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Condition Monitoring and Reporting Framework for Wireless Sensor Network-based Automatic Weather Stations

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Abstract: Automatic Weather Stations (AWSs) consist of sensors that automatically collect and transmit weather data. AWS efficiency is achieved if the amount of down time is minimized. Keeping track of AWS status is a daunting task, aggravated by increase in the observation network density. The purpose of this paper is to present a condition monitoring and reporting framework which relies on AWS sensor data to establish AWS health. The framework consists of four major components including a data receiver, analyser, problem classifier and reporter. On receiving the sensor data including input voltage, date and weather data, the analyser determines if there is a problem while the classifier uses a decision table to determine the probable cause of the problem. Based on the identified problems, the reporter logs each problem in a database and sends an SMS or email to the concerned person. Sending an SMS or email is performed on new problems or on problems not attended to within 24 hours in order to minimize the number of reports.

Keywords: Automatic Weather Stations, Sensors, Condition Monitoring, Analyser, Classifier

1. Introduction

Condition Monitoring (CM) has been used in many applications such as transport[1] and industry[2] among others to determine the condition of machinery while operating, in order to identify a significant change in the normal operation characteristics. Timely identification of significant change in machinery is indicative of a developing fault, which makes it possible to reduce machine downtime, hence facilitating preventive maintenance. Besides facilitating preventive maintenance, condition monitoring also assists in monitoring devices and establishing the status of a wide range of parameters in a short period of time and with minimal human interaction.

Sensors are a key component of condition monitoring, enabling automatic collection and transmission of data[3]. In regards to weather monitoring, sensors have been used in Automatic Weather Stations (AWSs), which are an automated version of the traditional manual weather stations[4][5][6] used to collect and transmit weather parameters such as wind speed, wind direction and many others. Because of the nature of wireless sensor networks (WSNs), characterized with challenges such as limited power supplies and packet dropping among others[7], the WSN-based AWSs are bound to face the same challenges.

For example, if the limited power is exhausted, the wireless nodes can neither collect nor transmit weather data. Such undesirable circumstances if encountered should be detected within a short period of time to reduce downtime. Timely detection of such problems however becomes impractical as the network of stations grow, a reason for improved methods of monitoring such as condition monitoring tools.

Condition monitoring has been used in many applications including structural monitoring [8], [9], industrial monitoring [10], [11] among others. WSN-based AWS monitoring is carried out by analysing the constituent AWS node data. Despite AWS challenges, limited work has been done to improve the process. Examples of condition monitoring tools include Advantage Pro [12], a smart wireless solution and Supervisory Control and Data Acquisition (SCADA) [13].

2. Objectives

The main objective is to design a framework to be used for monitoring the condition of AWSs to facilitate preventive maintenance. In regards to WIMEA-ICT[14] project, this paper addresses the challenges faced by the inefficient traditional means of monitoring conditions of a growing number AWSs, hence the prolonged down times experienced by many AWSs. The tool is meant to improve preventive maintenance by either avoiding the problems from occurring or by lowering the down time. The specific paper objectives include

- Analysing AWS data to establish symptoms for the problems
- Based on the symptoms, categorize the problems for customized reporting
- Design a visualization tool for status of AWSs monitoring

3. Developments

3.1 Experimental Set Up

We set up and monitored an AWS consisting of 3 wireless sensor nodes (2m, 10m GND sensor nodes), which collect and transmit weather data, node and network status data to another node called a sink. The sink node is attached to a raspberry pi[15], a combination of which forms a gateway, connecting the AWS using the Internet to a remote repository. Data received by the sink, including weather data and others, (see Table 1) is saved to a file on a raspberry pi, which may be downloaded via a web interface. Additionally, data may be transmitted to a remote location, also known as a repository for permanent storage as and when it is received by the sink node. Figure 1 shows the architecture of the AWS.

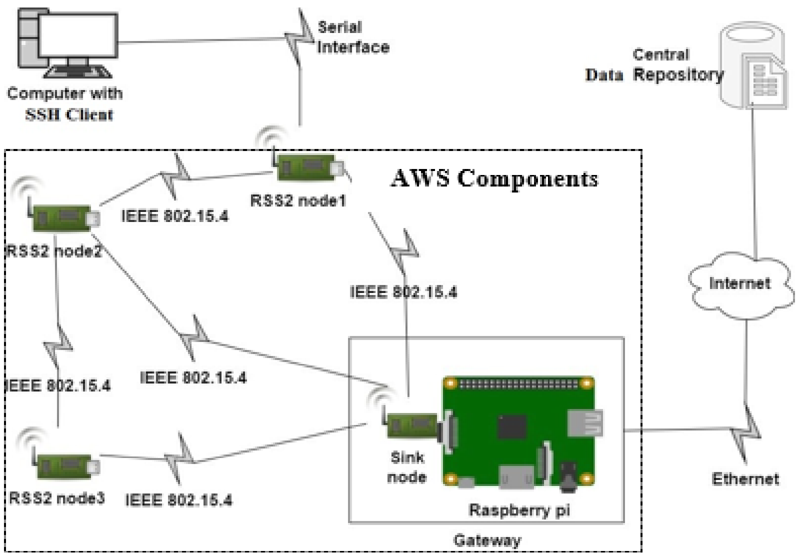

Figure 1: Architecture of the Automatic Weather Station

Before deploying the AWS, the node is configured for the frequency of data transmission such as, a node may send a data every hour, assigning a name to the node and setting which weather parameters a node should transmit among others. For instance, a node may be named 2m, transmitting temperature and relative humidity every 30 minutes.

Table 1 Non-weather data fields stored in the AWS gateway file

Field Name	Description
Date and time	Date and time the gateway received the data
Time zone	Time zone of the AWS gateway
Location	Location, showing latitude and longitude
Txt	Human readable name of the node that is transmitting the data
E64	MAC address of the sending node
V_MCU	Voltage of the microcontroller of the sending node
V_IN	Input voltage of the sending node
RSSI	Received Signal Strength Indication (Added by the gateways)
LQI	Link Quality Indicator

4. Results

We analysed data stored in the file and below are the results

4.1 Date and Time Synchronization

Before buffering or transmitting the data, the gateway first appends a date and time. A comparison of the records from the nodes with correct dates versus those with incorrect dates from the AWS is given in Figure 2. The first bar indicates the expected number of records, the second represents the received records while the third represents the number of records with correct date and time and the last bar represents the number of records with incorrect dates. Records with dates such as 1970 are automatically ignored and as such, considered as lost data.

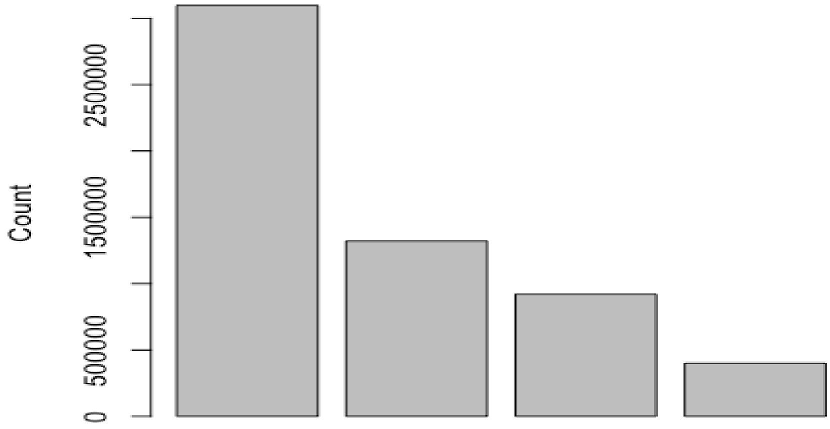

Figure 2: Records received from the Makerere AWS for the first 239 days

4.2 Missing Data and Station Availability

Each node is expected to transmit a report after a configured period of time and is expected to have 100% availability. Failure to receive a report in the expected period of time may imply sensor or node failure, node misconfiguration or communication problems among others. Node misconfiguration occurs when required parameters are left out during node configuration, a problem that can hardly be detected without a processing algorithm. Additionally, the gateway being the sink for all data and a connection to the Internet, presents a single point of failure capable of disconnecting the entire AWS.

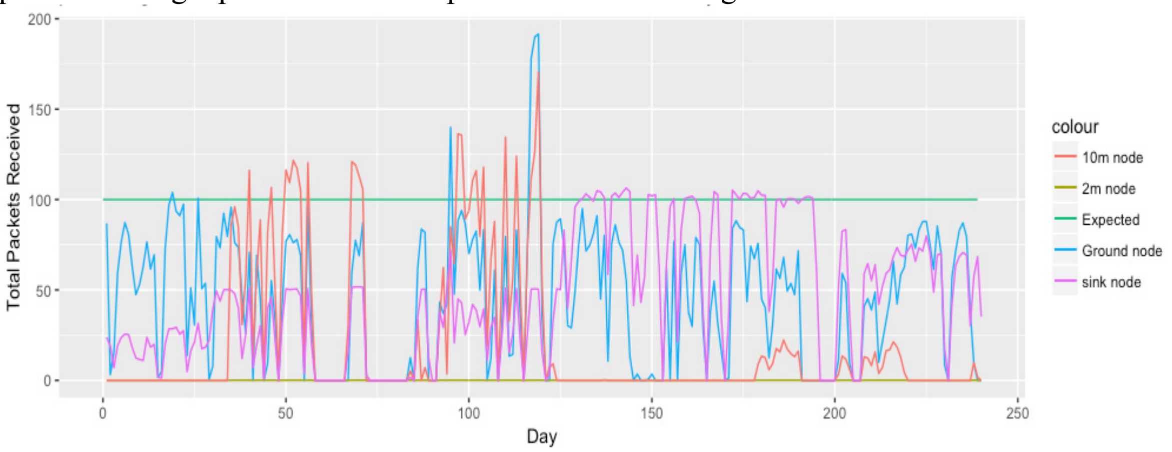

Figure 3: Packets received from the nodes at the Makerere AWS for the first 239days

Figure 3 shows the percentage number of packets received from 6th Dec 2016 to 26th Aug 2017. 0 packets from a node implies that the station was off or packets are time stamped with wrong dates. The 10m node was off for the longest period of time due to power problems, which were mainly attributed to the power consuming sensors attached. The station went off for more than a day on four occasions during the considered period as indicated in Table 2 mostly because the sink power was disconnected at the time.

Table 2: Times when the station went off

Date range	Day as represented on the graph	Days spent offline
2nd Feb 2017 to 09th Feb 2017	60th-66th	7 days

16th Feb 2017 to 26th Feb 2017	73rd - 83rd	10 days
20th June 2017 to 23rd June 2017	197th - 200th	3 days
28th June 2017 to 30th June 2017	205th - 207th	2 days

4.3 Weather Parameter Accuracy

The design and sensor selection of the AWS used in this study was based on the working assumptions specified in [16]. Our AWS condition monitoring tool establishes the accuracy of the sensor values using three mechanisms. That is: -

i. Comparing with minimum and maximum historical values collected from a particular location

ii. Minimum and maximum sensor values provided by manufacturers

iii. Format of data received

Examples of such problems include: - No data was received from the pressure sensor until the 96th day although the same node was transmitting. The GND node recorded packets with an average soil temperature of 0, hence a problem with the soil temperature sensor.

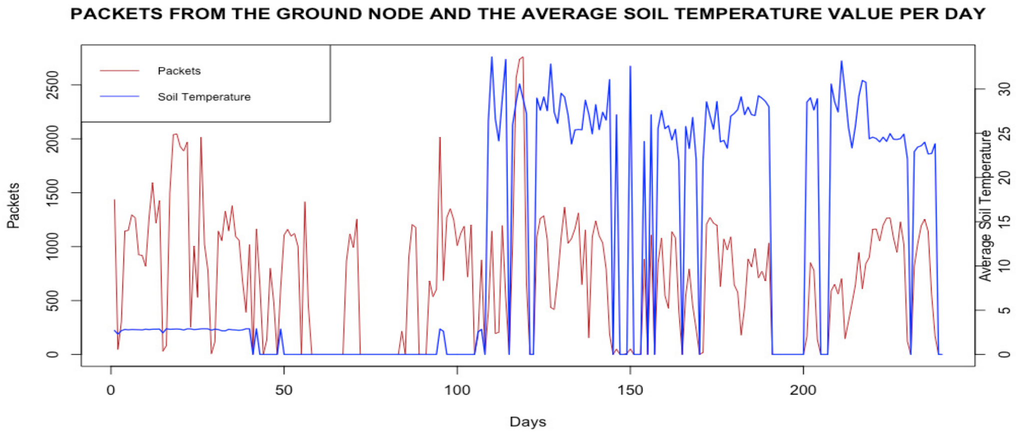

Figure 3: Comparison of the availability of the ground node and the soil temperature value

Figure 5 compares 10m node availability with the wind speed sensor values. A wind direction reading greater than 1 compared to a wind speed of 0 indicated a problem.

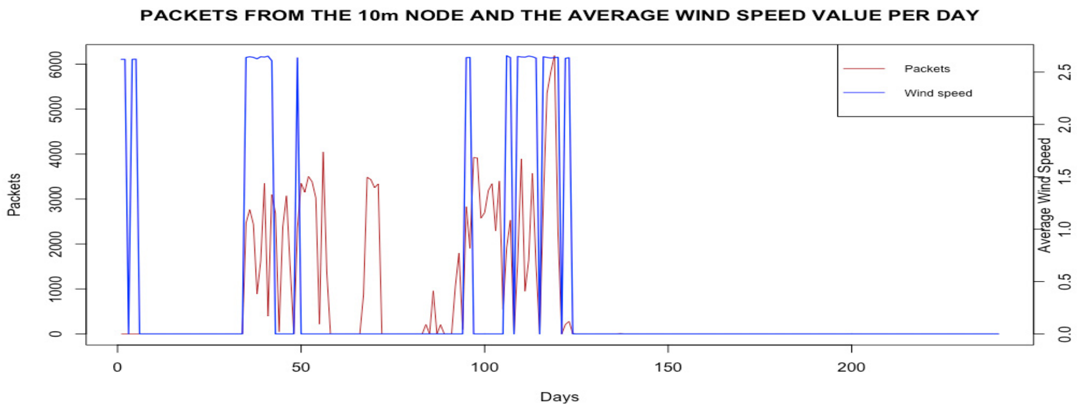

Figure 3: Comparison of the availability of the 10m and the wind speed values

AWS problems persisted for longer period before they were corrected, which led to loss of more than 15% of the total weather information expected in the first 239 days.

Table 3: Some Common problems and their frequency

Problem	Frequency (times)	Avg. duration (days)	No. of packets lost	% loss
Station being offline or Incorrect Date	14	2.8	280,800	16
Failure of 10m node	12	15	515520	74.5
Failure of 2m node	14	3	54720	15.8
Failure of sink node	23	2.6	84960	16.1
Wind speed & Wind Direction	4	8.75	50400	14.5
Very low soil temperature value	1	47	67,680	19.5
Soil temperature value not captured	3	11	47520	14

4.3.1 Power Availability

Each report contains values of input voltage, indicating node power supply. When power supply goes below a threshold, the node goes off, hence the inability to either collect or transmit data. Each sensor report received at the repository contains the power supply voltage, which can be compared to the reference minimum provided by manufacturers.

5. Technology Description

We designed a condition monitoring system, based at the repository to listen to incoming data from the AWS gateway, process it and permanently store it in a database. Once in the database, analysis is done to establish status of the AWS. Figure 6 shows the architecture of the condition monitoring system.

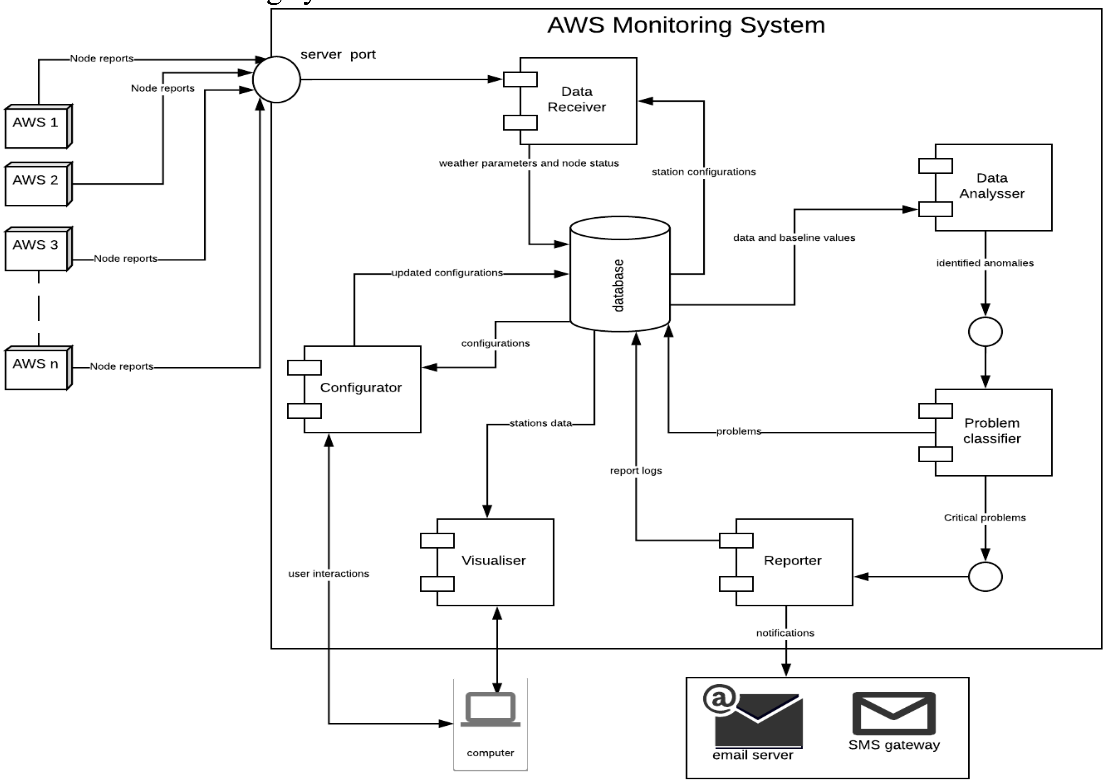

Figure 4. Architecture of AWS Condition Monitoring System installed on the repository

The framework consists of four major components namely: data receiver, data analyser, problem classifier and reporter. The configurator and visualizer are support components, which are used for system configuration and data visualization respectively. The data receiver receives data via a TCP port and stores it in the database, which doubles as a store for the manufacturers' reference values used by the analyser, combined with history of the stored data to detect problems based on symptom(s). The problem classifier determines the probable causes, and forwards the message to the reporter. While every problem is logged in the database, sending emails and SMS are only performed on new problems or problems which have not been attended to in a long time. That is, more than a day.

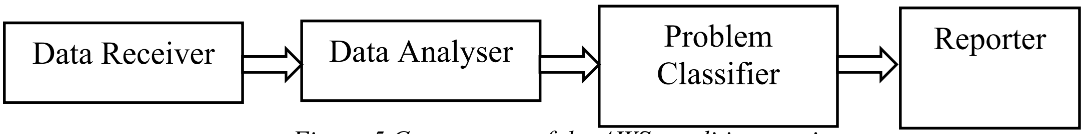

Figure 5 Components of the AWS condition monitor

Table 4. Decision table used by the data analyser and problem classifier

Condition stub	**Rules**								
Gateway date and Time compared to repository	!=	==	==	==	==	==	==	==	==
Weather reading values	WR	>Max	<Max	WR	WR	WR	WR	WR	WR
Sensor input voltage	WR	WR	WR	<Min	WR	WR	WR	WR	WR
Reporting interval	C	C	C	C	INC	C	C	C	C
Report with missing parameter	N	N	N	N	N	Y		N	N
Prolonged node missing report	N	N	N	N	N	N	Y	N	N
Data format	W	W	W	W	W	W	W	R	W
Gateway communication	Y	Y	Y	Y	Y	Y	Y	Y	N
Action (Problem category)									
Probable node failure							X		X
Internet or Communication problem							X		X
Device misconfiguration						X			
Faulty sensor						X			
Gateway date and time synchronization problem	X								
Packets dropping					X		X		
Data accuracy problem		X	X						
Current or future Power problems				X			X		X
Gateway failure									X

6. Business Benefits

The stations are distributed across a wide area, hindering the monitoring and maintenance process. Engineers and weather station observers are required to periodically check the stations to ensure their operation. The monitoring framework proposed provides an efficient and cost-effective way of performing maintenance of the stations. In cases where spare parts are not readily available, warning signs may compel timely procurement of the required equipment.

The more data received from the weather stations, the more accurate the weather forecasts. Sectors such as health, transport and tourism among others benefit from accurate weather forecasting

7. Conclusions and Future Work

This study was aimed at designing a condition monitoring framework for WSN-based AWSs and it has identified common AWS problems. Our CM consists of a data receiver, data analyser, problem classifier and reporting components. Based on the received data, the analyser detects symptoms, which are used by the classifier to determine the symptom categories. The reporter formats the reports and performs reporting using either SMS or email while ensuring that frequency is minimized. If implemented, condition monitoring reduces downtime and thus promotes timely response to problems with corrective action.

We have implemented the receiver and hope to design the rest of the components by May 31st 2018. Furthermore, the condition monitoring tool shall be tested with many AWSs, to determine if it can withstand big loads without failing.

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