RailMon: Distance, Temperature and Location Railway Monitoring using IoT technologies

Pa Saffiong Kebbeh[1] Madoune R. Seye[2] Bassirou Ngom[2]
Bamba Gueye[2] Moussa Diallo[2]

[1] University of The Gambia, Banjul, The Gambia
[2] Université Cheikh Anta Diop, Dakar, Senegal

Abstract – Internet of Things (IoT) is an emerging technology and have great potential to be applied in critical environments. In that regard, IoT is a remarkable solution to the challenge of collecting data from physical environments, thanks to their flexibility, low cost and ease of deployment. It has always been a dependent factor for early alert signals for the possibility of unforeseen technical issues that may occur within the mass transport networks. Our proposed infrastructure, called "*RailMon*" and based on IoT, is able to detect either rail track damages due to unbearable temperature or determine fixed object in a far-away distance in a railway network. Thus, an early warning system is deployed to avoid unforeseen fatal accidents.

Keywords: Internet of Things, Event detection, Structural health monitoring

1 Introduction

Since the evolution of wireless sensor networks can be a dependent technology for safety mass transport monitoring, introducing monitoring techniques in its different forms (damage detection, traffic monitoring, reliability assessment, etc.) can save costs by improving the reliability and efficiency of mass rail transport infrastructures [1], [2]. Indeed, granting the possibility to convey early warnings of problems that may develop within the mass transport networks.

In Senegal, there are two main critical issues of the railway network. Firstly, the lack of modern security monitoring system of the railway infrastructure. For example, the untimely crossing of the train route by the pedestrians, vehicles, and the uncontrolled movement of livestock within the local neighborhood can cause a high risk of train obstructions and accidents during movement. Currently, there exist no automatic detection mechanism of either a fast approaching train towards a pedestrian intersection crossing, or an unattended fixed object on the railway line.

Secondly, the men force who work as railway guards and track engineers have no technology instrument to make real-time and accurate assessment of rail track damages due to unbearable temperature on the tracks, or a determination of a fixed object in a far-away distance within the railway perimeter area.

As a result of the consequence of this challenge, this paper presents "*RailMon*", a wireless sensor network model for the continuous monitoring and detection of obstructive materials within the rail network using Wireless Sensor Networks (WSN) [3]. In our approach, we aim to deploy, analyze and evaluate the use of wireless sensor networks for a reliable geo-location data collection of object detection, monitor a moving train's location, and temperature measurement of the rail track infrastructure. This study was conducted in Dakar, using the rail network infrastructure, called "*Petit Train Bleu*" which serves Dakar to Rufisque. It should be noted that our proposition is also suitable for the Dakar-Bamako railway network. Principally, "*RailMon*" architecture focuses on practical engineering solutions, where "*Dragino*" IoT sensor devices [4] are used for their respective strengths to achieve the desired solutions of our study to in order avoid unforeseen fatal accidents.

The layout of the paper is presented as follows. Section 2 discusses the related work. Section 3 describes the "*RailMon"* deployed architecture. Section 4 highlights the experimental setup and technical specifications. Section 5 analyses the achieved results. Finally, Section 6 draws the conclusions and possible future work for a more scalable railway monitoring technique.

2 Related Work

Railway structures are design in various forms based on environment, infrastructure design, model requirement, and core needs. According to the authors of [1], [2], rail tracks are made of steel and can expand when temperature constantly rises to a certain degree, meaning they get longer and deform in shape. An 1800-foot length of rail will expand almost one foot with an 80-degree change in temperature. Heat-related expansion places a lot of stress on the ties and eventually, the tracks will buckle under the force. While the air temperature might be 31°C, the transport rail corps engineering standards and procedure publications [1] proofs that temperatures on tracks can exceed 50°C during heat waves.

According to the survey of intelligent transport systems [5], different experimental setups of WSN purposely for railway infrastructure monitoring were experimented. In their analysis, the authors proposed a real-time rail condition monitoring by using microcontrollers as sensor nodes, which transmits to base station using either *GSM* or *GPRS* as a communication medium. While the authors provide a generic architecture of a typical monitoring infrastructure using WSN where data is produced continuously or periodically, the paper did not address the specifics of which communication medium best provides the most effective transmission cost.

In a similar deployment of railway monitoring systems, recent works [6] [7] investigated and proposed an "*LED-LDR*" based design using an *Arduino MCN*, *GPS* and a *GSM* module to collect data and send it to a mobile phone for analysis. While the use of this technique was found to produce very accurate results in lab based testing, data transmission from the remote monitored location could be both expensive, and possibly be compromised by intermittent *GSM* signals or poor network coverage. Additionally, the author's approach of using *DC Motors* for distance traversing on the rail tracks, is not only uneconomical but could also be obstructive for a moving train.

In an evaluation of long range wireless transmission sensor devices, the authors of [8] conducted a survey on the evaluation of the *LoRa* (Long Range) wireless sensor antenna transmission coverage within the Dakar Peninsula. While the authors evaluated their most optimized results within a combined distance of over 40 km in between 4 base stations, it was concluded that their evaluated results proofs that a LoRaWAN gateway can cover a transmission range of up to 10 kilometers with a packet loss ratio less than 30% through a line of sight.

3 RailMon: design overview

The model of our architecture as compared to various related works provides continuous real-time data acquisition and improves data accessibility, with the capability of simultaneously collecting and processing data from combined variation of sensors in an integrated frame. While other authors use wireless sensor networks for real time monitoring of either event detection, temperature monitoring or malicious object detection at different times in a discrete method, the core competence of our deployment model is the capability of providing real time information of both the temperature data and information of a possible malicious object within the railway line, as well as the geo-location data of a moving train towards an endangered location instantaneously. Using sensor network mechanism, both temperature data and the location of a non-moving malicious object within the railway line can be analyzed and interpreted at the command center for further decision making.

3.1 RailMon architecture

Fig. 1 depicts the *RailMon* alert system that primarily encompasses a sensor network which monitors the railway track for deformation and obstruction before the train reaches the impending danger zone, and a module that monitors the geo-location of the moving train in order to avoid any impending disaster. With the *RailMon* monitoring mechanism, the following tasks were being measured and evaluated:

a. Measure the distance between a detected object within the parallel railway tracks using an ultrasonic sensor, measure the degree of temperature level at given sensor node locations; and subsequently send the combined data to a remote command center as illustrated in Fig. 1.
b. Monitor the location of a moving train in the form of geo-location coordinates including date and time stamp, through a GPS and consequently send the data to the command center in a separate frame from (a) above, for any further determination.
c. This technology solution is designed with relevance and effective low power consumption with long-range communication capability by means of aggregating both temperature and distance data in a single frame along the way to the sink.

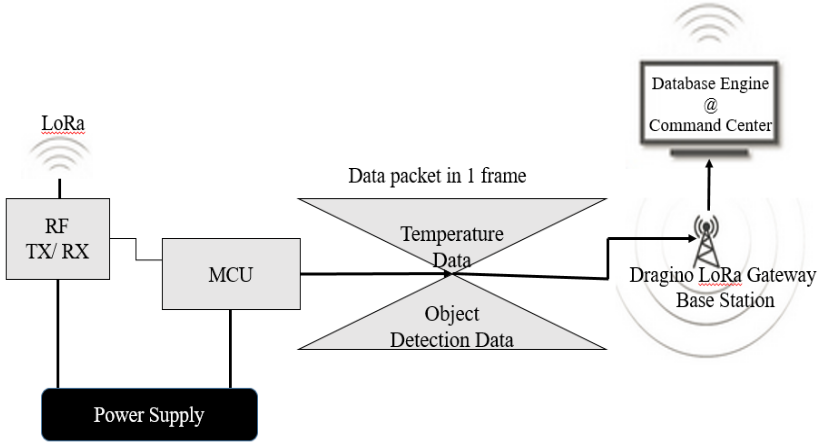

Fig. 1. Block diagram of the DTL WSN

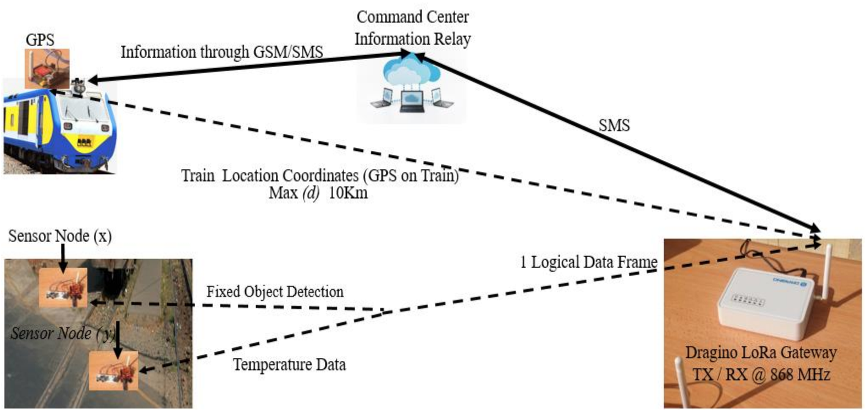

Fig. 2. *RailMon* architecture

Fig. 2 illustrates the deployed *RailMon* architecture. While sensors "*x*" or "*y*" detects different scenarios (i.e., temperature and object depending on its location, each node can sense both scenarios within its range, and send it to the gateway in 1 logical frame.

3.2 Occurrence detection in RailMon

Based on Fig. 2, sensor nodes are used to collect data from the environment and send it to a sink node or gateway using a broadcast messaging architecture. Irrespective of the fact that the data transmission device that we used in our deployment transmits data in a broadcast mode by default, (where the transmitted data can be received by similar devices operating on the same frequency), in our architecture, we programmed the sensor nodes and the gateway to transmit and receive on frequency 868 MHz. In our adopted method, data is collected from outlying nodes through a direct spanning tree to the gateway. Typically, some function is applied to the incoming data from each node to identify its location and other related attributes. The goal being that eventually, the gateway will obtain data only from nodes that are associated to the setup.

The approach is often called stepwise refinement:

i. Initially, all nodes send input to the gateway @ every 1 minute upon receiving Data (*d*) from Nodes (*x* or *y*):
ii. Upon the gateway receiving Data (*d*) from Nodes (*x*, *or y*),
iii. The sink gateway then forwards the data to the Database
iv. Append (*d*,) to the database.

With the above algorithm, if the base station (sink node) is interested in finding the maximum or average temperature in a region, each microcontroller node monitoring the region can easily aggregate the data generated by its sensors and simply send one frame containing the result. The attributes of such frame are "*ma"* (temperature), "*mm"* (distance) and "*addr"* (Location). For the fact that the GPS is in on different microcontroller board on-board a moving train, the GPS data can also be aggregated by collecting *coordinates*, *time stamp* and *date* in a separate frame.

Given a set of sensor nodes S = {S_x, S_y,...,S_{n-1}} in the network, with S_{n-1} being the sink node as the gateway, where each node has a data item that it wants to send to the sink node, this implies that the we had to programmed the sensors to transmit at every 1 minute but strictly on time slots to avoid bottleneck and interference.

As the monitoring network scales up, this algorithm can dramatically reduce the total number and size of packets sent, because each node sends 1 frame and the total number of packets sent is always equal to N−1 for every matured slot.

4 Experimental Setup

There are several sensors types used in railway condition monitoring for analyzing different aspects of the rail infrastructure. According to the proposed topology in [9], the authors setup a single-hop network architecture with application of a converge cast messaging algorithm. For RailMon-based approach, the gateway is positioned in the center of the sensor network where data is transmitted directly to the gateway through a single hop mode. The rail track measurement kit comprises of an Arduino microcontroller board which embeds several sensor kits as specified in Table 1.

4.1 Evaluation of LoRa transmission protocol

We compared two contending wireless IoT transmission devices; being ZigbBee and *LoRaWan*. Based on our investigations, it was prudent that after an in-depth comparison between the two technologies. Indeed, LoRaWAN is more suited for long range transmission with very low power consumption, and long-lasting battery operated autonomy.

Table 1: Deployed sensor kits and components for *RailMon*

Measurement Kits	
Kit Description	**Specifications**
Dragino LoRa Shield	Microcontroller (Arduino) ATmega328 Operating Voltage 5V Digital I/O Pins 14 (6 provide PWM output) Analog Input Pins 6
GPS Sensor	Based on MT3339. Programmable bit rate up to 300 kbps. Frequency Band: 868 MHZ/433 MHZ/915 MHZ
Dragino Gateway	Open Source OpenWrt system, Auto-Provisioning Built-in web server Managed by Web GUI, Internet connection via LAN, WiFi, 3G or 4G,
DHT11 Temperature Sensor	Detects surrounding environment of the humidity and temperature, Humidity measurement range: 20% ~90%, Temp Measurement range: 0 Degrees Celsius~60 Degrees Celsius,
HC-SR04 Ultrasonic Sensor	Power Supply :+5V DC, Ranging Distance : 2cm – 400 cm/1" - 13ft, Resolution : 0.3 cm, Measuring Angle: 30 degree,
Batteries	5 Volts Batteries / Mobile Power Bank

Both LoRa and ZigBee can operate on similar frequency bands of 868 MHz, and the latter being more efficient in short range transmission. The LoRaWAN is especially more efficient for use-cases where we have more uplink (device sending to cloud or gateway) updates than downlink, e.g. long distance condition monitoring. Thus, justifying our need of choosing LoRa as our data transmission mechanism.

As illustrated in Fig. 2, the network is typically laid out in a star topology, where the sensor nodes transmit directly to the gateway that in turn, is connected to a the database engine via standard Internet technologies.

Furthermore, Fig. 3 depicts our measurement kit which is formed by a micro-controller and a couple of sensor components. The components are depicted as follows:

- ***GPS*:** *L80 GPS* (base on MTK MT3339) is designed for applications that use a GPS connected via the serial ports to the Arduino such as timing applications that require GPS information. The module can calculate and predict orbits automatically using the ephemeris data (up to 3 days) stored in internal flash memory, with automatic antenna switching function.
- ***Dragino Gateway*:** LG01 LoRa Gateway allows bridging LoRa wireless network to an IP network based on WiFi, Ethernet, 3G or 4G cellular [4]. LG01 runs an open source embedded Linux system with full Ethernet and 802.11 b/g/n WiFi capabilities and can process/send to IoT server in an IP network.

- ***DHT11 Temperature Sensor*:** *DHT11* is a low cost humidity and temperature sensor, which generates calibrated digital output and can be interface with any microcontroller like Arduino, *Raspberry Pi*, etc.
- ***Ultrasonic Sensor:*** *HC-SR04* ultrasonic sensor module offers excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package. From 2cm to 400 cm or 1” to 13 feet, its operation is not affected by sunlight or black material like Sharp rangefinders.

4.2 Sensors Network Setup

According to our monitoring setup, wireless sensors are placed along a the railway line at a distance of 4 meters away from the rail track in order to monitor both the pre-defined temperature and object obstruction of the tracks.

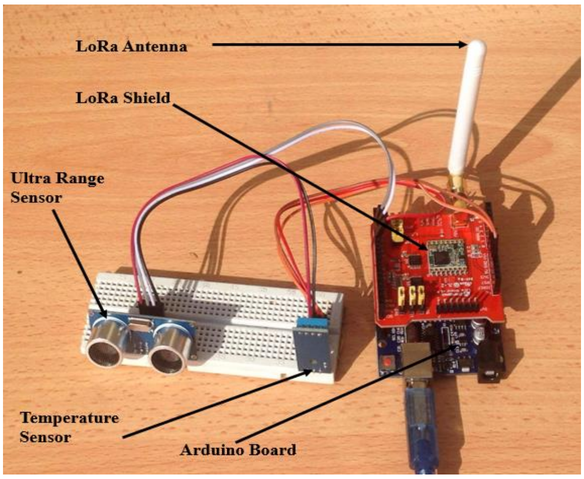

Fig. 3. Mico-Controller and sensor components setup

The microcontroller board (Fig. 3) enables the sensors to react to both an ultra-object detected within a range of 4 meters away from the rail track and a pre-defined temperature range of 0^{o}C to 60^{o}C. The data collected is transmitted by LoRa to the gateway @ a TX / RX frequency of 868 MHz. When data is sent to the gateway, it includes the sensor node location coordinates and the error type detected.

Unlike basic condition monitoring where information is triggered to the command center based on only abnormal event detection, with our *RailMon*, [10] data from sensor nodes are treated as time series, i.e. either periodically or continuously. For example, at every sensor node, data is generated and sent to the gateway every 1 minute as a condition of no critical error. Otherwise, data will be generated and sent every 5 seconds due to a constant error of either a malicious fixed object detected within the perimeter of the railway lines, or a measured temperature of more than 60^{o}C is being realized, which is enough to deform a railway track.

To achieve our desired solutions, we formulate a data frame structure in order to identify and interpret the received data from fixed sensor nodes. The frame packet as illustrated in table 2 is associated with the data types, (as implicit to a condition mode).

4.3 Analysis of the error codes

Depending on a given circumstance of a monitored location, the data frame that is being sent to the command center is segmented into different blocks, as illustrated in (table 2). The first ***X*** is denoted for a segment of a data frame which describes the error type of the detected anomaly within the railway line. The error codes ranges from type 0 to 3. With the interpretation of the frame segments, error type 0 implies that there exist no fault or critical issue for action.

```
The frame is: 0:1:1362.72:35.00
The frame is: 0:1:33754.35:35.00
The frame is: 0:1:33903.78:35.00
```

Fig. 4. An illustration of a captured data frame sent to gateway with no errors

In scenario 1, knowing the maximum threshold of the DHT11 temperature sensor coupled with the fact that temperature on tracks can exceed 50ºC during heat waves, therefore, if a temperature measurement is equal to or surpass the most extreme temperature of 60ºC, then an error code of type 1 is generated continuously for every 5 seconds which is transmitted to the command center for an alert of a possible "sun kinks", with high risk of causing railway accident. In this scenario, we set the temperature threshold to 35ºC in order to proof our use case and generate an error code, since it was impractical to witness a 60ºC temperature under normal circumstance.

```
The frame is: 1:1:1440.24:37.00
1
Data Sent
The frame is: 1:1:1004.87:37.00
1
Data Sent
The frame is: 1:1:1427.83:37.00
1
Data Sent
```

Fig. 5. An illustration of a captured data frame sent to the gateway with error type 1

In scenario 2, at a monitored location, while the temperature measurement may still be within a normal range, there could exist a situation of a constant fixed object within a distance of 0 – 4 meters, thus, causing a possible derailment of a speeding train. In such a situation, an error code type 2 is constantly transmitted to the command center, until the object is moves by default or physically removed.

```
The frame is: 2:1:93.67:38.00
2
Data Sent
The frame is: 2:1:77.35:38.00
2
Data Sent
The frame is: 2:1:92.31:38.00
2
Data Sent
```

Fig. 6. An illustration of a captured data frame sent to the gateway with error type 2

In scenario 3, at a monitored location, if both sensors (temperature and ultra-range) detects an anomaly outside the pre-defined variable parameters of the sensing function, then error code type 3 is generated and transmitted to the command center for an urgent reaction. Which implies that there is an issue with both temperature measurement and the presence of a fixed object on the railway tracks.

```
The frame is: 3:1:969.68:38.00
3
Data Sent
The frame is: 3:1:1128.46:38.00
3
Data Sent
The frame is: 0:1:33867.40:38.00
The frame is: 0:1:33835.78:38.00
```

Fig. 7. An illustration of a captured data frame sent to the gateway with error type 3

It worth noticing that the "X" value labeled in Table 1 means a segment of the data frame illustrated in Fig. 4., 5, 6 and 7.

Table 2: Data packet frame interpretation

Interpretation of the data packet frame TX/RV at the gateway from sensor nodes			
X:	**X:**	**XXXX.XX:**	**XX.XX**
The first block of the frame is the description of the Error Type:	The second block of the frame is the identifier (Location Address) of a sensor node	The third block of the frame is the description of the range or distance of an object away from the rail track (up to a max distance of 4 meters	The fourth block of the frame is the description of location temperature of the monitored area.

4.4 Data transmission architecture

Since our architecture of data transmission is through a wireless signal, it is evident that in wireless data transmission, attenuation due to unpredictable climate conditions may also occur at certain times of the year. Our "*RailMon*" model assumes the most ideal propagation conditions of clear Line-Of-Sight (LOS) between the transmitting sensor nodes and receiving gateway. Thus, not all packet frames transmitted from a given node may all the time be successful to the gateway.

With the gateway located in the center of the network, all the distributed sensor nodes are positioned to send data directly to the gateway in a single hop transmission.

Our data transmission mechanism from the sensor nodes to the gateway relates the effectiveness of our architecture to an energy efficient (EE) routing protocol [11]. In the architecture, much delayed packets or slow packets are removed from the queue to the gateway as it is impractical to traverse those packets to the destination, thereby saving the energy of nodes. With this procedure, the routing protocol calculates the expected delay for the current packet to reach the destination and decides whether to remove or not; as illustrated in the below formula for the current packet *p* at the current node *x* to reach the destination *d* (*Txd)* is given by the formula:

$$Tsx(P) = Dxd(P) - Dsx(P) \quad (1)$$

As shown in Fig. 1, while the data transmission speed relied on the performance of both the sensor nodes and the gateway, Dsx(*p*) is the distance already covered by the packet p from node x or y, to the gateway. Dxd(*p*) denotes the remaining terrestrial distance that the current packet *p* from sensor node x or y should span to the destination *d*, after the several repeated attempts of trials to reach the gateway. Therefore, Tsx*(p*) gives the delay for the packet to reach to the gateway, and after 5 attempts, the packet will be discarded and be replaced by a newer real time packet for a reliable informed decision at the gateway.

4.5 Temperature Variation

The variation in temperature depends on the amount of heat exerted or absorbed around sensed zone. The Temperature Formula is given by:

$$\Delta T = Q/WA \quad (2)$$

Where:
Δ T is the temperature difference,
Q is the amount of heat absorbed or exerted,
W is the weight of the rail track,
A is the average heat of the track.

To determine an outside temperature of heat on a rail track mass of 5 Kg on an average heat of 0.5/Kg^{o}C?

Given: Heat absorbed Q = 100 J, (3)
Weight of rail track W = 2 Kg, (4)
Average Heat A = 0.5/Kg^{o}C (5)
The temperature is given by ΔT = QWA (6)
= 100Jx5Kgx0.5/Kg^oC (7)
= 100^{o}C. (8)

5 Results

The final results achieved is an autonomous monitoring technique, thus, making it possible for a moving train to avoid reaching an unexpected disruption point within the railroad, We deployed multiple sensors on a single MCU for multiple monitoring functions of fixed locations. The RailMon model is very simple and robust. The failure of one node does not influence the operation of the whole network. This survey proofs that at a given time of the day, while the day temperature rises between 09:30 am to 19:00 pm, mass movement of either people or objects can still be detected within a range of 4 meters away from the rail tracks, and the maximum temperature recorded after various sampling test was 38°C.

6 Conclusion

We reviewed wireless sensor network applications for environmental monitoring and implement an effective WSN with several scenarios experimented. From the study, it has been proven that an alternative method of replacing a conventional routine of using men force in environment monitoring can be substitute with a more pragmatic technique to fulfill such functional requirement by using wireless sensor networks. The proposed "RailMon" architecture based on IoT, is able to detect either rail track damages due to unbearable temperature or determine fixed object in a far-away distance within track zone.

We plan to deploy and analyze multi sink base stations as cluster heads for coordinated processing in larger network environments coupled with more robust efficient and effective routing protocol.

Acknowledgement

The authors gratefully acknowledges the World Bank - Africa Center of Excellence STEM project, in collaboration with the Ministry of Higher Education, Research, Science and Technology of The Government of The Gambia and the University of The Gambia for supporting this research work.

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