A mobile based communication solution for monitoring remote agricultural locations

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Abstract. In this paper a method for the effective transmission of data, from a Wireless Sensor Network (WSN) in a remote agricultural location with limited connectivity, is proposed; along with a meaningful visualisation of the data at the user end to help in decision making and control of the irrigation system. The paper encompasses three main segments which are data compression, checking for network availability, and user interface. First data compression is implemented to reduce the amount of transmitted data, due to limited connectivity in the area, which is translated in low data rate and high cost of sending the data. Four different techniques are compared: Huffman encoding, Lempel-Ziv-Welsh (LZW), differential encoding, and Run Length Encoding (RLE) to carry out data compression, where Huffman encoding showed the best results when combined with differential encoding. The second phase is the handling of poor network conditions in the agricultural plant by switching between two different communication modes: Mobile data and Short Message Service (SMS). Lastly, the user monitoring centre which is a mobile application that allows the user to monitor and control the agricultural plant remotely. It includes mapping and visualization of temperature and soil moisture data and a control system to control the irrigation system. The solution presents a low-cost alternative for start-up agricultural projects in third world countries, where network instability is an issue and off-the-shelf expensive solutions are not a viable option.

1. Introduction

Smart farming is the future of agriculture where it uses modern Information and Communication Technologies (ICT) and applies it to everyday tasks of an agricultural plant. This phenomenon is taking over the agricultural field using the applications of ICT such as precision tools, sensors, Artificial Intelligence (AI), Internet of Things (IoT), big data, robotics, etc. [1].

Smart farming has the capabilities to facilitate all aspects of farming, resulting in higher production and better quality crops by giving farmers the tools to have more information about their agricultural plant such as temperature, water levels, or moisture levels to improve their decision making [1].

Smart farming can also be applied in the form of applications or programs on mobile devices where farmers can rely on having access to real-time data about the condition of their crop and based on this data; they can carry out the appropriate action they think is fit rather than relying on their intuition.

Hwang J, et al. [2] proposed a system where soil and environmental data were collected through a WSN, imaging through CCTVs, and GPS modules were used to collect information about location. The collected information is transferred to a server which contains a GPS manager to process the location information, a sensor manager to process data from the WSN, and an image manager to process information from the CCTVs. The user can preview the data through a web browser that
allows them to monitor the data processed by the mentioned components. The system relies heavily on good connectivity and has a very high cost of implementation, maintenance, and operation.

Wildeye [3] is an irrigation monitoring system that can remotely monitor all kinds of meters and sensors through a web browser or a mobile application, once logged in, the user will have immediate access to a graph for each of the connected sensors. However, it does need a stable internet connection as the software runs from an enterprise grade cloud based central database for water management.

In [4], the authors tackle this concept from a third world country's perspective where they mention how farmers in some areas of India can barely get 8 hours of electricity a day and some areas do not have access to internet, and the areas that do have access are limited to Edge or 2G connection. This solution was only carried out on simulations where they tested multiple scenarios. In [5] the authors proposed a smart drip irrigation system. The system is developed to optimize water distribution throughout the field by providing the suitable amount of water based on climate conditions. The irrigation system is controlled by an android application.

This paper focuses on the challenges involved in the transmission and visualisation of data from a WSN implemented in a remote agricultural plant located in Aswan, Egypt. Due to the land's remote location, there is limited mobile network connectivity in the area which poses a problem to data transmission. The paper proposes solutions to this problem, in addition to the steps taken to implement a user interface and control unit for monitoring this agricultural plant.

First, data needs to be compressed to a smaller size to be able to send it over the poor network conditions available in the agricultural plant. Multiple compression techniques are tested to find the optimum solution for this problem. Second, a condition is set to control how data is sent based on the network availability at the time of data transmission. When mobile data is available, only a 2G connection may be established with a data rate of 40-384 kbps. On the other hand, when there is no data connection only the basic service (calls and SMS) is available. The data transmission switches between two modes: mobile data (2G) and SMS, depending on availability. Finally, a design for the user interface is proposed, which is a mobile application that allows the user to monitor and control the agricultural plant remotely. It includes a mapping and visualization software and a control system.

2. Background

In this section, alternatives for implementing each phase of the communication solution are discussed. The best candidates are then chosen for implementation and presented in the next section.

2.1. Compression techniques

In order to be able to transmit the data at low data rates, or fit the entire data set in an SMS, data has to be compressed. This also reduces the cost of sending the data. Four different compression techniques are investigated, as possible candidates for this component: Huffman encoding, Lempel-Ziv-Welsh (LZW), Run Length Encoding (RLE) and differential encoding [6-8]. Table 1 compares between the proposed techniques, in terms of their advantages and disadvantage, in the light of our data.

2.1.1. Dictionary

Compression techniques such as Huffman and LZW require a dictionary, that needs to be shared by the sender and receiver. Generating, updating and sending the dictionary from the sender to receiver introduces overhead on the network connection. To reduce the overhead, the dictionary may be generated only once in the beginning and sent to the receiving end (the user interface) to be used for decompression, this is referred to a static dictionary throughout the paper. A static dictionary does not need to be updated and sent every time a new data sequence is to be transmitted, this may result in a degradation in compression ration if the data is non-stationary of if the dictionary depends on the values and not their statistics. A dynamic dictionary, on the other hand, is one that is updated by the sender and transmitted regularly to the receiver. This results in a higher compression ratio and better representation of the data but introduces additional traffic on the connection.
Table 1. Comparison between Huffman, Lempel-Ziv-Welsh (LZW), Run Length Encoding (RLE) and Differential encoding in terms of their advantages and disadvantages for implementing the compression component [6-8]

| Compression method   | Advantages                                      | Disadvantages                                      |
|----------------------|------------------------------------------------|---------------------------------------------------|
| Huffman              | The dictionary depends on data statistics and not on the values | Dictionary generation takes a long time            |
| LZW                  | Compression ratio is very high for long sequences | Dictionary must be regenerated every time the sequence changes |
| RLE                  | Does not require a dictionary                   | Works only when data is repeated in sequence       |
| Differential encoding| The compression ratio is very high for small changes in values | Compression ratio is very low for large values of the variance |

2.2. Data transmission
Since the agricultural plan under investigation is in a rural area, the mobile communication network will suffer from instability. In Aswan and other areas inside and outside Egypt, especially in third world countries, a vast area of agricultural plots suffer from poor connectivity, with only the basic service available, i.e. calls and SMS. The maximum size for an SMS is 160 characters only. When mobile data services are available, only EDGE or 2G data rates apply that are in the range of 40 kbps with huge fluctuations in the data rate and availability.

The data could be sent to the user interface directly or through an intermediate server, depending on the mode of communication. If data is sent through SMS, then it will reach the user directly. Whereas it will be more convenient to upload the data on a server, when data is sent over the internet through mobile data, since the user may not be connected to the internet all the time. If the data is uploaded to a server, the user can download the latest data at his/her convenience.

2.3. User interface
The user interface may be implemented as a mobile application or a web-based platform. The user interface should provide two main functions: meaningful mapping and visualisation of received sensor data and control over any automation systems in the farm, such as the irrigation system.

2.4. Scope
The scope of this paper is the transmission and representation of data from the WSN in the agricultural plan to the user. The existing WSN measures temperature and moisture in five different plots, with four moisture sensors and one temperature sensor per plot, resulting in a total of 25 sensors. The user interface is also required to provide control over the irrigation system, which is the only automation system currently installed in the plots.

3. Proposed Solution
The WSN sends the data to the fusion centre where the data is compiled. The data is compressed, on site on a Single Board Computer (SBC) that is attached to the fusion centre. The second stage is checking whether data connection is available or not. If an internet connection is available through mobile data, then the data is sent over the internet, otherwise the data is sent through SMS. The data then arrives at the user monitoring centre and the user may send a control command back to the fusion centre to control the irrigation system in any section. The overall process is illustrated in Figure 1.
3.1. Data compression
Since RLE depends on having consecutive values, this solution will not be viable for our purpose as moisture readings in consecutive sensors may vary. Therefore, our main focus will be on Huffman and LZW techniques. Research shows that Huffman has higher compression rates for text files while LZW is better for compressing image files [8]. In addition, LZW works better with a dynamic dictionary which calls for updating the dictionary regularly and creates overhead on the communication system. Therefore, Huffman encoding will be used to perform compression, with a static dictionary that is generated once from the data pool already available and kept by both sender and receiver. Since the variations in the data are comparably small, differential encoding is performed as an additional step before Huffman encoding and then only the difference is encoded and sent over the channel.

3.2. Network availability
Connectivity is checked using a broadcast process, where the sender (farm end) continuously transmits a signal to the server to determine whether or not there is a link, if the broadcast signal is received, this means that a link is established and data transmission can take place. If no acknowledgement is received, then a stable internet connection could not be established and the data is sent through SMS, directly to the user. The connectivity check and data transmission are performed on an hourly basis. However, the time lapse between data transmissions may be adjusted.

3.3. Storage
In the case where a successful internet connection is established, the data is sent to a cloud server. The data is stored on the server until the next update is received. To avoid running out of memory on the server, the older data file is replaced by the newer file each time an update is received. The entire history of sensor readings is stored on-site in a memory attached to the fusion centre and may be recalled at any instant.

When the user opens the interface, the latest file on the server is automatically downloaded to update the readings at the user end. Each time a file is downloaded on the user’s device, it replaces the last downloaded file to avoid congesting the device’s memory.

Figure 1. Block diagram showing the various steps of the proposed solution
3.4. User monitoring centre
The user monitoring centre is built as a mobile application for portability and ease of access. Four main tasks are performed by the application: reading the data, decompression, mapping and visualisation and control.

3.4.1. Reading data
The user may receive the data through an SMS or by downloading a file from the server. When the user opens the application, the latest file is automatically downloaded from the server. If an SMS has been received from the farm within the last hour, the application automatically detects the SMS and it is saved as a text file on the device’s storage. Then the data from the SMS is displayed to the user. If an SMS has not been received from the farm, then the data from the downloaded file is displayed to the user and is considered as the latest update.

3.4.2. Decompression
When the user downloads the application for the first time, the dictionary is automatically downloaded and stored on the user’s device. Later when the compressed data is received, this dictionary is used to decode the received values before they may be displayed to the user. Figure 3 shows a simple representation of the decompression process.

3.4.3. Mapping and visualisation
Since the agricultural plan is divided into five sections, the user may access the data from each section separately from the application. The sensor readings are projected onto a map of the section according to their pre-determined fixed locations in the section and are numerically displayed.

3.4.4. Control
The only automation system currently available in the agricultural plan under investigation is an irrigation system, that can only be turned on or off remotely. The application offers the user the option to send a control command to open or close the irrigation system in any subsection. Currently each section is divided into five subsections in which sensors are placed in the centre of each subsection. The user may choose to open or close the irrigation system in any subsection depending on the amount of water indicated by the soil moisture reading in that subsection.

4. Results
4.1. Comparison of compression techniques
In order to verify that a combination of Huffman and differential encoding would be the best choice for compressing the data, several compression techniques were tested on temperature readings and compared with the method of choice. Table 2 shows that a combination of Huffman and differential encoding offers a superior compression ratio of 96% for temperature readings compared to the a 62% when RLE is used. RLE is also expected to offer a worse performance for moisture readings, since
they are not as repetitive as temperature readings. LZW requires a dynamic dictionary, which undermines the compression ratio. Encoding the difference, instead of the actual values, significantly improves the compression ratio. Since there are larger variations in soil moisture readings compared to temperature readings, the maximum achievable compression ratio for moisture sensor readings is lower.

**Table 2.** A comparison of compression ratio of Huffman (with static and dynamic dictionaries), Lempel-Ziv-Welsh (LZW) (with a dynamic dictionary only), Run Length Encoding (RLE) (without a dictionary), when applied on temperature readings, and a combination of Huffman and Differential encoding (Huffman + Differential) applied on both temperature and moisture readings

| Compression technique    | Compression ratio |          |          |
|--------------------------|-------------------|----------|----------|
|                          | Huffman           | Static   | Dynamic  |
|                          |                   | 22%      | 32%      |
|                          | LZW               |          | 30% (dynamic) |
|                          | RLE               |          | 62%      |
|                          | Huffman + Differential | Temperature | 96% |
|                          |                   |          | Moisture  | 59%      |

4.2. *Case studies*

Three different scenarios are used to illustrate how the sending and receiving and the user interface work. The first case when there is an internet connection available on the farm, the second scenario, when no connection is available and data is sent through SMS, and finally a control scenario, where the user sends a signal to the farm through the server to control the irrigation system.

4.2.1. *Data connection available*

If an internet connection is available at the farm end on the time of sending, a text file with the compressed data is uploaded on the cloud server, as shown in Figure 4.
Figure 4. File upload through mobile data on the farm end

The file is uploaded to the cloud server and replaces the existing file on the server at the time. Hence the server always has only one data file with the latest update. Figure 5 shows a sample of the data file that may be sent and stored on the server.

Figure 5. File upload and storage on the cloud server

When the user opens the application, the latest file is automatically downloaded, as shown in Figure 6. Then the user may open any section to view the sensor data in this section.
4.2.2. Data connection unavailable

When the internet connection is unavailable at the farm end, the data is sent through SMS to the user. Figure 7 illustrates the sending process and shows how the target phone number may be set or changed at the farm end.

Afterwards the data is received as an SMS by the user and automatically detected and stored as a text file on the user’s device. Figure 8 shows a sample SMS and the corresponding data displayed on the user’s device. Note that for the purpose of testing, the sending/receiving component has been tested independently from the compression/decompression component to ensure each component is functioning correctly before integration.
Figure 7. Sending data through SMS and setting target mobile phone number, farm end

Figure 8. A sample of an SMS received by the user and the corresponding data displayed on the user interface

4.2.3. Control commands

Depending on the temperature and soil moisture data presented to the user through the application, the user might want to open or close the irrigation system in the area surrounding a certain sensor.
The user can send a control command through the application as shown in Figure 9. The command is interpreted as a text file and is uploaded to the server and then forwarded to the fusion centre on the farm end, as shown in Figure 10. The fusion centre downloads control files whenever an internet connection is available.

![Figure 9](image1.png)

Figure 9. Sending a control signal through the application to open or close the irrigation system

![Figure 10](image2.png)

Figure 10. Control file uploaded on the server to be forwarded to the fusion centre

5. Conclusion
This work provides a low-cost solution for transmitting and displaying data to and from a WSN in an agricultural plan in a rural area with poor network conditions. For the first component of the solution, after testing multiple compression techniques, we can conclude that the combination between Huffman encoding with a static dictionary and differential coding is the best solution for data compression due to its high average saving ratio of 96% for temperature readings and 59% for soil moisture readings. Secondly, after investigating multiple methods, a dual communication mode (mobile internet or SMS) is adopted for sending the data, so that the flow of information is not
disrupted by the absence of a mobile internet connection at times. Lastly, the user interface is an Android mobile application developed with the purpose of providing the user with monitoring and control over the agricultural plan remotely. It includes a mapping and visualization software where the user is presented with the sensor readings at their respective positions in the agricultural plan. The application provides control over the irrigation system on the farm end.

Several alterations, experiments, and tests could be added in the future, such as sensing the acidity/alkalinity level of the soil. Research shows that a certain pH level range facilitates optimum growth, while outside this range the availability of specific nutrients to plants, as well as the activities of both beneficial and pathogenic microorganisms are affected [9]. Sensors added to the WSN on the farm end may be easily integrated into the existing system.

Pest control is another potential upgrade to this design where specific motion sensors can detect areas of crop diseases and pests [10]. Finally, an add-on to the software can be developed to notify the user of any new agricultural advances that may interest them.

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