CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF TROPICAL AGRISCIENCES

Wireless sensors and networks‘ applications in agriculture

Bc. Thesis

Prague 2020

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“I hereby declare that this thesis entitled Wireless sensors and networks‘ applications in agriculture is my own work and all the sources have been quoted and acknowledged by means of complete references.”

In Prague 15.5.2020

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Acknowledgment

Abstract

The purpose of this work is a general overview of Wireless Sensor Network technology in developing countries agriculture. The agriculture in developing countries is the same as in other developed countries, has its own needs to be productive as much as possible, and WSN can be applied here. Therefore, it is always necessary to know the right situation on your field, actual data, and useful information through the most sufficient technologies such as WSN. Sensors are used for collecting information about physical and environmental attributes whereas actuators are employed to react to the feedback to have control over the situations. WSN can be used for different purposes not only in agriculture, but for example for mapping pollutions in a city, water, air and because of different purposes are different types of WSN, transmissions (long-range, short-range) hardware, data logger platforms, frequency, operating systems, network architecture, energy harvesting, data management. Like everything else in the world, WSN brings a lot of pros and cons. Despite poor electricity situation in developing countries mainly rural areas, I would like to show the current state of WSN with its options. Wireless System Network is difficult and new topic, so it should be deeply explained. The situation in developing countries is way different and its possibilities are different, the right WSN should be applied in developing countries.

Key words: Wireless sensors network, WSN in agriculture, WSN in developing countries, plant production precision farming, electricity in developing countries, data handling and processing

Abstrakt

Cílem této bakalářské práce je obecný přehled bezdrátových síťových senzorů zejména v zemědělství v rozvojových státech. Zemědělství v rozvojových státech je stejné jako v ostatních státech, musí být co nejvíce produktivní a k tomu by právě mohla pomoci tato technologie. V zemědělství je velice důležité vědět, co se právě děje na vašem poli či ve vaší produkci, proto zařazením senzorů do zemědělských systémů je přínosné pro farmáře. Senzory poskytují obrovské množství využití, od samotného sběru dar až po automatický chod obhospodařování pole. Senzory jsou ovšem využívány i jinak než jen v zemědělství, například můžou kontrolovat a mapovat znečištění vzduchu a vody ve městě. Jelikož tento systém nám umožnuje širokou škálu využití, tak máme i širokou škálu senzorů, přenosů dat, koncových systému, rozhraní, sběrů dat, operačních systémů a napájení. Jako se vším na našem světě i tato technologie má své pro a proti, i přes nepříznivou situaci co se týče elektřiny v rozvojových zemích. Síťové systémy bezdrátových systémů jsou poměrně nový přístup k zemědělství a je tu mnoho věcí, které by budoucí farmář používající tuto technologii měl pochopit, aby ji mohl efektivně využívat. Jelikož podmínky zemědělství v rozvojových zemích jsou jiné než podmínky v zemích, které jsou v zemědělství mnohem vyspělejší, je důležité vybrat tedy správné komponenty a konfiguraci této technologie.

Klíčové slova: Síťové systémy bezdrátových senzorů, WSN v zemědělství, WSN v rozvíjejících se státech, precizní produkce rostlin, elektřina v rozvíjejících se státech, práce s daty

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List of the abbreviations:

A/D - Analog to Digital

AFMS - Advanced Farming Management Systems

AGPS – Assisted Global Positioning System

ANN - Artificial Neural Network

ANN – Artificial neural network

AQP - Acquisitional Query Processing

CDMA - Code Division Multiple Access

DAQ – Data acquisition module

DBMS - Database Management System

DC – Direct current

FFD - Fast-forward Dissemination

FFD – Full function device

GIS – Geographical information system

GPS – Global positioning system

GSM – Global System for Mobile Communications

GUI – Graphical user interface

HW – Hardware

I/O – Input/Output

ID - Identity

IPM – Integrated Pest Management

IRIS - Integrated Risk Information System

ISM – Instrumentation-scientific-medical radio bands

ISO - International Organization for Standardization

IT - Information technology

MAC - Media Access Control

MATLAB - Matrix Laboratory

MEC – Micro energy cell

MLP – Multilayer perceptron

MLP - Multi-link procedure

MMS - Mobile Monitoring System

NiMH - Nickel Metal Hydride

OS – Operating system

PC - Personal computer

PDA - Personal Digital Assistant

PHP - Hypertext Preprocessor

PLF - Precision Livestock Farming

PP - Plant phenotyping

QoS - Quality of service

RAS - Remote application server

RF – Radio frequency

RFID – Radio frequency identification

RSSI - Received Signal Strength Indicator

SD - Storage Device

SPOT - Satellite Pour l'Observation de la Terre (Satellite for observation of Earth)

SQL - Structured Query Language

SW – Software

USA - United States of America

WCU - Wireless Sensor Network Control Unit

WSN - Wireless network system

1. Introduction

The bachelor thesis begins with a broader introduction of Wireless sensor network (WSN) technology. Only recently has Wireless Sensor Networks (WSNs) technology started to receive recognition as a key enabling technology for the emerging pervasive computing areas (Sherazi et al. 2018). The latest developments improved the key aspect of the WSN, range, size of collected data, low power consumption, multifunctionality, and one of the most important aspects for developing countries prices. Wireless sensor network is a complex system, with the appearance and convergence of several technologies, including the global positioning system (GPS), mini-authorized computer components, automatic control, geographic information systems (GIS), in-field and remote sensing, mobile computing, advanced information processing, telecommunications, detailed information on field and production variability both spatially and temporally can be assimilated and treatments can be adjusted to meet each site's unique needs (Zhang et al. 2002).

The second part of the work is focused on WSN and application in the agriculture of developed countries. Nowadays the production is shifting more to be automized and people are doing minor things (test cars, check data, maintain the machines). This trend is spreading across all types of products and this approach leads to increase yields in agriculture and help small-scale farmers. Agricultural production in remote and uncontrolled areas, the production depends on environment and crop conditions and on water. In the case of farming, there are three main actions needed, data acquisition, monitoring, and control, for these actions are controllers, sensors, and actuators with intelligence used.

The last part of the thesis is focused on WSN and application in agriculture in developing countries. The cons and pros of the approach in developing countries. What should be done in cases of efficient use of the WSN. The developing countries mostly tropical countries are fighting with a lack of water where WSN can significantly help with efficient water usage. Another problem is low production, which can be caused by lack of water, lack of nutrients, too high, or low temperature of other physical aspects of the farming can be eliminated with using WSN technology.

2. Objectives

The main goal of the present thesis is the overview of the use of WSN in different aspects of agriculture in developed and developing countries.

2.1 Specific Objectives

The specific objectives are to overview advantages and barriers of WSNs in developing countries and developed countries.

3. Methodology

The bachelor thesis methodology is based on secondary data collection.

3.1 Methodology of literature review

A literature review is elaborated based on scientific references from international databases including ScienceDirect, Scopus, Web of Knowledge, EBSCO, ResearchGate as well as governmental statistics of the agricultural sector. Journals I have used the most are Computers and Electronics in Agriculture, Livestock Production Science and Computer Science.

For searching information sources, the main following keywords were used: Wireless sensors network, WSN, agriculture, development, farmers, developing countries, farming, production, data.

4. Literature review

4.1 Current state and brief introduction of Wireless Sensor Networks

The development of WSN technology at the beginning was struggling, it was slow and almost without any attention, but recent years technologies, in general, are rapidly growing and it is the same for WSN and its popularity.

4.2 What is Wireless Sensor Network

A WSN is a wireless network of spatially distributed autonomous devices using sensors for monitoring, composed of many static sensor nodes with low processing and limited power capabilities that often communicate over unreliable, short-range radio links (Shaikh et al. 2013). Additionally, sensor nodes have limited storage capacity, batteries, and multiple onboard sensors that can take readings, for example temperature and humidity. Sensor nodes are deployed in an ad-hoc manner and cooperate with each other to form a wireless sensor network (Anastasi et al. 2009).

The development of WSN is primarily built on three key components: operating system (OS), hardware (HW), and network communication. The OS is the same as in the case of computers, mobile phones, etc., run on the nodes where coordinate HW components to complete the tasks (data collection, functions, processing, storage, and transmission). The hardware is all physical components of WSN, nodes, data storage (SD card), processing units, a radio transceiver, one or multiple sink or gateway, a power unit. The last key component of WSN is a network communication. The network communication is how data will be spread around, defines network topology and protocols. The selection of right network communication is based on routing, power, and resource management, size of data shared, node localization (range) (Gay et al. 2003).

The most important outcome of using WSN technology is data. The main goal of a WSN application is to gather, transmit and store data. For collected raw data, which is a mixture of valuable, unwelcome information and noise, a query processing system, which allows easily inquire, filter, and aggregate without writing any code (Han et al. 2005).

Table 1. OS summary invented for WSNs

Name	***Execution model***	***Levels of granularity supported in reprogramming***	***Scheduling***	***Power management***	***Support platform***
TinyOS	Event driven	Application level	Not real-time	Yes	Telos, Mica2Dot, TMote Sky, Eyes, MicaZ, iMote
SensorOS	Event driven	Modular/component level	Not real-time	No	Cricket, imote2, Mica2, MicaZ, tmote, Protosb, emu
MantisOS	Thread-based	Modular/component level	Not real-time	Yes	Mica2, MicaZ, Telos, Mantis, nymph
SenOS	Finite state machine based	Instruction/variable level	Not real-time	Yes	Not specified
Nano-RK	Reservation-based	Instruction/variable level	Real-time	Yes	Atmel ATMEGA 128 with Chipcon CC2420 trans.
kOS	Hybrid	Instruction/variable level	Not real-time	No	User defined

4.2.1 Wireless Sensor Network hardware

Presently, various general-purpose commercial platforms are accessible in the WSN product market. The platforms have often alike major components, mainly: data acquisition modules, power units, nodes with or without on-board sensors, and sinks/gateways modules. The platforms are often open source with very large user groups, and the technical support is secured through system developers forums (Wang et al. 2013).

As it was mentioned before, the commercial WSN platforms are a collection of, data acquisition interface modules, wireless transceiver modules, gateway, and sensor modules. Based on the requirement, a user can stack the modules together to reach the desired function of WSN (Wang et al. 2013).

The most known manufacturer is Crossbow Technology located in the USA, which manufactures a lot of hardware components. Data acquisition boards, MTS, MDA, IMB400, and ITS. Wireless transceivers such as IRIS, MicaZ, Mica2 and Imote2, gateways (MIB and Star-gate), and development software, XServer, XMesh, Crossbow Technology Inc. (Li et al. 2013).

Table 2. Commercial WSN hardware platforms

Platform	*CPU*	*Power*	*Memory*	*I/O interfaces*	*Radio*	*Max. range*	*OS*	*Manufacturer*
Mica2	Atmega128	3.3V battery, 15µA, Sleep; 8mA, Active Intel	128 kB ROM 512 kB Flash 4 kB EEPROM	Regular I/Os, 51 pin interfaces to other extension boards	CC1000	300 m outdoor	TinyOS 1.x/2.x	Crossbow Tech.
MicaZ	Atmega128	3.3V battery, 15µA, Sleep; 8mA, Active	128 kB ROM 512 kB Flash 4 kB EEPROM	Regular I/Os, 51 pin interfaces to other extension boards	CC2420	75-100m outdoor, 20-30m indoor	TinyOS	Crossbow Tech.
IRIS	Atmega128	3.3V battery, 15µA, Sleep; 8mA, Active	4kB RAM, 128 kB ROM, 512 Flash, 4kB EEPROM	Regular I/Os, 51 pin interfaces to other extension boards	RF230	>300m outdoor, >50 m indoor	TinyOS	Crossbow Tech.
Imote2	Intel PXA271	3.3V battery, 390µA, Sleep; 66mA, Active	256kB SRAM, 32MB SDRAM, 32MB Flash	GPIO/SPI/ UART/I^2S/USB/ AC'97/Camera/ IMB400 multimedia extension board	CC2420	30 m with antenna	Linux or Windows support	Crossbow Tech.
TinyNode584	MSP430	3.6V battery, 4µA, Sleep; 77mA, Active	10kB RAM, 512kB Flash	Regular I/Os, factory made extension boards	XE1205	Up to 2000 m	TinyOS	Shockfish SA

4.2.2 Network architecture

The network architecture is how are data spread. A network can be single-hop or multiple-hop and the difference is shown in Figure 2. The single-hop approach allows direct communication between a wireless sensor and a gateway (sink). Multi-hop networks spread data through several relays in order to extend network coverage, avoid difficulties between a source and a sink, and provide users elasticity to design data routing maps to improve performance and energy efficiency (Wang et al. 2013).

A network topology is installed to connect and communicate between sensors and gateways. Types of network topologies: Hybrid, Bus, Star, Ring, Mesh, Fully connected, Line and Tree are shown in Figure 1. For WSNs are mainly used star, hybrid, and mesh networks. Several levels of networking may be mixed when many wireless sensors need to be networked (Wang et al. 2013)

The most efficient network uses peer-to-peer, mesh networks, where every node has routing capability. Mesh networks let nodes to self-assemble into the network, sensor data to transmit across the network with a high consistency and over an extended range, and to prolong battery life (Karl and Willig et al. 2005).

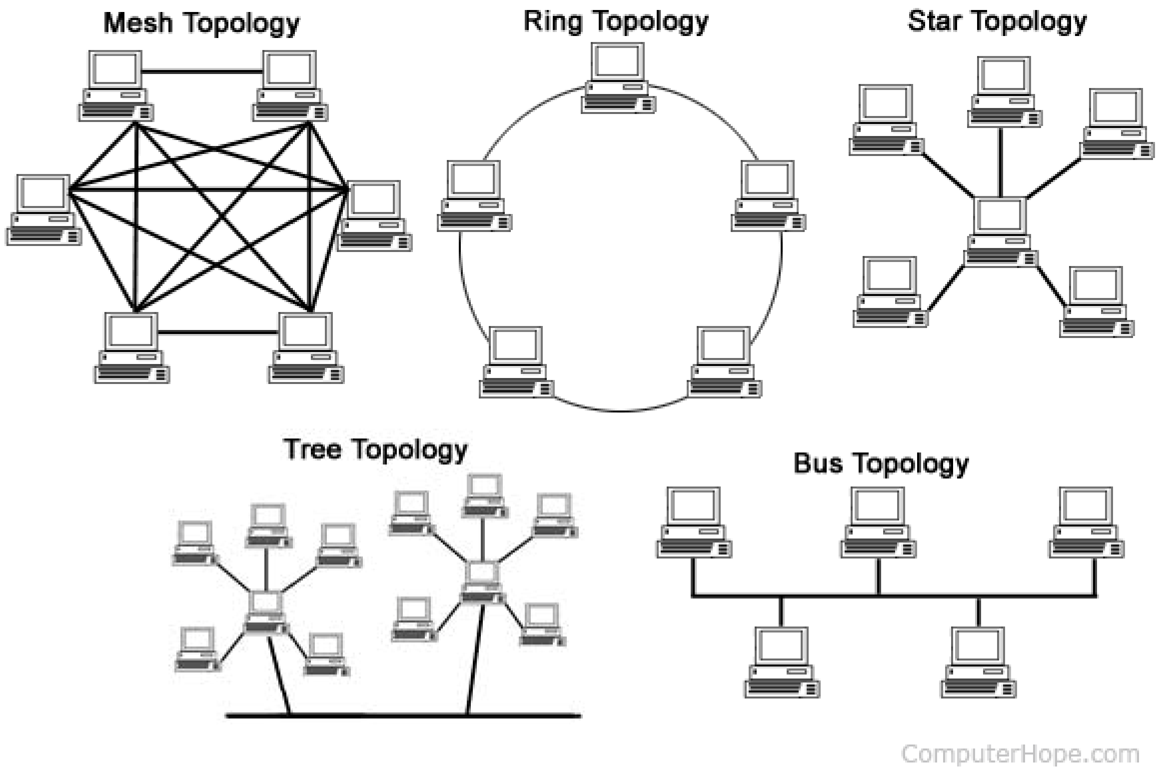


Figure 1. Types of network topologies

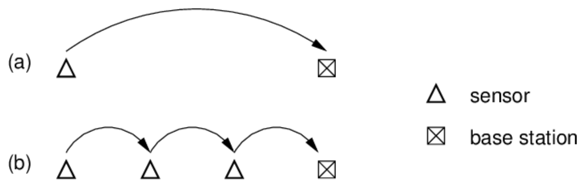


Figure 2. a) Single-hop b) Multi-hop

4.2.3 Wireless data logger platforms

A data logger is an electronic device used to store data over time. Analog, digital I/O, parallel and serial ports (stand-alone data loggers) are widely used in agricultural applications. Data logger platforms are easy to program, use and are very rugged under various environmental conditions. Some of the data logger include RF modules to convey data, nowadays more and more producers are adding radio frequency modules (Wang et al. 2013).

Campbell Scientific Inc. provides modules for communication: Ethernet, spread spectrum RF, satellite, cellular (GPS and CDMA) etc. which can be paired to data loggers. Decagon Devices Inc in the USA (Decagon 2010) wireless radio data logger Em50R and the Em50G wireless cellular data logger, which allow long-distance networking and data communication. Onset (2010) manufactures a series of Hobo data loggers and wireless data loggers for temperature and/or humidity for indoor and outdoor applications (Wang et al. 2013).

The data logger platforms are close to OSs and development tools from their manufacturers. The problem is connecting different brands together which can be difficult, connecting the same branded modules is not a problem. The cons are the HW and SW flexibility, cost, and for large complex WSN it is not very suitable (Wang et al. 2013).

Table 3. Wireless data logger platforms

Platform	*CPU*	*Power*	*Memory*	*I/O interfaces*	*Radio*	*Max. range*	*OS*	*Manufacturer*
CR1000+RF4xx	Renesas H8S 2322	12V battery off, 0.6mA on, 27.6mA/100mA for CR1000, 9-16V battery 1mA Stand-by 75 mA max for RF4xx	4 MB SRAM CF card extension	16 analog inputs, 3 analog outputs, 8 digital I/Os, communication ports	RF401 (915 MHz) RF411 (922MHz) RF416 (2.4GHz)	Up to 1.5 km	LoggerNet 3.x, PC400 1.2 or ShortCut 2.2	Campbell Scientific
V/SG/G-link nodes+ 2.4GHz base station	N/A	0.5 mA off, 25 mA max	Up to 2 MB	Fixed on-board sensors depending on series 'x'	2.4 GHz, 16 nodes max for simultaneous streaming	70 m line of sight, up to 300 M with optional antenna	Precompiled sys in VB/VC++/LabViev	Micro Strain
Em50R/G	N/A	5 AA batteries	1 MB	4 analog inputs, serial input port	50R: 900 MHz or 2.4 GHz selectable, 50G using cellular network	N/A	ECH_2O Utility and DataTrac	Decagon Devices
HOBO W-TMB	N/A	AC powered or 3 AAA batteries	N/A	TMB: Temperature, SMC: Soil moisture	2.4 GHz	420 m clear line of sight or 300 m typical	HOBO Node viewer	Onset

4.2.4 Radio frequency identification systems

The main task of RFID is to read and capture data using radio waves. RFID systems consist of many hardware components, but there are three main components:

- A RFID tag or transporter carrying ID or other information
- A two-way radio transmitter receiver
- A backend system that stores and processes the information for various applications (Finkenzeller et al. 2010)

RFID systems are contactless, independent of line of sight, and robust in harsh conditions (Jaselskis et al. 2003). An RFID system can work at different bandwidths (narrow to ultra-wide) which can be additional categorized to low, high and ultra-high frequency (Xue et al. 2018). The computer systems work with product IDs, information, and can store it and organize information. RFID tags can be active or passive. (Wang et al. 2013).

The active RFID tags have greater memory, more I/O ports, on-board sensors and more powerful radio range and can carry more information because of larger memory than the passive tags (Nam et al. 2017). The active tags mainly operate at frequencies of 455 MHz, 2.45 GHz, and 5.8 GHz (Ruiz-Garcia et al. 2009).

Most passive tags operate at low frequencies between 125 and 148 kHz (Ruiz-Garcia et al. 2009). The passive tag is used for animal tags since 1980s, to regulate the animal RFID applications, the ISO standards 11784/11785/14223 are in force. The price of the passive tags is low, around US$2 per tag (Wang et al. 2013).

4.2.5 Data management

Data can be often misleading, so it is better to give a definition and distinguish data and information. Data is a piece of unprocessed information (fact, text, number), raw material used to create information, and information is a processed piece of data.

The biggest outcome of WSN and the possible measurement of the success is determined by the quality of data generated. The data, as it was mentioned before, has to be processed, filtered, interpreted, stored and displayed to end users.

In WSN applications, the data are commonly used in two ways: (1) queries on current data; (2) queries on historical data (Diao et al. 2005). The existing data are frequently used for decision-making to determine control operations, for instance a soil moisture level (predefined threshold), if it is under, a water pump should be powered on. Push-down filter methods are utilized to preprocess unprocessed data before broadcasting to save energy, it is used mainly for multimedia WSNs with large data sets (images, audio, or video streams) (Ganesan et al. 2004; Diao et al. 2005). TinyDB, BBQ (Deshpande et al. 2004) and Direct Diffusion (Intanagonwiwat et al. 2003) offer instruments for continuous queries to the current information. An Alternative method, acquisitional query processing (AQP), presents functionality to determine which nodes, which parameters, and at what time to collect data (Ganesan et al. 2004).

A lot of WSN applications, sent data collected by sensors to a remote traditional database (SQL). End users can query stored data any time. For processing, analyzing and query the data, data mining artificial intelligence, and multivariate statistical analysis methods are used. Several new energy-efficient query methods and database management systems are still under development that views the WSNs as a database that supports archival query processing (Diao et al. 2005).

4.2.6 Energy harvesting

One of the major drawbacks in WSN is energy (Shaikh et al. 2015). When a node is without energy, it will no longer fulfill its tasks in the network and becomes useless. (Tillute et al. 2007). Most of the WSN platforms use batteries (alkaline, cell, and lithium) which are replaceable or changeable. In many cases, the battery long life claimed by manufacturers is shorter than it is referred by a producer, mainly when external sensors face a high sampling rate, and high data transmitting rate, plus extreme environment conditions. (Wang et al. 2012). Except for the major problem with battery life, there are few minor problems associated with, its usage and extreme weather conditions which can lead to chemical leakages and further environmental damage (Tillute et al. 2007).

There are two key tasks in energy harvesting, energy capture and storage. The most used harvesting system is based on solar energy. (Wang et al. 2012). The efficiency is between 50% and 75% over a 100 m range (Sudevalayam et al. 2011).

Solar-based energy harvesting, solar energy is a cheap affordable, and clean energy source which is the most used type of energy harvested in WSNs. The farmers should focus on the position of the sensors to be exposed to the sun as much as possible to achieve their potential (Shaikh et al 2016).

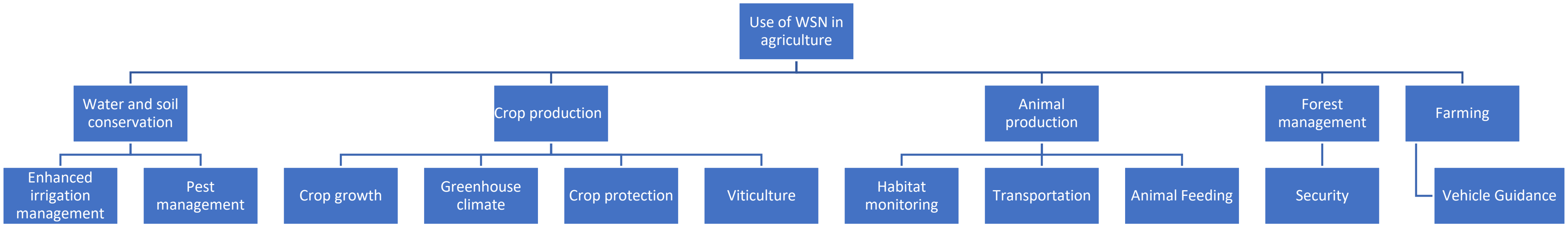
Thermal-based energy harvesting/Thermoelectric converting heat energy into electrical energy. Due to the potential difference or gradients of temperature between two poles of the same material, thermoelectric harvesting is made possible that is common in a variety of prospective applications these days (Tan et al. 2010). The efficiency with new more efficient modules is around 10% (Satyala et al. 2014).

Table 4. Comparison of maximum power density from energy harvesting technologies

Harvesting method	*Power density*	*References*
Solar energy – outdoor	15 mW/cm 3 - bright sunny day 0.15 mW/cm 3 -cloudy day	Zhou et al. 2014
Solar energy – indoor	6 µW/cm 3	Roundy et al. 2003
Vibrations (piezoelectric – shoes inserts)	330 µW/cm 3 -105 Hz	Sudevalayam et al. 2011
Vibrations (electrostatic conversion)	184 µW/cm 3 -10 Hz	Zou et al. 2016
Vibrations (electromagnetic conversion)	0.21 mW/cm 3 -12 Hz	Lee et al. 2015
Thermoelectric (5-20C)	40 µW −10 mW/cm 3	Hieu et al. 2016
Magnetic field energy	130 µW/cm 3 -200 µT, 60 Hz	Tashiro et al. 2011
Wind energy	65.2 µW/cm 3 -5 m/s	Vatansever et al. 2011
RF energy	0.08 nW-1 µW/cm	Kim et al. 2014

4.2.7 Wireless Sensor Network in Agriculture

The characteristics of agriculture changed over time, at the beginning agriculture was associated with the primary production. Nowadays it has broader portfolio and is associated with forestry, dairy, fruit cultivation, poultry, beekeeping, etc. Another part of agriculture at present are marketing, processing, distribution, and cultivation. Agriculture plays a vital role in today's word and is also a big part of the economy of a country (export, employment, income) (Kowalczyk et al. 2019).



Graph 1. Use of WSN in agriculture

Water and soil conservation

Agricultural water management

Agriculture is very intensive in using of water, roughly 69% of fresh water is used by the agricultural sector (Koncagul et al. 2015). About 69% is a high number and worldwide goal is to decrease this percentage to a minimum, which can be achieved through using freshwater efficiently and responsible, WSN supports watersaving, precision irrigation and water quality monitoring (Culman et al. 2015).

Modern farming needs an enhanced irrigation management system to maximize agricultural water use (Adamala et al. 2014; Greenwood et al., 2010). Another reason for the need of an advanced device is the increasing decline in ground water levels. The micro-irrigation techniques are cost-effective and water-efficient in this context (Raina et al. 1998; Westarp et al. 2004). However, the performance of micro-irrigation can be further enhanced based on the knowledge on the climate and soil. WSNs are used in this way as the coordinating technology (Lichtenberg et al., 2015; Gutiérrez et al. 2014; Lorite et al. 2013).

In 2010, authors Rehman et al. (2010) presented system's water conservation over traditional irrigation methods. They used TelosB sensor motes and Ech2o soil moisture sensors to establish irrigation control system. The system was tested for University green area irrigation and field testing showed the 30–50% water conservation). On-farm decision-making by individuals, irrigation plant managers, and so on is needed to be made on the data basis at microscale. WSNs will deliver real-time, and long-term, high-resolution spatial and temporal data to support this need (Gommes et al. 2010).

Pest management

Worldwide annual usage of pesticides is around 200,000 tons, more than 45% is used in Europe. Excessive usage of pesticides increases the pest resistance, destroys the good soil microbes, and reduces the soil biodiversity which leads to desolation of the natural habits (Kumar et al. 2018). Integrated pest management (IPM) refers to the precise use of pest control mechanisms and measures to produce healthy products while reducing the use of pesticides and the risk associated to its use on human health and the environment (FAO 2005 & 2011). The increased use of fertilizers and pesticides contribute to a decrease of groundwater quality. Placing wireless communication-enhanced sensor nodes aid in monitoring water quality (Lin et al. 2008; Zia et al. 2013).

Climate monitoring

Lee in 2007 built a software system for climate change management, it manages and preserves data in real time and focuses on spatiotemporal query processing. The system is using spatial and existing temporal approach to assist spatiotemporal queries and keep sensor data and build a system for environmental observing sensor network. The inbound data is kept as a segment and labelled with timestamp if changes occur in the value of item (Lee et al. 2007). At plant level spatially spread environmental measurements can be used inside of a greenhouse and to create a precise and detailed representation of the climate. Very important for the size of yield, quality, quantitative and productivity is climatic heterogeneity and cause significant differences also diseases. To investigate the spatial variation of the existing condition, the enhanced WSN was then installed. Based on WSN analysis measurements showed significant spatial variability in temperature and humidity with average differences up to 3.3 °C and 9% relative humidity and transpiration, with the greatest variability occurring during daytime in the summer period (Ferentinos et al. 2016).

Agricultural monitoring

Nowadays, many animals are living in poor conditions without proper treatment. It is very important, to monitor animals, their behavior and health regarding to production and health reports. The design of RFID-based Mobile Monitoring System (RFID-MMS) helps users control animal behavior and movement (Ting et al. 2007).

With the advent of the internet of things, it is now possible to remotely monitor and diagnose farm equipment such as pumps, lamps, heaters, valves in machinery (Fukatsu et al. 2011; Coates et al. 2013).

The vital factors for plant growth and crop quality are soil fertility and water with the agricultural activities made in field. Therefore, the classification of crop growth can be made based on climatic data, plant related data, and soil associated data. WSN is a tool to obtain these data but it can be extended to a bigger data source (Culman et al. 2015).

Crop production

Crop growth

At agriculture level, soil fertility and water are vital for plant growth and crop quality as result of all the agricultural activities made in field. Hence, the characterization of crop growth can be made based on climatic data, plant related data, and soil associated data. WSN is a tool to obtain these data but it can be extended to a bigger data source

(Culman et al. 2015). In 2004, Zhang proposed sensor network to analyze the current state of plant nursery, it monitors air temperature, humidity, ambient light, soil moisture and temperature. Such a network may also help to identify plant diseases (Zhang et al. 2004).

Greenhouse monitoring

According to Kochhar researchers done in 2019, since 2010 they could find just around 2390 WSN projects in greenhouse monitoring. Kochhar thinks that a WSN has the potential to bring a green revolution like scenario (Kochhar et al. 2019). One of the most important measures is greenhouse monitoring, to ensure the stabilization of the environment. Gao developed monitoring system using TinyOS to monitor and measure environmental parameters including light, temperature, and humidity. The system can gather, spread and control of the information automatically (Gao et al. 2011).

Crop protection

WSN offers high resolution temporal and spatial data in real-time and long term, to contribute to on-farm decision making, the data basis at microscale (Gommes et al. 2010). WSN application for crop protection to divert animal intrusions in the agricultural land. The farms near the forest are exposed to attacks of wild animals which is decreasing the income for farmers. WSNs are used for crop protection, have sensors which activate nodes equipped with sound generating devices, light flashers, and RF module (Bapat & Kale et al. 2017).

Viticulture

Beckwith deployed a WSN with 65 nodes using multi-hop approach in a vineyard for half of the year to collect information the most important for the production, heat summation and potential frost damage (Beckwith et al. 2004).For viticulture are measurements such as daily temperature profile, bunch temperature, soil water, leaf wetness and solar radiation very important, and WSN can measure all these important aspects (Matese et al. 2009).

Vehicle Guidance

Charles and Stenz et al. (2003) deployed an autonomous tractor to spray fields during the activity, the tractor drove fully autonomously at least 90% of the time and could be controlled by a supervised through a radio link. In Spain, an autonomous guide tractor was developed to spray citric and olive trees fields. A user-friendly visualization agent for human operators was created to remotely monitor and supervise unmanned tractors in a field via WLAN (Ribeiro et al. 2003).

Animal production

Habitat Monitoring

In 2000, Mainwaring proposed a system architecture to monitor seabird nesting and behavior. The system allows users to gather information online without disturbing the birds' life and schedule. The guidelines of habitat monitoring kit are created for the further usage of other researchers and scientists in other fields (Mainwaring et al. 2002). Murad developed and proposed a poultry monitoring system based on web application, so users can monitor poultry, temperature, and humidity of the chicken (Murad et al. 2009).

Transportation

Gebresenbet et al. (2003) and Geers et al. (1998) projected a monitoring system for an on-the-road monitoring for animals during transportation. The sensors were installed in the animal compartment to identify the animals and to monitor the air-quality, vibration, and animal behaviors. AGPS provided the location of the vehicle. A data was transferred to service center via the GSM network. The program has been stated to have significantly improved animal health during handling and transport.

Animal Feeding Facilities

To maintain optimal animal health, it is important to monitor climate related variables inside of an animal house. The most important variables are temperature, relative humidity, brightness, noise, and ammonia content in the air. (Pessel and Denzer et al. 2003) developed a portable, mobile instrument to measure these variables, transferred the data wirelessly to a PC through an infrared data.

Forest monitoring

To ensure long term forest autonomy, it is important to implement a monitoring system responsible in providing effective monitoring for its environment (Tao et al. 2009). In 2012 a Slovakian team used a WSN as a main tool to guard the forest. People nowadays are using forests as a source for income or they own good and it is not always right, they do not know how to work with trees and making mess and decrease the forest area. The network was based on sound detection, to detect sound of chainsaw (Papan et al. 2012).

Food processing

Food packaging

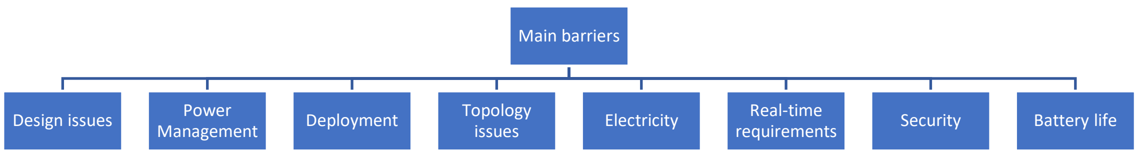
A study aimed at inexpensive, disposable RFID biosensor tags used for history checking on food products and contamination and inventory control was conducted. The biosensor was based on an acoustic wave platform and was used to detect bacteria (Wentworth et al. 2003).

Food inspection

Najjar et al. (1997) created a device (handheld PC) to check a food processing plant for food processing plant consistency inspectors. The system was able to complete the form and send data to plant manager's computer and was handled by inspectors.

4.2.8 Wireless Sensor Network barriers

Despite enormous potential which WSN brings into agriculture and different activities which is described in the thesis, it still comes with some disadvantages which are described below. The disadvantages or challenges of WSN are security, battery life, communication speed, price, and deployment. The problem with WSN and its security is vulnerability to be hacked (Raju et al. 2018). The second disadvantage is a battery life. Depending on a capacity of a node's battery, nodes must be charged at regular intervals. The energy problem is also connected with the load balanced clustering and routing problems (Dixit et al. 2014). The third disadvantage is communication speed which cannot be simply compared to wired, plus it is less stable and have more data losses (Raju et al. 2018).



Graph 2. Main WSN barriers

Design issues

Harsh or uncontrolled environment can lead to nodes to become faulty and unreliable (Akyildiz et al. 2002). A WSN deals with task and data should be proceed as fast as possible so an operator can react immediately (Dixit et al. 2014).

Topology issues

A common problem in developing countries is the availability, there are regions where either node is not available at all or available nodes cannot participate in the network for different reasons. Different networks need different types of sensors consist different hardware which can be sometimes challenging to buy due to geographical location (Dixit et al. 2014).

Challenges in electricity

Huge barrier of a WSN is a need of electricity, according to Our World in Data website, in 2016 around 13% of the world did not have access to electricity. This problem is pronounced in developing countries, mostly in Africa countries. There are only 6 countries with share of the population with access to electricity over 90% and the majority of countries are under 50%, the worst situation is in Chad, South Sudan, Central African Republic, Burundi, Malawi and Liberia (Ritchie et al. 2020).

Challenges in real time

WSN main task is to deal with real world environment. The importance of pace of data spread is very important and must be delivered as fast as possible so appropriate data handling and tasks can be made. The majority of WSN are not capable to meet real-time requirements. Numerous other activities, including data transmission, data fusion, target and event detection and classification, query processing, and security, should also meet real time constraints. It is not only important to establish real-time protocols for WSN but also to establish related analytical techniques (Dixit et al. 2014).

The wireless sensors are generating massive data and have the potential to overwhelm and without quality process data are useless. Security problems need to be solved; the WLAN security crisis may serve as an example. Complexity and excessive cost for coverage in large fields prevent fast adoption. Power supply is always a great concern for wireless systems. Lack of experienced staff for troubleshooting (Wang et al. 2006).

Challenges in power managements

Wireless sensor network big advantage is low-cost deployment but on the other hand, the energy is a big issue and will last for some time, because of slow progress in developing battery capacity, and batteries in bad environment tend to not be able to last for long time and needs often change (Dixit et al. 2014).

Challenges Network Scale and Time-Varying Characteristics of WSN

Under severe energy constraints, sensor nodes operate with limited computing, storage, and communication capabilities (Duato et al. 1996). Based on network, the density of nodes may vary widely from sparse do dense. To self-organize and conserve very important energy, nodes are dynamic and highly adaptive.

Challenges in management at a distance

Sensor nodes must be deployed as suitable sink in a central house at the center of a sector. Managers or operators are having a tough time personally running the network. The structure will also include an indirect method of remote control / management (Dixit et al. 2014).

Challenges in security

Security, as already mentioned, is a major problem. A commonly used term often encompassing security, honesty, anonymity, non-repudiation, and anti-playback characteristics. The greater the reliance on the data provided by the networks, the greater the possible risk of safe information transmission in the networks. Several cryptographic, steganographic and other techniques are used which happen to be renowned for the safe transmission of various types of information over networks. In this segment we discuss the basics of network protection that you bet the techniques are intended for wireless sensor networks (Pathan et al. 2006).

Challenges in deployment

Deployment can be sometimes a labor-intensive witch increases deployment cost and cumbersome task as environmental influences (Beutel et al. 2009). When it comes to deployment, it is cheaper in case of a WSN, but it is more difficult to deploy and configure whole network. There are plenty of signal interference, walls, large distances, cattle, plants and trees, vehicles etc. (Tiwari et al. 2015). The deployment of WSN can be very challenging and at the same time, it is very important. There are many aspects which should be considered while deploying the WSN. An overall planning, considering the segmented land structure, farmer requirement, location, rainfalls, wind, wild animals, range etc. are required for attaining success in bringing automation in agriculture and farming domain. (Ojha et al. 2015).

Challenges in physical limitations

Another problem is vulnerability for WSN is to be stolen. If it is mounted in the nature or in public spaces, it is highly vulnerable to capture and vandalism. Physical security of sensor nodes with tamper-proof material increases the node cost (Khichar et al. 2010).

4.2.9 Advantages of Wireless Sensor Network in Agriculture

There are lots of various options to gather information in agriculture for establishing better agricultural practices in animal and crop production. Wireless Sensor Network is recognized as a strong technology to gather and process data within the agricultural domain with low-cost and low-energy consumption. WSN offers a high spatial and temporal resolution to observe crops through sensor nodes deployed across the field (Culman et al. 2015).

WSN does not have fixed infrastructure and is flexible, so if needed, some nodes can be added or removed or whole network can be changed very quickly. It is also suitable to be used in cases of places which are non-reachable like in mountains, over the sea, deep forest, or different areas. Implementing phase is cheaper than wired network and avoids a lot of wires and possible breakage of wires. The whole field with sensors can be accessed by using a device with data from the sensors (Tiwari et al. 2015).

It assists and improves work performance both within the field of industry and our existence. Wireless Sensor Network has been widely utilized in many areas especially for surveillance and monitoring in agriculture and habitat monitoring. Environment monitoring has become a very important field of control and protection, providing real-time system and control communication with the physical world. An intelligent and smart Wireless Sensor Network system can gather and process an oversized amount of knowledge from the start of the monitoring and manage air quality, the conditions of traffic, to weather situations (Othman et al. 2012). High-density data in terms of your time and space is required for planning within the agriculture sector, hence, observations of the physical and biological variables are required at the microscale (less than 100 m) with a timescale of seconds to hours (Murthy et al. 2010).

Growth rates of freshwater demand from the agriculture sector are unsustainable (Culman et al. 2015). Projections indicate that from 1999 to 2030 irrigated land will increase 33% but from 2003 to 2030 irrigation water withdrawal will increase only 14%, so there is an expectation in improving irrigation efficiency (Culman et al. 2015). Inadequate use of pesticides causes environmental degradation, loss of biodiversity and pollution (Culman et al. 2015). Wireless Sensor Network is a very important and key technology in Precision Agriculture to extend the productivity, water resource monitoring, soil quality and its strength characteristics monitoring (Kumar et al. 2018).

In developing countries electricity supply is rather low which leads to basic harvesting and farming methods. Electricity is needed to run more advanced methods. WSNs needs some electricity, but the majority of WSN are based on batteries which does not require electricity supply, but often replacement and a different approach to data review.

Since in the developing countries poverty is higher than else, the cost of agriculture method is important. Wired networks are way more expensive than wireless. According to CIO United States, deploying a wireless network can save up to 50%. An example from CIO a deployment of a wired network in a five-floor building with 100 users a floor would cost US$300,000 (requiring cabling for 140 points and three 48-port switches) while the cost of wires is only US$120,000 (cabling for 30 points and one 48-port switch (Merrett et al. 2013).

4.2.10 Is Wireless Sensor Network for Developing Countries

After all, is WSN in Developing Countries relevant? As it was mentioned before and proved with official data, the electricity supply in developing countries especially in some parts in Africa are rather very low and for WSN electricity is important, but here also come its big advantage. There are several factors or rather problems. The main challenges are deployment, knowledge, and cost. All these three challenges are intertwined. Without knowledge it is very hard to even deploy WSN and also will take more time to do. Time is equal to money, the cost is growing with a little knowledge, also deployment itself is very important step, and bad network set up can cause problems or additional future cost. It is better to pay a specialist to deploy the networks, to make it efficient but on the other hand it adds extra cost, especially in rural remote areas where the density of educated people is close to zero. The access to knowledge also because of electricity is minimal and for many people zero. The knowledge is not needed just during the first phase, but also needed to manage data, and deal with possible problems, from easy fixes of HW to reprogramming of code, changing data storage or information spread. Another challenge is availability. A WSN components both HW and SW is not something, which can be bought at your local grocery, and without access to internet people will not have a clue that something like this exists.

But on the other hand, the majority of WSNs are based on batteries. Which brings a huge potential since it is possible to deploy rechargeable batteries based on different types of energy harvesting methods. Unfortunately, it brings again additional cost, but compared to wired network cost will be still smaller. Some projects need electricity to review data, but not all the projects, some projects have different purposes and except energy for the network itself, there is no need to have constant electricity.

4.3 Wireless Sensor Network in Agriculture of Developed Countries

The following chapter is focused on real examples and possible solutions of WSN within agriculture of developed countries. WSN technology can be applied for both animals and crop production. In past years, the technologies have been rapidly growing. The goal of modern agriculture systems is to connect all electronic devices together. Fortunately, the system can be connected wireless and there is no further need to use wires. In case of a big field, using wires is not practical, very expensive and can be destroyed. The reason why I chose these cases is their simplicity, it is easy to understand and how a WSN can contribute.

4.3.1 Animal production

4.3.2 Monitoring and classifying animal behavior using ZigBee-based mobile ad hoc Wireless Sensor Network and artificial networks in Poland

Introduction

In modern food production the animal welfare is extremely important part. Animal behavior provides dependable information about animal welfare, health, and product quality. The good animal wellbeing is beneficial for both consumer and producer. Just during writing this thesis there was a report about imported meat form Poland to Czech Republic from ill polish cows on seznam.cz. It is very important to monitor cattle during all stages of processing and life of cattle.

A consumer more likely will buy a beef cut from known resource with good results than from an unknown producer or even worse from a producer with bad reputation or history. Knowing something about the background of a product is important for a daily consumer, but more important for restaurants or bigger consumers.

Insufficient levels of animal welfare can significantly affect animals in many for production important aspects. Inadequate levels of animal welfare can significantly affect the animals' growth, reproduction and survival rate, which in turn may compromise the quality and safety of the produced food (Nardone et al. 2004). Improving farmed animals' welfare positively affects animal pathology and disease resistance (Mepham 2000). Numerous studies have proven that the behavior and physiological responses of farmed animals provide trustworthy information about animal health status and welfare (Mepham, 2000; Nardone et al. 2004).

Therefore, the design and deployment of a monitoring system capable of measuring behavioral parameters (animals' spatial distribution, movement velocity or head movement) and transforming them into the corresponding behavioral modes (such as grazing, lying down, standing and walking) has been the focus of several recent studies (Oudshoorn et al. 2007; Schwager et al. 2007; Umstatter et al. 2006; Ungar et al. 2005; Nadimi et al. 2008).

Cow behavior can be classified into two classes, moving and stationary. The behavioral parameters of a herd of animals can be measured using different types of sensors and different strategies. Global positioning systems (GPS) are the most popular systems deployed in outdoor environments to estimate the temporal and spatial distribution of herds of animals (Butler et al. 2004; Oudshoorn et al. 2007; Schwager et al. 2007). The use of accelerometers and offline data loggers attached to the hooves of dairy cows were investigated by (Munksgaard et al. 2005).

The objectives of this study were the following:

- establish a mobile ad hoc wireless sensor network to measure and monitor behavioral parameters of each individual animal (sheep) in a herd
- enhance communication reliability within a patch network
- classify the behavior of each individual animal into five different modes (i.e. grazing, lying down, standing, walking and other modes) using an artificial neural network.

Monitoring the behavior of the herd was of interest when the herd was in the field (not inside the barn) but dismounting the sensor nodes during the experimental period to update the sampling rate or to renew the batteries was not possible. The network sampling rate was adjusted during the experiment. When the herd was in the field, the sensor nodes over the air to disseminate the packets once per second and once per hour when they were in the barn (Nadimi et al. 2012).

MANET

For this project, the MANET Network was used. MANET is a mobile ad hoc wireless sensor network also called a mobile mesh network, is a self-configuring network of mobile devices connected by wireless links. There are four basic components in MANET:

- wireless modules or sensor nodes (an assembly of distributed or localized sensors)
- interconnecting network
- base station (central point of information clustering)
- set of computing resources at the base station

They act as a gateway between the sensor nodes and the end user. The central points of data clustering are one or more distinguished components of the MANET with more computational, energy and communication resources than the sensor nodes (Nadimi et al. 2011).

System description and deployment

The project is running on a 2.4-GHz ZigBee-based mobile ad hoc wireless sensor network, using multi-hop mesh networking, relay nodes and handshaking communication protocol. Achieving reliable communication, low energy consumption and a high rate of data packer reception. The IRIS modules were provided with improved communication and memory features. A wireless module contains of a low-power microcontroller, analog to digital (A/D) converter, radio, antenna circuit, battery and a set of sensors. The communication was also improved up to three times, and the direct sequence spread spectrum radio with a 250-kbps data rate resistant to RF interference was utilized. The program MICA memory was increased up to two times. To evaluate the animals' head actions, MTS310 sensor boards equipped with dual-axis ADXL202 accelerometers were installed.

In the research, every single sensor in the patch network acted as full function device (FFD) in multi-hop IEEE 802.15.4 ZigBee based mesh network. To achieve the highest packet delivery performance, the radio channel 26 associated with frequency band 2.48 GHz was selected because several studies have demonstrated that the RF interference between ZigBee and Wi-Fi can be avoided at this radio channel (Wang et al. 2006; Nadimi and Søgaard et al. 2009). In the installed mesh topology, all nodes acted as routers, which provided easy network extensibility without requiring any line power. The designed mesh network also was able to self-forming, self-healing, and optimized for dynamic routing.

Once the behavioral parameters are measured and transmitted over the network to a central base station, the data need to be processed and transformed into the corresponding behavioral mode. To perform data processing, different methods, for example the classification tree, k-means classifier, and multiple-model adaptive estimation approaches, have been suggested by (Umstatter et al. 2006; Schwager et al. 2007, Nadimi et al. 2008; Nadimi and Søgaard et al. 2009). Estimating the power consumption of each sensor node within the patch network was important, the power supply for each sensor node was limited.

The experiment was carried out at Bramstrup on Fyn Island in Denmark over 5 days with eleven sheep for 9 h per day (starting at 8:00 AM and terminating at 17:00 PM). A wireless sensor measuring and transmitting the head movement acceleration measurements was installed on apiece sheep in the herd with a sampling rate of 1 Hz. Considering the sampling rate, number of animals and length of the project: $5_{\text{days}} \times 11_{\text{sheeps}} \times 9_{\text{hours a day}} \times 3600_{\text{samples per hour}}$. 75% of the data received (1,336,500) were used, and the rest 25 % (445,500) were used for the testing and performance evaluation of the trained neural network.

The initialized ANN classified the behavioral modes into two basic modes: 1 active and 2 inactive, and into five “smaller” modes: 1 grazing, 2 lying down, 3 standing, 4 walking, 5 others. When only two behavioral modes, active vs. inactive were the most important and in the interest. The designed ANN was trained to classify the ‘‘grazing’’ and ‘‘walking’’ modes as ‘‘active’’ and ‘‘lying down’’ and ‘‘standing’’ as ‘‘inactive’’.

Results

The average percentage of the data packet loss of all the sensors nodes was 14.8%. To check efficiency of the performance of the handshaking communication, protocol and the successful use of acknowledgment messages, enhance communication reliability, calculating the number of retransmitted data packets were used. According to the table, the sensor nodes close to the gateway had lower transmission rates. The low percentage of data packet loss (14.8 %) in the patch network compared to the other studies 27 %, 30 % and 35 %, as reported by (Nadimi et al. 2008; Ipema et al. 2008) was a result of the proper selection of the routing protocol, communication protocol and network structure. In the study, each sensor node in the network was FFD, and multi-hop routing was successfully performed. Using a multi-hop routing protocol to enhanced packet delivery performance, also lead to less energy consumption. The battery of the sensors lasted the entire experiment, which was 5 days, whereas in other study cases the power source needed to be renovated at the end of each tested day. The batteries of the relay nodes were renovated several times during the experiment due to the network congestion and high rate of data traffic on them.

To categorize the behavior of a sheep in the flock, an MLP-based feedforward backpropagation neural network with five layers (one input layer, three hidden layers and one output layer), and contained 10 neurons, was set and trained. The best performance was achieved when the network was using the Levenberg–Marquardt back-propagation algorithm. The high-level rate of positive classification (grazing: 83.8%, lying down: 83.2%) is justified because the accelerometer measurements in the X-axes and Y-axes (network inputs) was set up to the nature of the head movements (grazing: the neck was in the vertical position, lying: the horizontal position.

To enhance the network connectivity and decrease energy consumption, the deployment of two relay nodes and the multi-hop communication and handshaking protocol among the wireless nodes resulted in high communication reliability and low energy consumption.

4.3.3 Plant Production

4.3.4 The road towards plant phenotyping via Wireless Sensor Networks in Turkey

Introduction

Plant phenotyping (PP) is the identification process of the environment effect and of the genetic code differences on the phenotype. PP is used in both forward and reverse genetic approaches to obtain advance crop improvement and/or obtain fundamental insights (Yalçınkaya et al. 2000). Whole concept of PP is nothing new. It has been used for over 20 years now and is generally correlated with the application of crop production input elements based on the assessment of the flexibility of need for a specific input (Heuvel et al. 1996). Back in the days, before oil and gas era, phenotyping was vital for small scale farming, herding, and fishing. The Turkish government is trying to revive the plant and animal production to be a self-sustained country with less imported food. They have recently issued number of projects: medical phenotyping, Mediterranean fever in Turkish population, and Alpha-Thalassemia Mutations (Yalçınkaya et al. 2000). According to the Turkish government, in 2015 food supplies imports were decreased by 7.1%, deploying and using WSN can decrease imported food even more.

The agriculture is facing major obstacles. Population growth is rapidly growing faster than the agricultural production. To increase the agricultural production, a possible solution is the application of a novel farming model, the models must be high economic efficient, optimal use of scarce resources, minimum impact on the environment, and sustainable (Berckmans et al. 2004). A key solution can be implementing advanced farming management systems (AFMS) to measure, observe and respond to inter and intra-field variability in the farms. To build AFMS, PP is one of the key technologies, which can introduce a significant increase to the poultry, livestock and crops productivity by effectively managing the available resources and providing the optimum quantities of nutrition, temperature, humidity, sun exposure, wind and etc. The integration of PP leads to better management of the farms, increase output and decrease input, but its biggest con is the price, all records had to be processed in laboratories.

More recently PP has evolved to be used with other advanced technologies to achieve higher output for instance with GPS, field mapping, yield monitors and record archiving, planting equipment and variable rate application. PP should be understood as the gathering and effective use of information obtained from the field. The future of PP is not to replace human beings but help them to increase the capability and requirements for highly trained farmers and engineers. Recently a couple of farmers after implementing PP (in case of animals it is called Precision Livestock Farming (PLF)), with advanced technologies achieved higher income and efficiency. Depending on needs of a farmer, but PLF records information of individual animals mainly: age, pedigree, production, growth, health status, feed conversion, temperature, etc. (Berckmans 2004).

Plant phenotyping examples

In 2014, authors Mutka and Bart reviewed status in plant disease phenotyping and proposed future possible directions that would hasten the development of resistant crop varieties (Mutka and Bart 2004). *In Fig. 1(A) Pseudomonas syringae infection on Arabidopsis thaliana with gray water- soaked lesions surrounded by chlorosis. Fig. 1(B) Early-stage Xantho- monas euvesicatoria infection on pepper with small water-soaked lesions. Fig. 1(C) Xanthomonas oryzae pv. oryzae infection on rice with grayish green water-soaked lesions coalescing into yellow streaks. Fig. 1(D) Xanthomonas axonopodis pv. manihotis infection on cassava with dark water-soaked lesions that are spreading and leading to leaf wilt* (Al-Turjman et al. 2018).

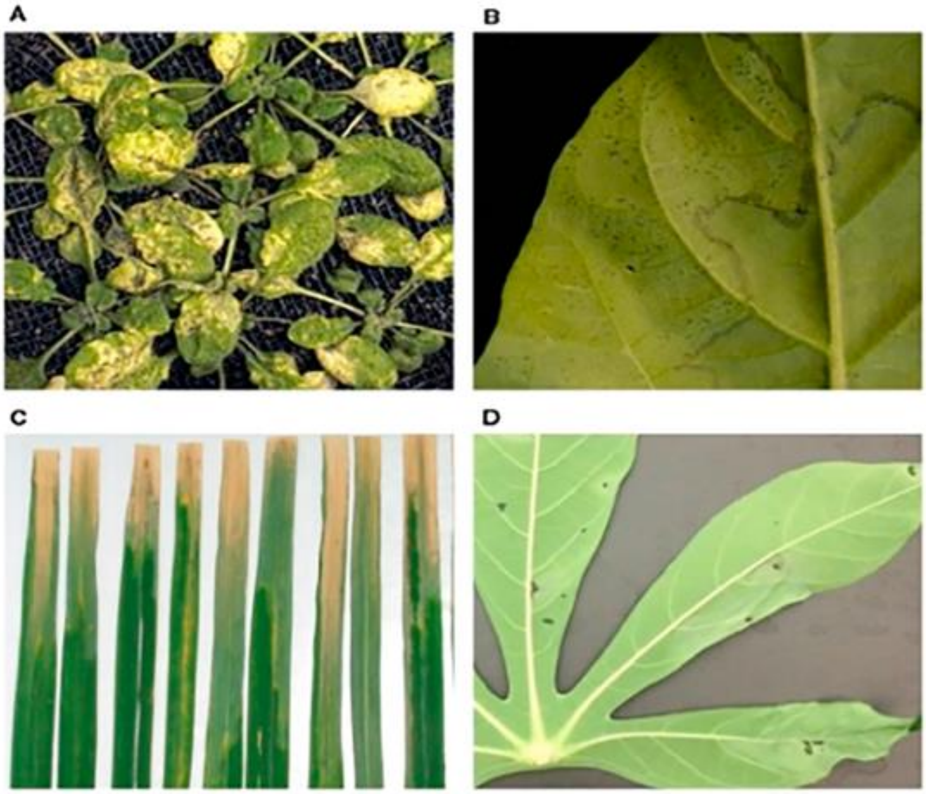


Figure 5. Examples of disease symptoms caused by bacterial plant pathogens discovered by phenotyping (Mutka and Bart 2014)

In 2014, Li tested a range of different wavelength imaging techniques in plant phenotyping (see Fig. 5) (Li at el. 2014). Physical properties, knowledge of depth, robust technology, and pipelines for image analysis are prerequisites for the imaging sensors applied to plant phenotyping to facilitate the collection of phenotype data. Visible imaging for shooting biomass estimation and 2D growth patterns (individual leaves to canopies) has been used efficiently for breeding crops. Fluorescence imaging was used mainly for the detection of foliar disease and for the detection of plant water status thermal imaging. A reconstruction of a 3D surface involves calibration for the measurement of biomass.

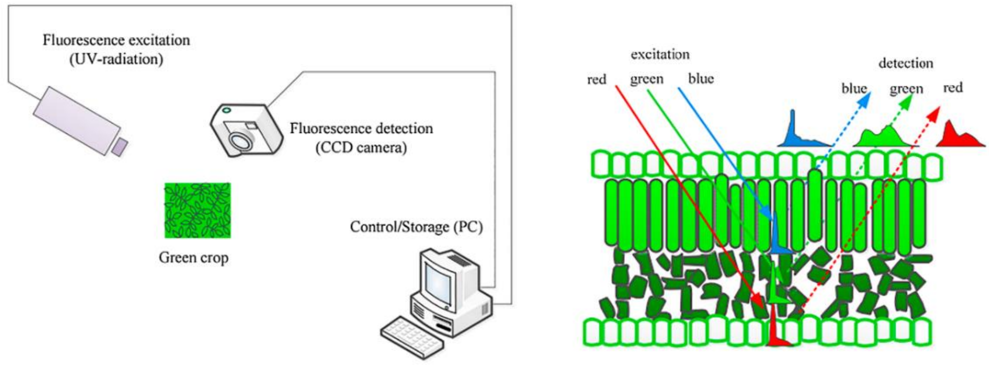


Figure 6. A scheme for the multi-color fluorescence imaging system and the chlorophyll fluorescence emission of green leaves and induced blue, red and green excitation light **Source:** (Li et al 2014)

Wireless Sensor Network design aspects in phenotyping

The main purpose of installing a WSN technology to a PP project is the ability to handle remote monitoring and control over a large amount of sensing and monitoring devices under variable density and conditions of mobility. The WSN Network should be able to work under certain constraints for instance low energy consumption and power transmission, using reliable and cost-effective network techniques. The architecture of the network should be durable to prolong its lifetime and be able to deal with various unpredictable elements at both network deployment and operation stages.

Wireless Sensor Network prototyping and implementation in PP

WSN deployment is very important step in every WSN project and is often overlooked or not investigated enough by people implementing the technology. Node placement can have a profound effect on connectivity, coverage and reliability (Li et al. 2014; Al-Turjman and Hassanein 2012; Al-Turjman et al. 2013). However, the coverage area in the 3D space can change significantly overtime in PP applications, resulting in a failure of an optimized 2D deployment strategy (Ishizuka and Aida 2004; Younis and Akkaya 2008). Some of the factors which can cause a significant change are plant growth in different directions, animal migration over seasons, concertation of gases, etc. To achieve longer network life, installing 3D strategies is a right way, by deploying 3D can also provide higher degrees of freedom for node placement, but it has also its cons which are covering very large space which is challenging thus optimization of node placement which is computationally overwhelming. A new metric shall be developed to precisely evaluate the performance of WSN and to measure the lifetime. To address the issue with overwhelming, a 3D grid-based deployment strategy was proposed (Al-Turjman et al. 2008).

To be energy efficient, network is put the mobile node into sleep mode during its idle listening or overhearing time, otherwise it leads to waste of energy. Energy consumption can be also reduced by decreasing MAC overhead and transmission crashes among nodes (Al-Turjman, Alturjman et al. 2018). One approach is to let a node contends to transfer a batch of packets within required lag bound only once, followed by assigned contention-free channel time.

Standard sensors used for PP applications contain soil moisture, relative humidity, temperature, and gas (carbon dioxide (CO2), methane (CO4), carbon monoxide (CO)) detection sensors (Al-Turjman et al. 2017). Fusion field-programmable gate array (FPGA) module is designed for PP to build the necessary sensor nodes in WSNs. Flash availability will allow low-power sleep modes to be used instead of the wake-up reconfiguration expected in other FPGAs types. In order to identify general yield trends within fields, yield maps can be produced in real time after data collection. Such maps allow in-field spatial variation to be recognized for variable rate applications, enabling farmers to estimate the economic revenues of various farm management plans. In addition, they are important for field-level developments such as land leveling, irrigation systems scheduling, drainage, fence construction, and off-field data usage. In Plant Phenotyping, the information provided is a valuable resource because it allows for real-time decision-making on critical issues, for instance setting water conservation policies while providing adequate irrigation and selecting the right time for farming activities such as planting, harvesting, determining fruit maturity, etc.

Plant Phenotyping project conclusion

It is important to stress that PP is attracting growing attention from the governmental and industrial sectors in several countries around the world, including the United States, Canada, Brazil, Malaysia, India, and many other countries. A significant effort and emphasis in such countries is aimed at researching and incorporating PP technologies. A significant effort and emphasis in such countries is aimed at researching and incorporating PP technologies. Many industry leaders like IBM, AG Leader, and Precision Planting are also interested in PP. Incorporating state of the art technologies like internet of things and cloud computing is the immediate next step towards involving WSNs in large-scale PP deployments. As a future work, we anticipate the immediate next steps to include field studies with large-scale deployments, data collection and mining, as well as incorporating state of the art information technology such as things Internet and cloud/edge computing to further enhance performance. In addition, the evaluation requirements for the performance of any underlying PP network will be based on custom node energy efficiency and MAC/Routing algorithms, as well as other well-known service quality (QoS) related measures applicable to agricultural applications for instance delay and reliability.

4.4 Wireless Sensor Network in Agriculture of Developing Countries

Due to the price, knowledge and electricity situation, the use of WSN is more limited compared to the developed countries. Despite the barriers, there is an increasing number of WSN projects in recent decade.

4.4.1 Animal Production

4.4.2 A Conceptual Framework for Implementing a Wireless Sensor Network Based Cattle Recovery System in Case of Cattle Rustling in Kenya

Introduction

The livestock in developing countries is very important, and it is not different for African Kenya, with additional social importance. The livestock farming main purpose is certainly food and secondary income generation, but it is also important for the social status (as a symbol of wealth). In Kenya we can find two types of farmers like everywhere else, commercial and subsistence farmers. The cattle farming is facing a lot of challenges and one of the main challenges in developing countries is rustling for both types of farming.

In November 2012 more than 40 policemen were killed by rustlers (Momanyi et al. 2012). The main reason of being killed is because of poor tracking techniques.

The main goal is to reflect benefits and features of the tracking technology using mobile communication, WSN and advancements in animal identification. Previous similar studies were used to make even more precious technology, but none of previous study was focused on cattle rustling.

Animal Identification and Tracking

Despite all earlier projects/experiments, which were done in constrained environments, the actual project is running in various types of environments. In case of the other experiments, where are normal collars or a mounted device used, in this case it is necessary to choose different approach, because it can be easily removed by rustlers (left on ground, destroyed, a trap). Another approach can be the video sensors, video sensors connected to strategically deployed nodes, which requires a presumed path the cattle rustlers would use, which is not efficient, because it cannot be predicted and if so, rustlers can use a different path next time after being captured.

To identify the animal, we need to link the identification and registration of an animal individually. *Tracking is the capacity to isolate the current estimated location of an animal using the identifying device* (Wamuyu et al. 2017). To successfully track the animal, real-time identification is needed to identify the animal's location. *It is easy to identify the position of an animal in a WSN as the position of the sensor node, where the animal would be hosted, is known in the sensor network* (Ghumares et al. 2016).

Proposed Framework

The system proposed for cattle tracking and recovery contains a rumen sensor module, a WSN control unit, a Worldwide Interoperability for Microwave Access (WiMAX) gateway, WiMAX base stations and a data center. TinyDB is used for database.

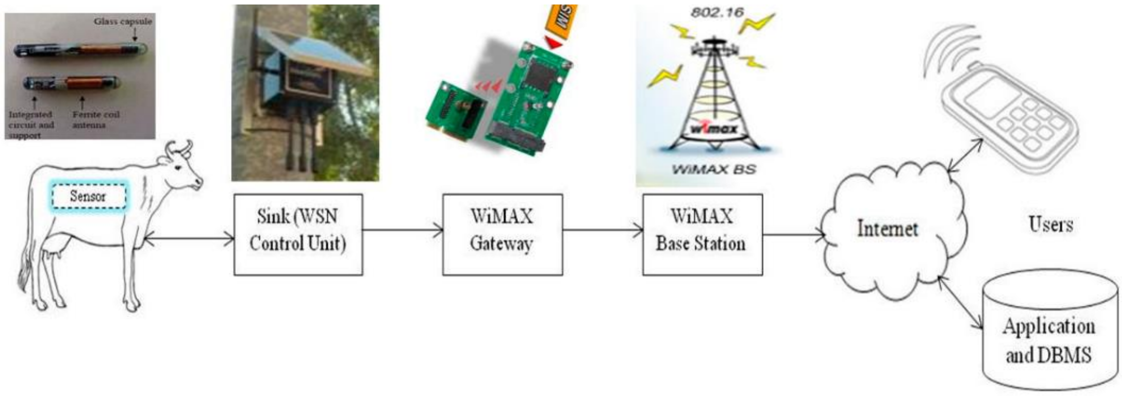


Figure 9. Basic system structural framework

Source: (Wamuyu et al. 2017)

The figure above is a basic system structural framework, first the rumen sensor module secures the real-time location data of the animal and transmits the data to the wireless control unit. The WSN Control Unit (WCU) module controls the data received from the sensor and sends it to the WiMAX Gateway. The proposed gateway is Waspmote with a dedicated socket for solar panel input, hardware for 3G + GPS module and is able to communicate from 7 to 12 km, and also the output will be a calculation of the location based on information received from the sensor nodes. Gateways should be deployed with a possibility to stay connected as long as possible. One of the possibilities is solar power. The Database Management System (DBMS) is used to store and review data.

To calculate the exact position of the animal, there are 3 steps included and 3 anchors needed:

- The WSN control unit transmits a message including its position and hop count field set to zero
- The anchor gets positions of other anchors as well as the minimum hop counts to other anchors and transforms the hop count value into a physical distance
- The unknown node location is estimated by the multiliterate method utilizing the distance estimations from at least three anchors

Simulation and Results

To be able to evaluate effectivity of the project, simulation tests were done. To build the simulation, MATLAB Simulink software was used. The batch data was average localization error of 100 experiments.

Table 4. Default simulation configurations

Parameters	Default Values
Network Area	1000 × 1000 m
Simulation Time	180 s
Mobile target velocity (λ)	1~10 m/60 s
Range Nodes Propagation Range	R = 300 m
Number of Nodes	200 (10% of 2000 animals)
Placement of Nodes	Random
Number of Gateways	11 (Vary gateways between 5 and 15)
Placement of Gateways	Deterministic (but random in this case)
Mobility Model Used	Random Walk Mobility Model

In the network area the population of animals is 2000, 10% are having the animal bolts (200 sensor nodes). To calculate the location also 11 anchors were installed. The distribution and position of all sensor nodes and anchors are random. But good distribution has a high impact on the effectivity.

Conclusions and Future Work

The paper describes ongoing work to facilitate quick and safe recovery of stolen animals and to defeat rustling using WSN. The future plans contain a real testing a possible deployment. The boluses have several benefits and can also be used different ways in case of animals.

4.4.3 Plant Production

4.4.4 Monitoring system for agronomic variables based on Wireless Sensor Network technology on cassava crops in Colombia

Introduction

The aim of this project is to map the opportunity of WSN in cassava productions. Many researches have been already using the technology, for example Italy and France on grape crops and water consumption optimization, mango crops production and greenhouses in India, Spain in cabbage production, in cotton plantations in China and many more.

Combining knowledge from agriculture and information technologies comes precision agriculture, based in field technification brings enough tools to agriculturists *to keep control and monitoring of the variables that influence the correct development and traceability of their crops in real time* (Cama-Pinto et al. 2014; Montoya et al. 2013). This situation contrasts with the fact that many farmers do not have any information system, and they only use an empirically proven technique of trial and error. Cassava is the world's sixth largest staple crop with annual production of 185 million tons after rice, wheat, maize, potato and sweet potato, making Colombia one of the top ten producers worldwide and second in Latin America behind Brazil.

This study, in the Colombian Atlántico Department, we developed a WSN-based monitoring system for agronomic variables applied to cassava crops. The purpose of this tool is to provide information in real time, to measure humidity and soil temperature. The Atlantic coast is one of the regions with higher cassava production (Tofino et al. 2015). The temperature parameter has to be between 20 and 30°C, with the optimal being 24°C, although experiments have shown that it can grow at temperatures between 16 and 38°C and its growth is stopped below 16°C. Recommended thresholds were not found for the second parameter, only that it does not allow ponding (Sánchez and Aristizábal et al. 2007).

Materials and methods

RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) is a dynamic routing protocol based on Destination Oriented Directed Acyclic Graphs (DODAGs). A DODAG is a graph based on nodes and links forming the path to the network root, which is basically the sink or network coordinator following a many-to-one scheme, facilitating the sensor deployment regardless of the position of the nodes. Beside this, takes into account the trade-off of energy efficiency, networking performance and is designed to adapt to TCP/IP (Tian et al. 2017; Estévez et al. 2016; Cama et al. 2013).

Contiki is an open source operating system using C programming language (IoT, WSN) and can be based on microcontrollers with a low requirement of energy consumption and low processing capacity (2 KB RAM and 40 KB ROM) (Raju et al. 2013).

The Z1 nodes capable to work with many major operating systems also including Contiki and one of the most popular OS TinyOS. Supports analog also digital sensors. It is equipped with 16 MHz microcontroller, 8 KB RAM, 92 KB of flash memory, accelerometer, a temperature sensor. Z1 nodes can be powered by batteries 3.3V or 5V u-USB port and does not require additional HW to program.

To review the data and store them a web application is using client server XAMPP, data was stored in a MySQL server using PHP to offer a graphical interface.

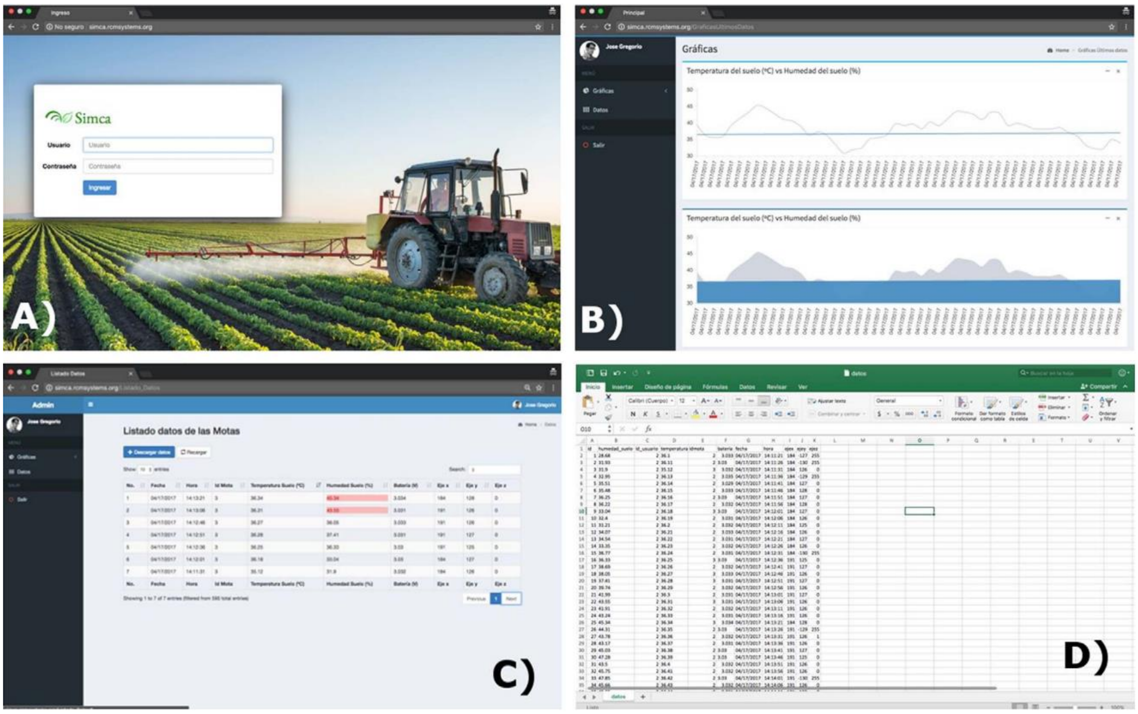


Figure 7. User interface

Results and analysis

To test the best and the most efficient connectivity, 10 tests were carried out with duration of 10 min. and 200 packets sent from the transmitter to the receiver. The Received Signal Strength Indicator (RSSI) test showed that the best connectivity is 10 m without the line of sight and 50 m with the line of sight, in case of 100 m 28 packets out of 200 were lost.

Another test showed important difference between single and double hop connection, single hop time range start in 13.4-16.65s while double hop 192.51-236.15s.

For the project the network deployment model was a regular node distribution using tessellations defined by regular polygons in case of 2D. The group of nodes are surrounding a central node through different depths. Tessellations are formed by polygons (triangles, squares and hexagons).

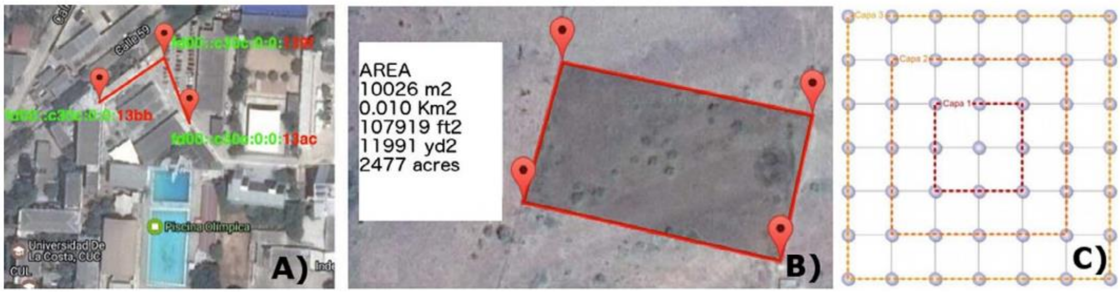


Figure 8. (A) Convergence Test Deployment. (B) Evaluation area for the network deployment model. (C) Node Distribution in layers for grid tessellation (Stark et al., 2013)

The location of the project was located in municipality of Manatí, south of the department of Atlántico in Columbia (10°26′24″N 75°02′43″W).

Network coverage is analyzed on two, three and four deployment layers, this may differ according the size of the crop and the desired density of nodes in the network. For convenience of the farmer also for power supply requirements and other pros, the sink should be deployed in the central house.

This principle also refers to nodes located in the grid as they are at ranges of 25, 18 and 14 meters from each other, making the dimensions of contact similar for any point in the network. It is necessary to remember the suggested range for cassava plants is 0.80 m between plants. To avoid plant falling outside the monitoring area, short distances are suggested for nodes.

The tests showed that, all three distances, the values of the signal at the receivers are greater than the sensitivity (- 95 dBm) which is enough to obtain communication between the Z1 motes. *With a tolerance range greater than 10 dB it is possible to obtain yields of 70–100% in the links* (Zennaro et al. 2010).

To review links between nodes and neighbors, the first test was without any vegetation, the distance of 30 m was reviewed with Radio Mobile software, the tolerance margin obtained was 31.6 dB, which is more than three times of minimum of 10 dB. The side result of the test of connection was the clearance was equal to 1.6 F1 (radio of the first zone of Fresnel), while theoretical sufficient value is 0.6 F1 (ensuring a stable link between transmitter and receiver) (Cama-Pinto et al. 2017; Zennaro et al. 2010). The second more realistic test was including vegetation. Everything kept the same, except vegetation, the loss was around 4 dB, 27.9 dB.

The tests were running during the day, at noon. The temperature was ranging from lowest 40°C to 45°C, while the soil moisture values were between 27.96% to 40%.

Conclusion of the project

All tests made with our prototype clearly show its feasibility, usefulness and viability to implement in cassava plantations. It also demonstrates that our WSN can work in optimal conditions with typical cassava crops in the Colombian Caribbean region, in field areas shorter than 50m×50 m, and if necessary, it can cover greater distances with multi-hops links using RPL protocol to provide automatic route discovery (Caicedo-Ortiz et al. 2018).

5. Conclusion

The main objective of the present thesis is to find out the potential of a WSN in developing countries and show the ability in different aspects of agricultural activities and in developed and mainly in developing countries. The importance of agriculture is vital for all human beings. It is crucial for small self-sustained farmers, but it is not less important for countries and its income from exporting agricultural goods.

The current situation in developed countries is more than satisfying. The WSN has a lot of potential and can be used for different purposes not only connected with agriculture. The technology nowadays is also used for measuring other important data in and out of cities, it can be pollutions, traffic density, access control, public lighting, parking etc. According to the data found, the WSN provides a lot of different variations how it can be used and what it will be measured in agriculture, from animal to plant production.

In developed countries, the technology is more affordable than wired network, which is very important for developing countries, because poverty level is significantly higher than in the rest of the world. Unfortunately, information spread in these countries is not very high and people are not receiving always the best education and with low accesses to the internet, farmers have very little or even zero knowledge about WSNs. The deployment is very important step. To deploy efficient long lasting network a person needs a lot of knowledge or to invite an expert company to deploy the WSN and to get basic know how which can be deepened later by self-education (scientific papers, printed books, etc.) if possible and highly recommended, but inviting an external person for deployment and know how adds additional cost. Unfortunately, the situation is very different in developing countries. There are already some projects running but comparing the number to the number of developed countries we can see it is still behind, even the trend is growing worldwide. Due to the current state of developed countries, farmers are facing several challenges why it is difficult to deploy and operate. The main challenges are price, knowledge, and electricity. Despite the availability is increasing, the price and cost are high, and majority of the farmers cannot simply afford it, even it is more affordable than wired networks. The deployment itself is very expensive, a farmer needs to buy all the equipment which already requires knowledge, deploy it which also takes some time and money and then maintain it operating. Electricity in some countries is not optimal and can be very important for a WSN, depending on a project. Some projects require a stable electricity supple while some other can run without electricity and are based on batteries and energy harvesting, which can be only possibly option for a remote area without energy supply. But batteries life is not that long and sometimes have to be switched often if they are not charged from any of energy harvesting methods which both brings additional cost. To review obtained data, a user needs a computer which also requires electricity, without constant electricity it is almost impossible, or not very efficient. During the last years, the number of projects is increasing so it is just a matter of time it will be more widespread and accessible. Each of the proposed project showed its pros and cons, where it excels and where are the limitations and problems. It also underlines a huge potential of the technology on agricultural field.

At the moment, I would say in developing countries WSN definitely can bring a lot of different fruits. The current state in developing countries does not allow farmers to fully use the technology yet for various reasons. Obviously deploying a WSN is fruitful and if there is possibility to do so, do it. The difference in economy and education is too significant now and it needs some work and years, but in the future, I believe we will see more and more farmers using WNSs. It provides a lot of pros overcoming its cost. It is just a matter of time.

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