An Internet of Things Infrastructure for Rainfall Monitoring in Dakar

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Abstract. Rainfall is a very important climatic phenomenon for the Sahelian economies. In Senegal, it has a very tremendous impact on agriculture and human life, which justifies the need for effective monitoring systems. In fact, the country has been experienced number of extreme events such as floods and public health problems. Despite the efforts made, it remains challenging to have real-time observations, which impact directly forecasts quality. In addition, systems used are not efficient and they are often expensive for implementation and deployment throughout the country. In this paper, we present an automatic rainfall station adapted. A prototype has been designed and implemented to ensure the reliability and availability of data in real time. In addition, a validation study is carried out in order to know its performances. For this, the designed prototype is installed on the same site near an approved industrial station, between July 1st and October 31st, 2017. The comparison between obtained results of these two stations is very satisfactory with a correlation of 99%.

Keywords: Internet of Things · Rainfall monitoring
Connected rain gauge · Automatic weather station
Real-time observations

1 Problematics and Motivations

1.1 Impact of Rainfall Disasters

Since the end of drought of the 1980s in the Sahel [1], we observe an intensification of the rainy season reflected by an increase of extreme events. Because of this, largest cities suffer a lot, especially in Senegal. These extreme phenomena are amplified since the beginning of the 2000s [2]. They have very great impacts on the environment, the survival of the population as well as the economy. Dakar, the administrative and economic capital of Senegal, is not left out. Indeed, 40.3% of Senegalese population is centered in urban areas like Dakar, according to the "Agence Nationale de Statistique et de la Démographie" (ANSD) in 2013[1]. With

[1] http://www.ansd.sn/.

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the problems of planning and the increasing urbanization in these agglomerations, floods are more and more recurrent causing sometimes inestimable damage such as insalubrity in public places, inaccessibility, traffic jams, collapse of buildings and even losses of human life [2]. The Fig. 1 shows an example of flood consequences in Dakar city.

Fig. 1. Impact of flood and rain disasters in Dakar during rainy season

In addition, there is the sewers backflow with all the health risks they imply. Environment and health of people are both concerned too. During rainy season, many diseases proliferate such as malaria, plague, dermatological diseases, diarrhea, etc. Wastewater, contents of garbage cans, dirt and other dangerous and sometimes toxic substances are often found in water. People crossing these waters are then exposed to all kinds diseases and infections. In this context, the United Nations (UN) has set up the World Food Program (WFP) with major packages including Agro-Meteorological Watch (AMW) which shows the need to have warning stations and aims to better inform users and to better predict the drastic consequences on agricultural yields, human health and socio-economic activities [3].

In view of all these problems, in-depth rainfall monitoring becomes a necessity in Senegal cities. In this paper, we propose an improvement of the rainfall data collection process. We design an automatic monitoring systems with real time data visualization, simple, adapted and efficient.

1.2 Process Used in Senegalese Institutions

Senegal has a Sahelian climate composed of two seasons: a shorter rainy season (from June to October) with a peak in August-September and a longer dry season. This country has a long history of climate data with more than a century of observations. First rainfall measurements date from 1854 in Saint-Louis [4]. Since then, many structures were born, such as "Agence Nationale de l'Aviation Civile et de la Météorologie" (ANACIM)[2], "Centre d'étude régional pour l'amélioration de l'adaptation à la sécheresse" (CERAAS) which is a center of "Institut sénégalais de recherches agricoles" (ISRA)[3], and "Laboratoire de

[2] http://www.anacim.sn/.
[3] http://www.isra.sn/.

Physique de l'Atmosphère et de l'Océan - Siméon FONGANG" (LPAO-SF)[4] of "Université Cheikh Anta DIOP" (UCAD).

Nevertheless, systems used by these structures don't allow real-time measurements and require human intervention for data collection. ANACIM has a fairly diversified network of meteorological observations with 24 synoptic weather stations and more than 300 rainfall stations, of which 150 are operational and distributed throughout Senegal. These stations record data which are transferred with an important delay. Indeed, ANACIM has several agents responsible for collecting and sending data to the agency by email or SMS (Short Message service) at the end of each day. In addition, the number of stations is far from achieving recommended standards of the World Meteorological Organization (WMO) and insufficient to ensure protection's missions of people and goods and also provision of climate services. LPAO-SF has a network of 33 rain gauges acquired as part of AMMA (African Monsoon Multi-disciplinary Analysis) international project[5]. These stations are spread over three zones: the North Zone with 8 stations, the South Zone with 9 stations, and the dense zone in the center-west of the country with 16 stations. This network is installed to cover the space centered on the NPOL radar (−17.09804 West, 14.65654 North) in Kawsara. It aims to document well the spatio-temporal variability of rainfall in the far west of Africa and also the contribution of different types of convective systems in the annual cumulative rainfall. However, the data are not collected in real time.

2 Design and Implementation of Proposed Rainfall Measurement System

2.1 Network Architecture

Our used network consists of several entities. The general architecture is shown in the Fig. 2.

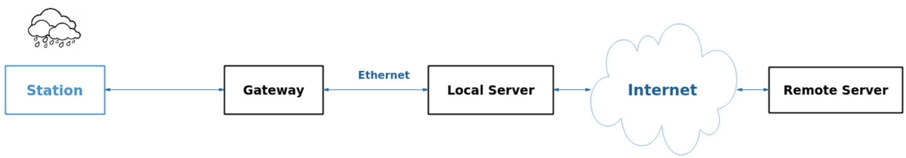

Fig. 2. Network architecture

– **Station:** It allows rainfall data acquisition and transmission to the Gateway. Each station is composed of different entities. The Design and material used are presented in the following part.

[4] http://www.esp.sn/?p=1658.
[5] http://www.amma-international.org.

- **Gateway:** This element is responsible for the mediation between stations and servers. It ensures the protocols conversion, retrieves and sends station data to the server via an Ethernet network. The data transmission is based on HTTP (HyperText Transfer Protocol). The Gateway is placed in Computer Science Department of "Ecole Supérieure Polytechnique" (ESP).
- **Local Server:** It receives data from the Gateway and stores them instantly. It hosts an Apache2 web server, a MySQL database server and a PHP application. Finally, data are sent to the remote Server using HTTP through Internet. They are temporarily stored in a buffer when Internet access isn't available. After 15 min, the local server retries sending all the data and emptying the buffer if successful.
- **Remote Server:** Its role is to allow data exploitation and visualization in addition to stations monitoring. It hosts an Apache2 web server, a MySQL database server and a PHP application with some JavaScript technology (AJAX, REST, HIGHCHARTS). Data are visualized as real time graphs. A monitoring and administration interfaces are also integrated.

2.2 Designed Station

Acquisition system is the most important element in the network. It carries out the collection of rainfall data and consists of the deployed automatic stations. An automatic station is a smart-sensor, with several units (Fig. 3).

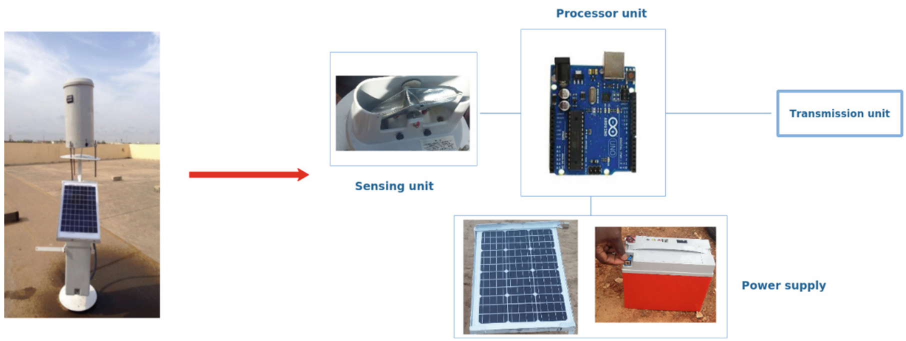

Fig. 3. Station components

Sensing Unit: Sensing unit is generally composed at least one sensor. Our stations are each equipped with a rain gauge which is the oldest sensor [5] and the most used instrument in meteorology to measure the amount of rain [6]. In this work, we use the tipping bucket rain gauge. It has two parts: a funnel-shaped collector and a container for receiving water. The collector directs rainwater towards a kind of small swing in the container, formed of two small metal buckets on each side of a horizontal axis. Water that falls is accumulated and then causes tilts. Each tilt corresponds to 0.2795 mm of rain.

Processor: It is responsible for station's intelligence. It retrieves the data from sensors, performs the processing, and formats messages. After that step, it sends data to the remote server via the communication unit. It consists mainly of an Arduino UNO board which is a microcontroller based on ATmega328P. It counts the tilts coming from the rain gauge.

Power Supply: An automatic station is supposed to be placed in areas which are difficult to access. Then, it must have a minimum of autonomy to work as long without human intervention. The proposed station model has a solar power supply thanks to a solar panel. A battery is added for storing energy and allowing station to operate when there is no sun.

Data Transmission: To communicate with the central server, the station must be equipped with a transmission module. Processing unit fully controls it. For our stations, communication unit can use various means of transmissions:

Wireless Sensor Network: We use essentially two types of wireless network transmission.

- **RF 433:** 433 MHz band is part of ISM (Industrial, Scientific and Medical) band. It is a free band intended for the use industrial, scientific and medical purposes [7] for communications via radio waves. RF band 433 allows low-coast wireless transmissions with low cost [8,9].
- **LoRa:** LoRa (Long Range) is a wireless communication technology belonging to the Low Power Wide Area Network (LPWAN) category. It allows long distance transmissions with low power consumption, low cost and a bit rate of less than 50 kbps [10]. LoRa commonly refers to two different layers: a physical layer (also called LoRa) using Chirp Spread Spectrum modulation (CSS) [11], and a LoRa Wide Area Network (LoRaWAN) protocol which provides a mechanism for controlling access and using LoRa modulation [12]. LoRa is used on ISM band 433, 868 or 915 MHz depending on the geographical zone. In early 2017, we conducted coverage tests with LoRa in Dakar, with a maximum range of 10 km [13].

Cellular Phone Networks

- **SMS:** Cellular phone networks, particularly 2G (Second Generation), are generally a choice to replace wireless sensor networks for very long distance communications. GSM (Global System for Mobile Communications) is the most widely used 2G standard and allows SMS (Short Message Service) short text messages. In Senegal, GSM covers almost the entire national territory. As a consequence, SMS is very convenient for sending data in a near real-time way [14,15].
- **GPRS:** GPRS (General Packet Radio Service), still qualified as 2.5G or 2G +, is an extension of the GSM network. It has the advantage of being faster than SMS and less expensive [14].

– **3G:** 3G has started to be used in order to satisfy users in terms of speed. Offering bits rate up to 42 Mbps, it is often an ideal candidate for a real-time system with a lower cost [16, 17].

ADSL: Station can also use the Asymmetric Digital Subscriber Line (ADSL) when placed far from Gateway. In Senegal, ADSL is widely used, well before the advent of 3G, offering speeds of up to 10 Mbps. Thus, the station sends data directly over the Internet to the Gateway via the wired network, which is more stable and more available than wireless networks.

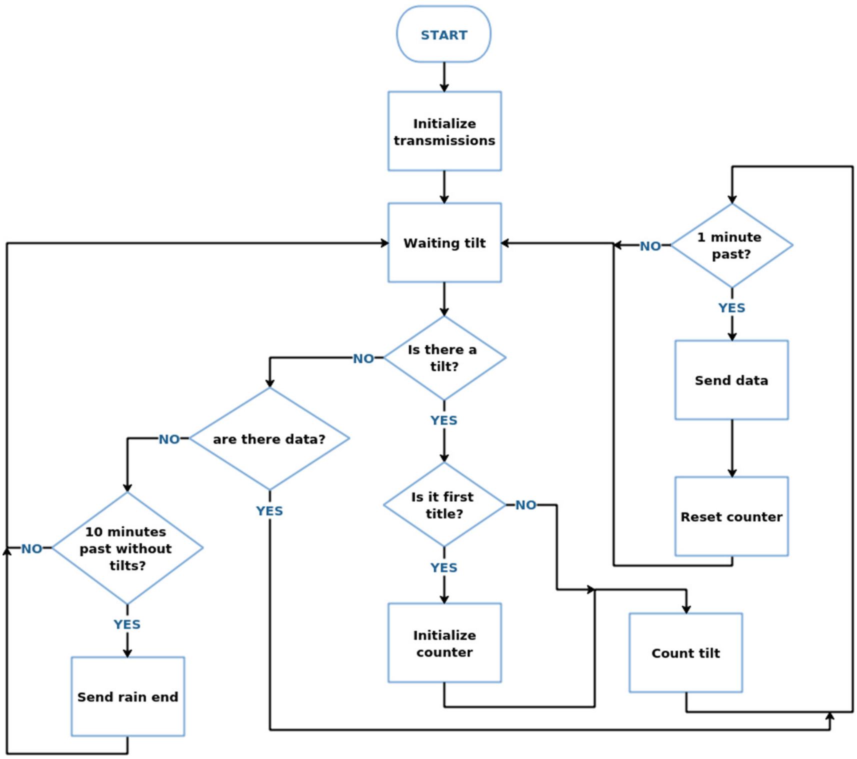

Fig. 4. Rainfall data processing flowchart

2.3 Data Collect

Data collection is done in several phases, from station to servers.

Algorithm in Station: In initial state, system waits for tilts. Then when rain starts, system considers a new rain event and then starts counting number of tilts. After each **1 min**, a message is formatted and composed of the total number of tilts, date and time, and is sent to Gateway. After this, counter is then reset. When there is no tilts after **10 min**, the system considers it is the end of rain event, and sends then a rain end message to Gateway. This process is described by algorithm in Fig. 4.

Transmission Process: Once the message is formatted by station, it is sent to the gateway which stores it in its internal memory after cleaning up errors. Finally, data are transmitted to central site. Data is then sent to remote server which stores it in its turn. Redundancy in storage allows us to ensure data availability and reliability. It allows our system to be completely independent from Internet.

2.4 Monitoring Application

In order to exploit data, a web application is integrated in the solution. The purpose of this application is mainly to:

- allow real-time viewing of data from automatic stations.
- enable researchers to consult the historical data and to be able to download them.
- allow system administration, accounts creation and deletion, consultation of details of stations and also setting.

User who comes on the application can directly observe the evolution of rainfall in real time, in the form of cumulation on a graph. He can also see total amount per rain event for the current day for all stations in the network.

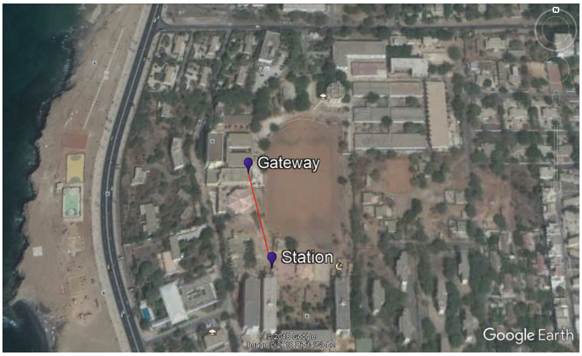

Fig. 5. Gateway and station positions in Google earth map. This image show the exact position of the Gateway which is placed in Computer Science Department and the station placed in Social Campus, in ESP

3 Validation Study

In this part, we present the validation of performances of our station. Concretely, we compare collected data of our station to data of an industrial station, both placed side by side. We collected rain data during the entire rainy season of 2017, from July 1st to October 31st, 2017.

3.1 Prototype of Our Automatic Station

To validate, we placed one of our stations in ESP Social Campus, at a distance of 110 m from the Gateway as shown in the Fig. 5.

That station uses RF 433 module for wireless communications. It consists of a CC1101 module presented in Fig. 6. This module we have already used in another monitoring project [18] has satisfactory performance and is easy to use. Communication between Processing unit and RF module is done via **SPI** (Serial Peripheral Interface) protocol. This protocol is a synchronous serial data bus which operates in full-duplex mode according to the master-slave model and compatible with Arduino cards. A CC1101 module is also used in the Gateway.

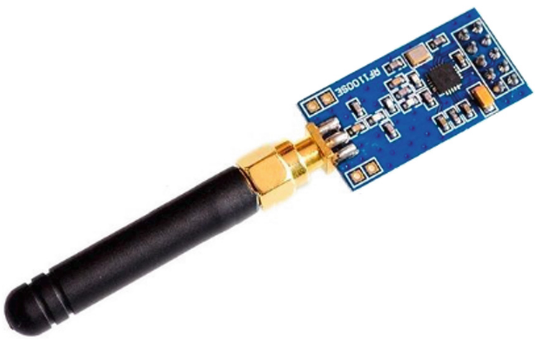

Fig. 6. CC1101 module used in our prototype for validation

3.2 Industrial Station

The industrial station used consists of a rain gauge from **LAMBRECHT meteo GmbH**[6]. It is shown in the Fig. 7 on the right. It has a precision of ±0.1 mm. It requires at least a supply voltage equal to 9.8 V.

Data collection from this rain gauge is done using a wireless transmission too but on a commercial frequency. Station counts and saves total number of tilts every 10 min and sends data daily to a remote server in LPAO-SF. It uses its own transmission protocol.

[6] http://lambrecht.net/de/niederschlag/meteorologie_hydrologie.

Fig. 7. Our automatic station designed (left) and Industrial rain gauge (right)

3.3 Data, Periods and Method

We have deployed a station placed with an industrial station side by side. These two stations have measured rainfall from July to October 2017. They recorded a total of 31 rainy events. We retrieved all these data and did analysis and comparison. To do this, we used **Python** programming language which is quite easy, open source and very powerful as well as **MATLAB**.

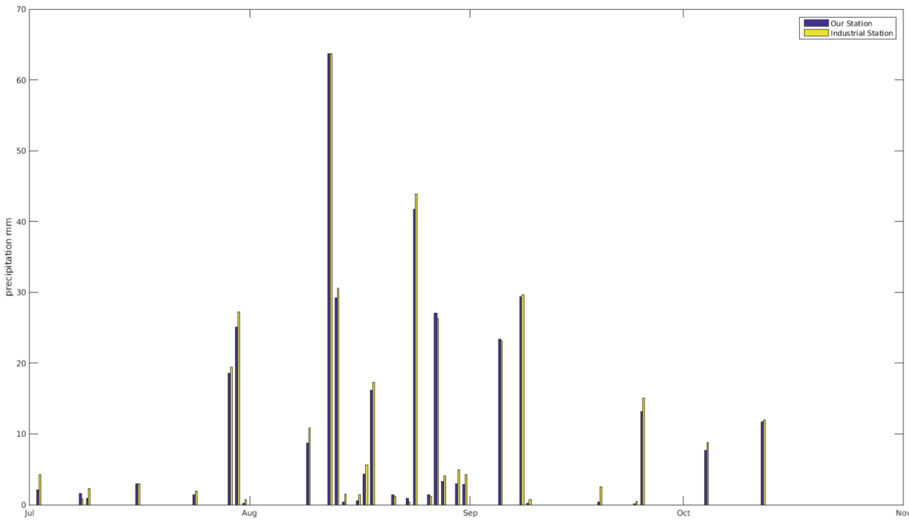

Fig. 8. Rainfall seasonal cycle. In blue, we have our station and in yellow, we have industrial station. (Color figure online)

3.4 Correlations and Results

First, we made a comparison of daily total measurements. In Fig. 8, we represent the daily measurements without any treatment. We have in yellow the data of the industrial station and the collected data of our automatic station in blue. We find that these two stations measure daily quantities substantially equal.

We obtain a correlation coefficient **r** equals to 0.99 between the collected data of our station and industrial station. The difference in total cumulation is less than 10 mm. So it is very satisfying as result. Cumulation is shown in Fig. 9.

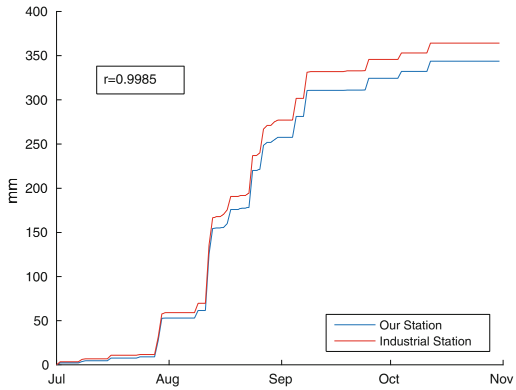

Fig. 9. Rain daily accumulation throughout the season. Our station data is blue color and red color represents industrial station data. (Color figure online)

We also studied the daily differences in the measures (see Fig. 10). In this figure, we represent the difference between the total quantity of rain measured by our station and total quantity of rain measured by industrial station used. During the rainy season, the difference fluctuate between 0 and 2.5 mm in absolute value. Nevertheless, in the majority of cases, this difference is negative (in real terms), in other words, the daily quantity measured by the industrial station is usually greater than the quantity measured by our station.

4 SenPluvio Project Overview

In what precedes, we presented a prototype of an automatic rainfall station, autonomous in energy and low cost implementation. It is placed in ESP next to an approved industrial station during 2017 rainy season under optimal weather conditions for validation. As pointed out earlier, our aim is to overcome rain damage especially floods. It is with this in mind that we initiate the SenPluvio project in LPAO-SF to design and to deploy a wide automatic rainfall stations network, less expensive, reliable and suitable for rainfall monitoring in Dakar city. On the one hand, we will improve existing data collection process used in

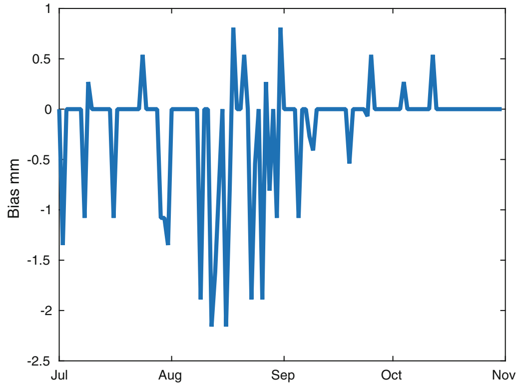

Fig. 10. Biais or difference between total quantity of rain measured by our station and total quantity of rain measured by industrial station used.

LPAO-SF. The station model that we proposed in this paper will be used. On the other hand, we will monitor and exploit the rain in real time. Every Internet users could view data in real time. An alert system will be also used to warn the competent authorities of the risk of floods. The automatic stations will be deployed in various areas of Dakar in order to constitute a very homogeneous network.

5 Conclusion

In this paper, we propose a rainfall collection system adapted, efficient and at a lower cost compared to industrial systems. We designed and implemented an automatic station for periodic measurements with a real-time storage and visualization system. After that, we studied the performance of our station using an industrial station. The result obtained reveals that our station has very coherent performances and accuracies compared to the industrial station.

We also presented a short overview of SenPluvio project whose objective is to ensure the deployment of many stations like the prototype presented here, throughout Dakar city. It's also the next step of our work. On the one hand, we are going to work and add many improvements in communication part, in particular data compression before transmission, intelligence in stations, and also security which is necessary if we want to ensure integrity. On the other hand, we will proceed to the deployment of stations in several sites in the city, chosen strategically in order to represent rain phenomenon. Finally, a warning system for populations and competent authorities will be set up with a real-time decision-making and forecasting system.

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