for a wide variety of applications ranging from a simple wireless weather station to a full mesh network of environmental monitoring nodes. This project utilizes the Sensirion® SHT11, a single-integrated circuit (IC) humidity and temperature multi sensor module comprising a calibrated digital output in MTS400. . This sensor's power and the control interface signals can be enabled through a programmable switch. An analog-to-digital converter in the sensor provides the conversion from humidity and temperature to digital units.

2) Data Acquisition Board : The MDA300 is a multi-function direct user interface, which offers a convenient and flexible solution to those sensor modalities commonly found in the areas of environmental and habitat monitoring as well as many other custom sensing applications. As part of a standard mesh network of Motes, the MDA300's easy access micro-terminals also makes it an economical solution for a variety of applications. The data logging and display can be supported via the user interface. Software that provides an intuitive user interface to database management along with sensor data visualization and analysis tools can be developed. Analog sensors can be attached to different channels based on the expected precision and dynamic range. Digital sensors can be attached to the provided digital or counter channels. Mote samples analog, digital or counter channels and can actuate via digital outputs or relays. The combination of an IRIS (XM2110) and a MDA300 were used as a low-power wireless data acquisition device or process control machine. Preliminary study had been performed for MDA300 as an extra feature for the future improvement of this project.

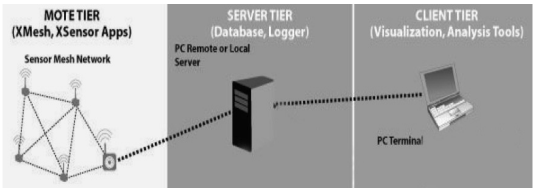

Figure 3. Software framework for wireless sensor network

3) Processor/Radio Board: The IRIS (XM2110) is the latest generation of Motes from Crossbow Technology. The XM2110 with frequency range of 2400 MHz to 2483.5 MHz band uses the Atmel RF230, IEEE 802.15.4 compliant and ZigBee ready radio frequency transceiver integrated with an Atmega1281 micro-controller. These enhancements provide up to three times improved radio range and twice the program memory over previous generation of MICA Motes. The ATmega1281 is a low-power microcontroller which runs MoteWorks from its internal flash memory. A single processor board (XM2110) can be configured to run the sensor application/processing and the network/radio communications stack simultaneously. T These interfaces makes it easy to connect to a wide variety of external peripherals.

In most Mote applications, the processor and radio awake for a period of time, followed by a sleep cycle. This method extends battery life; however, due to the current surges, it reduces specified battery capacity.

4) Radio Communication: The radio used by IRIS is an IEEE 802.15.4 compliant RF transceiver designed for low power and low-voltage wireless applications. It uses Atmel's AT86RF230 radio that employs Offset Quadrature Phase Shift Keying (OQPSK) with half sine pulse shaping. The 802.15.4 radio includes a Digital Direct Sequence Spread Spectrum (DSSS) baseband modem providing a spreading gain of 9 dB and an effective data rate of 250 kbps. The radio is a highly integrated solution for wireless communication in the 2.4GHz unlicensed ISM band. It complies with worldwide regulations covered by ETSI EN 300 328 and EN 300 440 class 2 (Europe), FCC CFR 47 Part 15 (US) and ARIB STD -T66 (Japan).

B. Software Development

The wireless sensor network software development consists of three software tiers which are the Mote Tier, the Server Tier and the Client Tier. The fundamental of the three software tiers had been studied and applied in this project. Figure 3 illustrates a three-part framework for deploying a sensor network system. The first part is the Mote layer or sensor mesh network. The Motes are programmed with XMesh/TinyOS firmware to do a

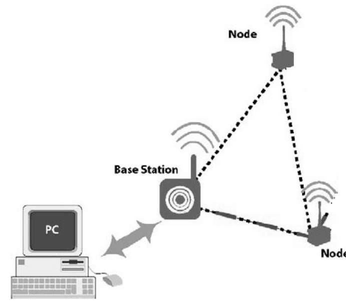

Figure 4. Xmesh network diagram

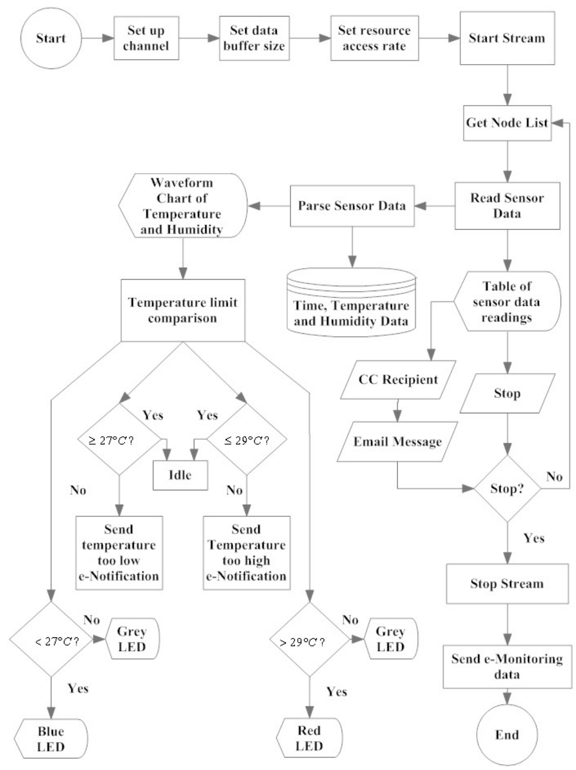

Figure 5. Monitoring software development flowchart

specific task like microclimate monitoring. The second layer or Server tier provides data logging and database services. At this layer sensor readings arrive at the base station MIB520 and are stored on a server. The third part is the client tier in which software tools provide visualization, monitoring, and analysis tools to display and interpret sensor data. Apart from that, custom client software had been designed and developed using LabVIEW. For remote accessing and controlling the system from other places, the software applied is called LogMeIn. The functions of the three software tiers, the design of this Wireless Sensor Network System for Monitoring Swift Habitat GUI and functions of the LogMeIn software are further discussed in the following section.

1) Mote Tier: The Mote Tier is the software that runs on the cloud of sensor nodes forming a mesh network where the XMesh resides. The XMesh software provides the networking algorithms required to form a reliable communication backbone that connects all the nodes within the mesh cloud to the server. XMesh is fully featured multi-hop, ad-hoc, mesh networking protocol developed by Crossbow for wireless networks. XMesh software library using the TinyOS Operating System that runs on embedded devices called Motes. Motes consist of: Microprocessor Atmel ATmega 128 with 128K of flash memory, 4K of RAM, 4K of EEPROM, Radio at 2.4GHz, and Serial Flash with external storage flash memory to support over-the-air-programming and data logging. The entire XMesh network consists of one or more motes which participate in the network, a base station node with another radio mounted on an interface board and programmed with XMeshBase application. It manages the network and forwards messages into and out of the mesh. Figure 4 shows the XMesh network diagram. An XMesh network consists of wireless nodes (Motes) that communicate with each other and are capable of hopping radio messages to a base station where they are passed to a PC or other client. The hopping effectively extends radio communication range and reduces the power required to transmit messages. By hopping data in this way, XMesh can provide two benefits: improved radio coverage and improved reliability. Two nodes do not need to be within direct radio range of each other to communicate. A message can be delivered to one or more nodes in-between which will route the data. Likewise, if there is a bad radio link between two nodes, that obstacle can be overcome by rerouting around the area of bad service. Typically the nodes run in a low power mode, spending most of their time in a sleep state, in order to achieve multi-year battery life.

XMesh provides a TrueMesh networking service that is both self-organizing and self-healing. XMesh can route data from nodes to a base station (upstream) or downstream to individual nodes. It can also broadcast within a single area of coverage or arbitrarily between any two nodes in a cluster. Quality of Service (QoS) is provided by either a best effort (link level acknowledgement) and guaranteed delivery (end-to-end acknowledgement). Furthermore, XMesh can be configured into various power modes including High Power (HP), Low Power (LP), and Extended Low Power (ELP). XMesh network requires a base station which acts as a gateway for a PC, Stargate or other client to interface with the XMesh network. Base stations consist of a radio board running XMeshBase and mounted on the Crossbow interface board: MIB520 using USB port to interface with the client. It uses a standard serial protocol for communication. The base station communicates with host through a serial bus at 57,600 bps. The incoming and outgoing packets are framed using a Point to Point Protocol-High Level Data Link Control (PPP-HDLC) protocol. The FramerM TinyOS component handled this in XMeshBase.

To configure and download pre-compiled XMesh/ TinyOS firmware applications onto Motes, an interface called MoteConfig is used. MoteConfig is a Windows-based GUI utility for programming Motes. With this utility, the Mote ID, Group ID, RF channel and RF power could be configured. High-power and low-power XMesh applications are available for each sensor board and platform manufactured by Crossbow. As this is an early stage of development for this system, high-power XMesh application had been selected to shorten the time for testing and analysis purpose.

2) Server Tier: The Server Tier is an always-on facility that handles translation and buffering of data coming from the wireless network and provides the bridge between the wireless motes and the internet clients. XServe is a server tier application that can run on a PC. XServe serves as the primary gateway between wireless mesh networks and enterprise applications interacting with the mesh. It can connect to the Mote Tier directly or through other forwarding applications including other XServes. At its core, XServe provides services to route data to and from the mesh network with higher level services to parse, transform and process data as it flows between the mesh and the outside applications. XServe can convert raw data into the System International (SI) units of measurements as well as other easy-to-read engineering units. Higher level services are customizable using XML based configuration files and loadable plug-in modules. XServe offers multiple communication inputs for applications wishing to interact with XServe or the mesh network.

3) Client Tier: The Client Tier provides the user visualization software and graphical interface for managing the network. Crossbow provides free client software called MoteView that bundles software from all three tiers to provide an end-to-end solution. MoteView is designed to be an interface between a user and a deployed network of wireless sensors. MoteView had been studied and applied in the initial stage of this study in order to test the functionality of all the equipments deployed. However, to fulfill the GUI requirements for this Wireless Sensor Network System for Monitoring Swifts Habitat, a custom client tier has been designed and developed using the LabView.

C. Monitoring Software Development

LabVIEW is used to develop the monitoring software in this study. Figure 5 shows the flow diagram of monitoring software development. The connection or a stream between the remote accesses to the WSN gateway will be created immediately after the set-up process is done. During the process of connectivity, the "get node list" will request a list of known node IDs within the network. The data received from the sensors will be displayed in table form and waveform chart at the GUI front panel. The temperature data received will be compared in the comparison blocks. Warning on temperature will be displayed and emails notification will be triggered if the temperature is out of specified range. When the stop button is entered, the program immediately stops acquiring data from the network and disconnect the connection to the gateway. This will allowed the base station to send a notification message to the system owner.

1) Email Block Design: Email block design (e-notification) has been designed and developed in order to notify the system owner if there are any changes in the system through email services. In this email block design, three types of nodes were employed in LabVIEW. They are the constructor node, property node and invoke node. The constructor node creates an instance of a .NET object. The constructors may contain initialization parameters, for instance Mail Address, Mail Message, Attachment, Simple Mail Transfer Protocol (SMTP) Client and Network Credential. The property node gets (reads) and/or sets (writes) the properties of a reference. The property node automatically adapts to the class of the object that is being referenced. LabVIEW includes Property Nodes preconfigured to access VISA properties, .NET properties, and ActiveX properties. Finally, the invoke node invokes a method or action on a reference.

2) Remote Access Software: LogMeIn : This study applies LogMeIn services software for accessing the remote base station through internet connectivity. LogMeIn remote access products used a proprietary remote desktop protocol that is transmitted via Secure Sockets Layer (SSL). An SSL certificate is created for each remote desktop and is used for cryptographically secure communications between the remote base station and the accessing computer. The service connects the remote desktop and the local computer using SSL over Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) and utilizing Network Address Translation (NAT) Traversal techniques to achieve peer-to-peer connectivity when available.

3) Database Management Systems: The base station currently uses Excess database. The database stores the date and time-stamped, power level, temperature and humidity measurement from the sensors.

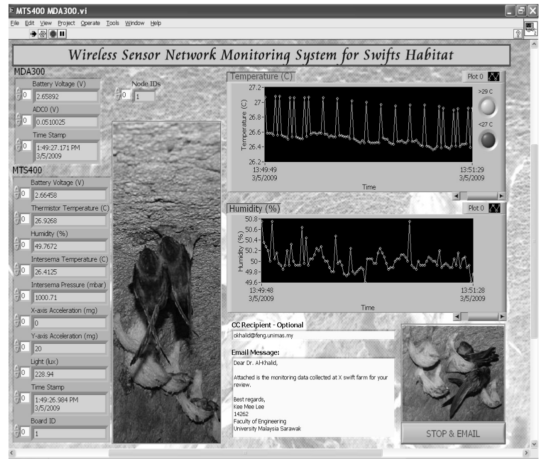

Figure 6. LabView user interface for wireless Internet base remote site monitoring

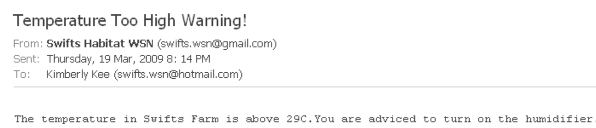

Figure 7. Notification email received when temperature is out of range

V. Results and Discussions

Wireless sensor networks for swift habitat monitoring application are deployed at one of the swift farm at Sarawak, Borneo. These sensor networks comprising of two sensor boards attached to a radio transceiver running XMesh application and a USB interface board attached to a radio transceiver running XMeshBase. The sensor networks have been deployed for 2 weeks. Figure 6 shows the interface of the monitoring system. As this is an early stage of development for such application, high-power XMesh application has been selected to shorten the time for testing and analysis purposes. After

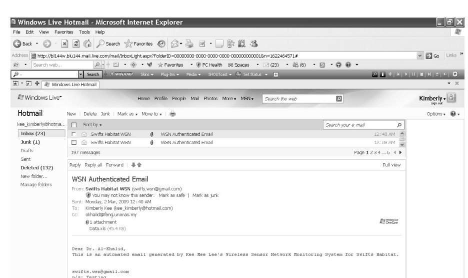

Figure 8. Email sent to recipient, email message and monitoring data attached

the deployment and the data obtained, it shows that there were consistency on the measurement (humidity and temperature) from the sensor nodes thus indicate the reliability in the system design. The system also demonstrated the performances of monitoring where the system successfully trigger an automated notification email message when the temperature is out of range. This is also shown in the automated email or message sent when there is no activity on the monitoring. Figures 7 and 8 illustrate the notification email received when the temperature is out of range and messages from base station respectively. Even though the system has been successfully developed and tested, the energy management of the sensor nodes must be considered in order to gain longer time of deployment task. The energy budget must be divided into several system services such as sensor sampling, data collection, routing and communication [4].

VI. Conclusion and Future works

Statement of problems in swift farming in the country of bird nest producer has been identified and solution has been proposed in order to improve the productivity. This shows that habitat monitoring represent an important category of sensor network applications. The remote access software using LogMeIn has been developed to enable this monitoring system to be accessed from anywhere around the world as long as there is internet connectivity. We believe that the automated incident resolution and more efficient management will increase productivity of the swift bird nest for the farmers. Furthermore, the data gained from the system can be used for further improvement on the utilization of hardware and management resources. Finally, the systems is believe to decrease the operational time, maximizing services and increase the accessibility without disturbing the swift habitat at the farms.

For future works it is suggested that more sensor nodes and networks are deploy in order to study the reliability and performance of data transfer in the system. For instance, a sensor node can be placed at every corner of the swift farm. Another alternative solution is by adding specific external sensors to the data acquisition board of MDA300. The current e-notification block in this system is designed to send notification emails when the temperature measurement is out of range. This e-notification can be replaced or upgraded by sending a notification through the mobile phone using GSM.

VII. Acknowledgment

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