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Seed Money Grants 2018

FINAL SCIENTIFIC REPORT
Submitted by the Swiss Principal Investigator

The achievements of the funding instrument will be evaluated with this final scientific report (due April 30, 2020).

Parts 1 / 2 may be published in our reports and/or on our website.
Part 3 will be used for internal purposes only, in order to assess the project and to improve this funding instrument.

Please submit the report electronically and in Word format only to leadinghouse@unisg.ch

Project title	Fog Computing for Fog Harvesting and Environment Monitoring (FOG2)
Project no.	
Project start/end	01/12/2018 – 31/03/2020
Reporting period	
Principal Investigator Switzerland	Torsten Braun
Institution(s) Switzerland	University of Bern
Principal Investigator Latin America	Eduardo Cerqueria
Institution(s) Latin America	Federal University of Pará, Brazil

1 General project information

1.1 Researchers working on the project

Please list all persons involved in this project (incl. Master students):

First name, last name	Zhongliang Zhao
Academic degree / title	PhD in computer science

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Academic degree / title	PhD in electrical engineering

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Academic degree / title	PhD in electrical engineering

First name, last name	David Carrera
Academic degree / title	PhD in water sciences

First name, last name	Hugo Santos
Academic degree / title	Master in electrical engineering

First name, last name	Jose Carrera
Academic degree / title	PhD in computer science

First name, last name	Stefany Pinheiro
Academic degree / title	Undergraduate student in computer engineering

First name, last name	Derian Alencar
Academic degree / title	Undergraduate student in computer engineering

2 Scientific information

2.1 Abstract of the project

Due to population growth and global warming, many Latin American cities will have water shortage problems in the near future. Paradoxically, there are years when precipitation is high and the El Niño Phenomenon causes floods that damage the cities in the lower basin. Therefore, it is necessary to relate climatic variables to manage water resources in the case of droughts and to prevent damages by installing early warning systems close to end-users to reduce the damages in the populations flooded in high precipitations. The FOG2 project aims to setup a platform to discuss the design, implementation, and testing of a wireless network infrastructure and a fog computing-based catcher system in the mountain/river areas of Brazil and Ecuador, called Warka water tower, to collect and harvest potable water from the air and deliver an early hazard warning system. In this project, we will investigate the feasibility to apply the fog harvesting technique and deploy removable metal structures in a surface hydrographic basin located in the Andes of Ecuador. A data collection system will be deployed to interconnect all the Warka water tower sensor data, as well as the river flow sensors. A fog computing system will be deployed next to the sensor node in order to perform real-time sensor data processing. The pre-processed data will be sent to cloud/edge computing system to find relationships between the collected data and the flow rate using advanced machine learning algorithms. The insights will then be transmitted in real-time by the flow conditions in case of an atypical precipitation.

2.2 Aims of the project

The main goal of this project is to design, implement, and test a wireless network infrastructure and a fog computing-based catcher system in the mountain/river areas of Brazil or Ecuador to collect and harvest potable water from the air and deliver an hazard early warning system. In the following, we explain the relevance of environmental data collection, edge computing nodes for real-time data processing and warning notifications, and also Wireless networks.

2.3 Deviation from work schedule and results

There are no major deviations from scheduled work plans. Some planned flooding monitoring experiments using the testbed deployed in Belém-Brazil cannot be performed due to the university lockdown caused by COVID-19 outbreak. The deployed infrastructures will allow researchers to conduct these experiments in the future.

2.4 Results and conclusions

2.4.1. Fog Harvesting

The FOG2 project aims to set up a platform to provide a wireless network infrastructure and a fog computing-based catcher system in the mountain/river areas of Ecuador, called Warka water tower, which collects potable water from the air. In this sense, we deployed in the Warka water type windbreaker in a surface hydrographic basin located in the Andes of Ecuador to collect the potable water from the atmosphere.

We tested some designs of the fog collector systems to determine which is the one that captures the most water, also, based on a cost benefit study, which is the most technically, economically and environmentally feasible to replicate in the Andes of South America. The first prototype is presented in Figure 1 as a pyramidal system. The second prototype is presented in Figure 2 as a square section system. The third prototype is presented in Figure 3 as a circular section system.

Considering that LoRa devices can transmit over a range of several km in Line of Sight (LOS) conditions, we performed a transmission test in the deployment area. After the tests we defined 400m as the optimal distance of communication. From the Warka water tower, the sensor nodes with a LoRa transceiver transmit information to the LoRa Gateway. Afterwards, data is transmitted to an application and database server through IP networks. The data of the fog harvesting is transmitted every 4 hours to the application server at University of Bern. in Switzerland.

Figure 1. Fog collector system pyramidal

The manual collection of information in the Andes area of Ecuador is infeasible due to difficult access conditions. The fog collector system provides an automated way to determine the amount of water collected under different environmental conditions. The fog collector systems were installed in August 2019 and we continue to monitor them, we wait until August 2020 to complete at least one year of data to start analysing them, however, some analyses have been carried out. We obtained the relationship between the liquid level sensor of the tank with the environmental parameters information. The sensors are solar powered, temperature, humidity, optical fog sensor, air pressure, liquid level sensor and anemometer. The obtained results indicate a low percentage of relationship between liquid level sensor and environmental sensors. The correlation values are presented in Table 1.

Table 1. Correlation values.

Environmental variables	Estimated	Error Standard	T value	Pr major t
Solar powered	0	0.10	0	1.0
Temperature	0.13	0.21	0.64	0.52
Humidity	-0.15	0.13	-1.21	0.23
Optical fog sensor	-0.06	0.21	-0.28	0.78
Air pressure	-0.10	0.12	-0.83	0.41
Liquid level sensor	-0.02	0.13	-0.12	0.90
Anemometer	-0.17	0.12	-1.41	0.16

Figure 2. Fog collector system square section

Figure 3. Fog collector system circular section

Figure 4. Project meeting in Quito

A study was carried out to determine the best place to locate the three fog collectors systems and to represent the typical areas of the Andes of Ecuador. Figure 5 shows the location map.

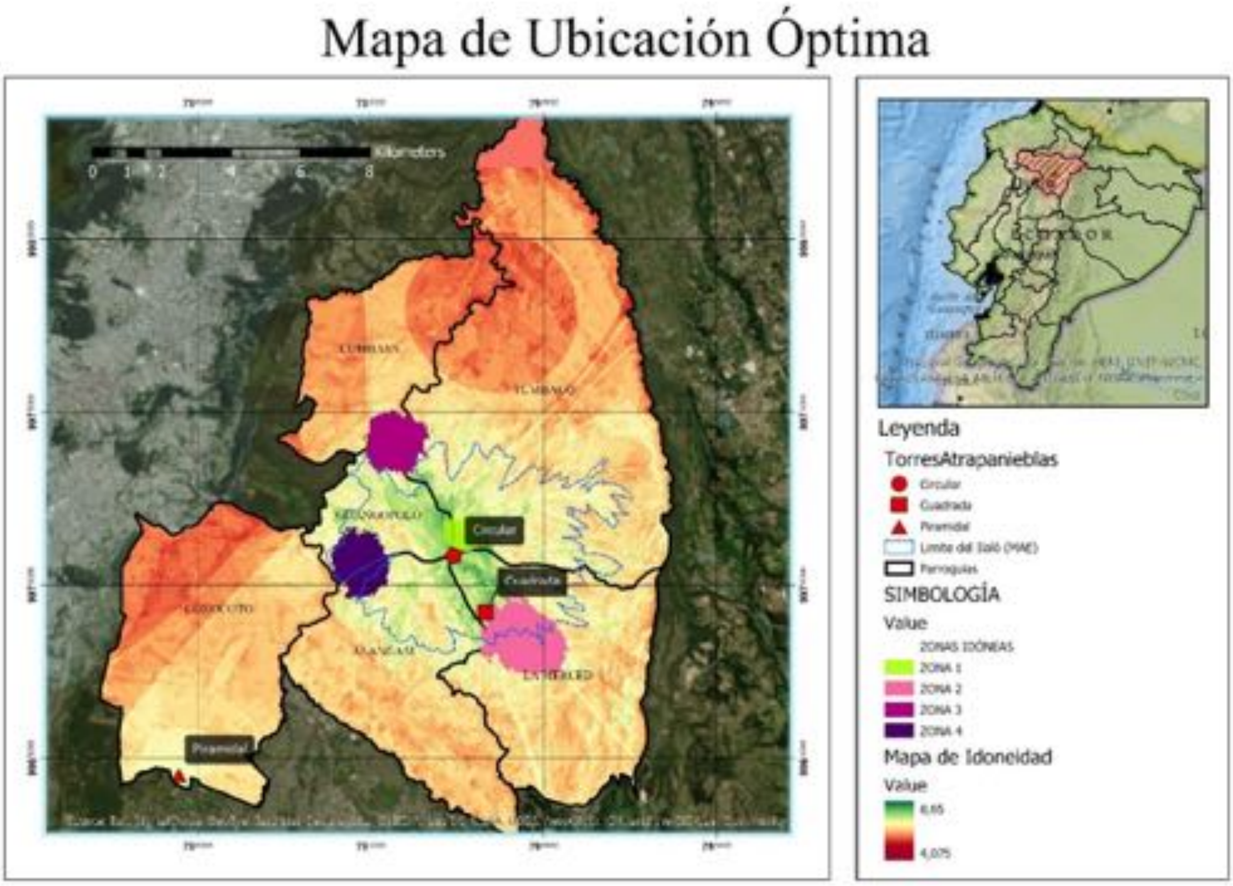


Figure 5. Location of the three fog collectors systems

With the preliminary data it has been determined that the best prototype was the fog collector system square section, capturing 4.57 liters of water per square meter of mesh and per day. The sensors installed today have more than 1000 data about liquid level sensor of the tank, the solar powered, temperature, humidity, optical fog sensor, air pressure and anemometer.

2.4.2. Environmental Data Collection

One of the goals of this project is to deploy some sensors in order to collect and to send sensor data on the Warka water tower in real-time, which can be used to calculate the amount of water that is collecting. To this end, we deployed a LoRa network infrastructure, since LoRa network architecture considers a star-of-star topology, granting a single hop between the sensor device and gateway, eliminating the need to build and maintain a complex multi-hop network. Figure 6 shows the environmental data collection for the Warka tower communication setup, which consists of sensor devices that collect data from the Warka tower environment, and transmit them to an application server deployed at the University of Bern via LoRa gateway. Specifically, we deployed sensor devices on the Warka water tower to monitor a set of variables, such as visibility level, wind speed temperature, humidity, light, liquid level, and air pressure, which are transmitted to a LoRa gateway. The LoRa gateway deployed at ESPE communicates with the cloud infrastructure deployed at UniBe through an IP network. The cloud infrastructure performs data storage, and implements a web-based interface to online access the monitoring information collected from the sensors of the Warka tower, as shown in Figure 7.

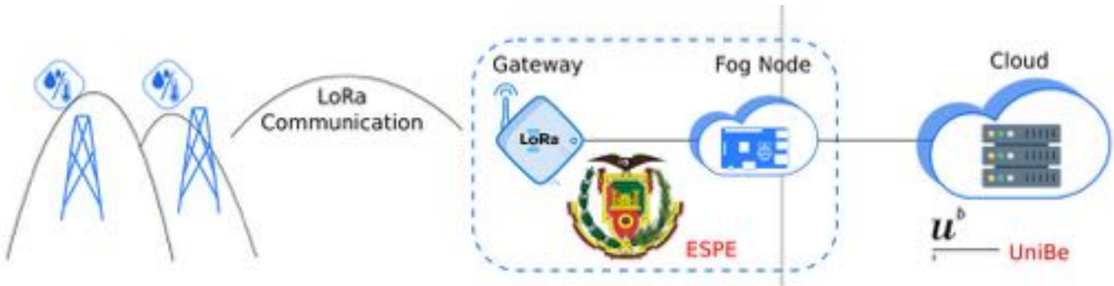


Figure 6. Warka tower communication setup

The prototype development consists of the use of an Arduino Uno deployed on each tower, which has multiple sensors to collect visibility level, wind speed temperature, humidity, light, liquid level, and air pressure. Each Arduino Uno has a LoRa radio shield for communication, which is used to broadcast LoRa messages with collected data. These messages are received by the TTN Gateway deployed at ESPE, which forwards radio transmissions to the cloud server. In our deployment, we consider a Raspberry Pi connected to the TTN Gateway to work as a fog node in order to store the collected data for a short period, because there is an inconsistency in the connection between TTN gateway and cloud. In addition, the raspberry acts as a backup to send the data later.

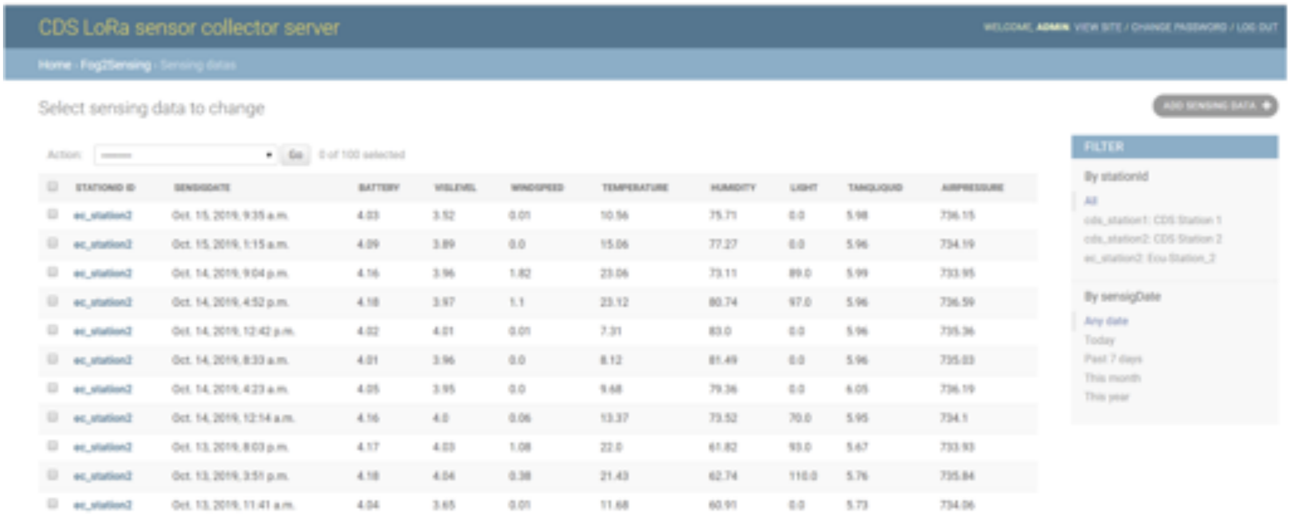


Figure 7. Monitoring System Web-based Interface

For the exploratory statistical analysis and Machine Learning models, the data were grouped with a daily frequency, allowing better information management and eliminating the large number of outliers that can generate noise. The development of the exploratory statistical analysis was carried out in free software R. Before carrying out any statistical model, it is essential to know the quality of our data and its behaviour. One of the most important statistical tools is the generation of histograms to know the frequency and distribution of the data.

For the temperature values, a slightly right-biased form is presented with a frequency ranging from 0 to 150 with greater accumulation in the range of 11 ° C to 13 ° C and an average of 13.17. The histogram for air pressure presents a normal distribution with greater accumulation between 735 to 737 mmHg. Wind speed has a histogram in the form of a cliff tilted to the left with accumulation of values between 0 and 1 m/s with a frequency of 0 to 500. The level of visibility has a cliff shape inclined to the right with the accumulation of the distribution of values between 3.5 and 4.5 volts with a frequency ranging from 0 to 280.

Humidity has a bimodal behaviour since it presents two realities with a high frequency, the lowest being between 35 and 40% humidity and the second where the largest distribution of data is accumulated, ranging from 70% to 90% humidity in the air. The last variable is the amount of light whose distribution in its highest percentage is 0 and a small warhead between 80 and 100. The graphs of each of the variables are as annexes Multivariable exploratory analysis is essential to determine the relationship between the elements that make up the study. Pearson's correlation is the statistical tool that indicates the relationship between two variables (Figure 8).

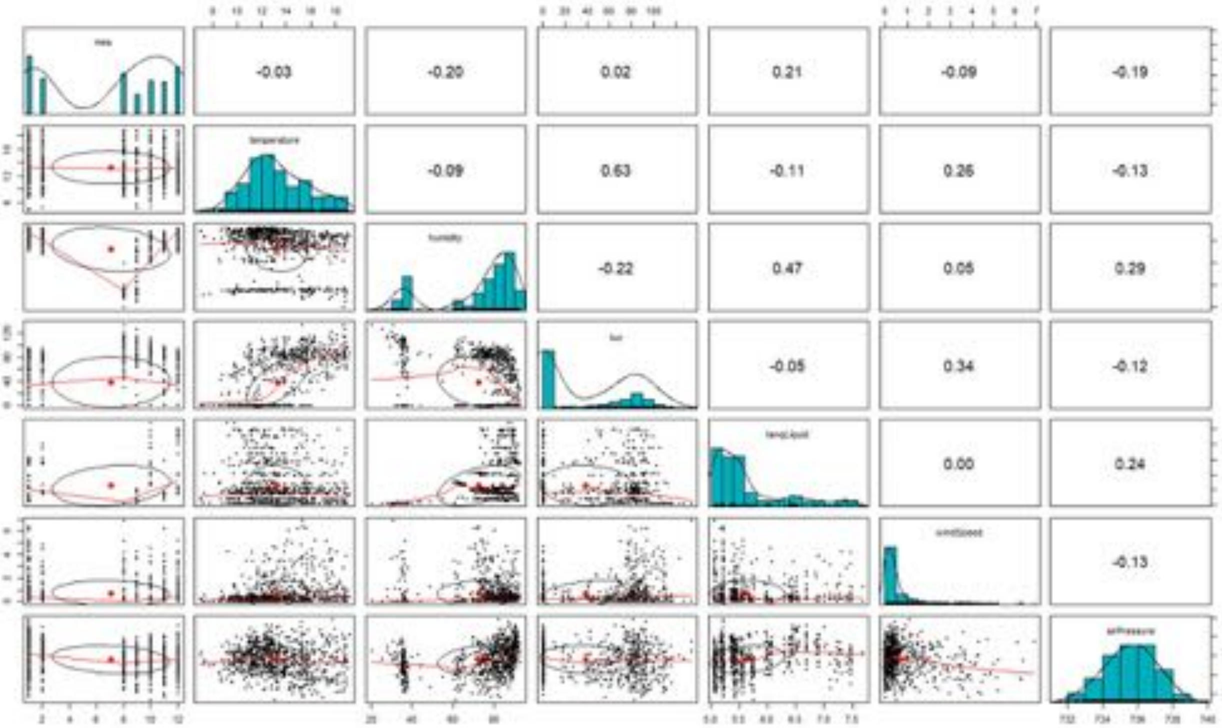


Figure 8. Correlation between variables of about liquid level sensor of the tank, the solar powered, temperature, humidity, optical fog sensor, air pressure and anemometer.

We also deployed a flooding monitoring system, which uses real-time data collection to detect the risk of flooding in different areas. This is because it is important to prevent damages caused by current climatic changes, which can be achieved by installing early warning systems close to end-users to reduce the damages in the populations flooded in high precipitations. In this way, we deployed a monitoring system in the flooding areas of Belém-Brazil in order to provide a hazard early warning system. It is similar to the Warka water tower communication setup, but it needs a quick response based on real-time sensor information. In this way, we must collect sensor data from the environment, such as, air pressure, humidity, light, rainfall, temperature, and water level, which are transmitted via LoRa Gateway for an application server, as shown in Figure 9. A fog computing system can be used to find relationships between the collected data and the flow rate using advanced machine learning algorithms. The insights will then be transmitted in real-time by the flow conditions in case of an atypical precipitation.

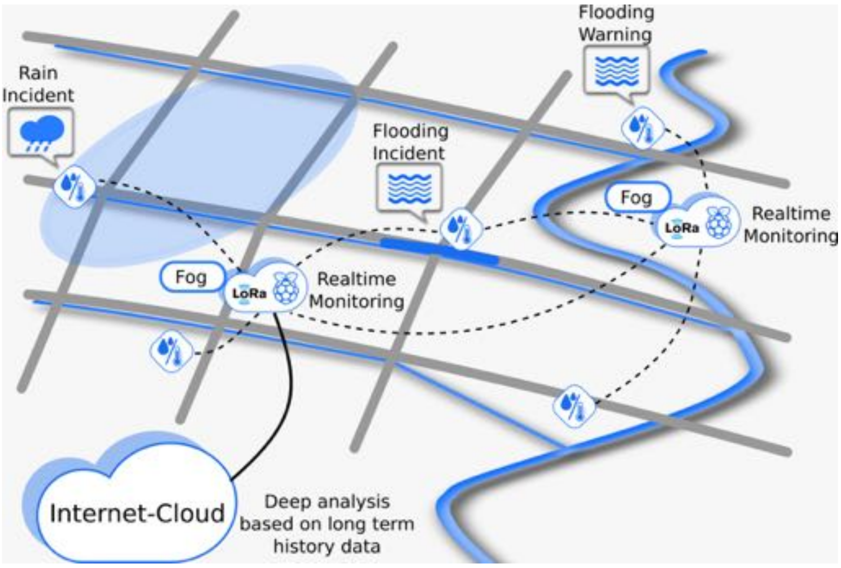


Figure 9. Flooding and rainfall monitoring deployment

Figure 10 shows a schematic of the prototype setup, which consists of a set of sensor devices collecting and sending the data through a LoRa device like ESP8266 LoRa. These data are received by the TTN LoRa Gateway deployed at UFPA, which forwards the data to the cloud server and fog node. A Raspberry Pi is connected to the TTN LoRa Gateway by serial communication in order to work as a fog node, which is responsible for sending this data to the cloud and also storing locally. We use this dataset as inputs of the machine learning model to predict rainfall. In this sense, the sensors work in a similar fashion as the Warka water tower sensors, and the Lora devices act like the TTN gateway of the deployment scenario.

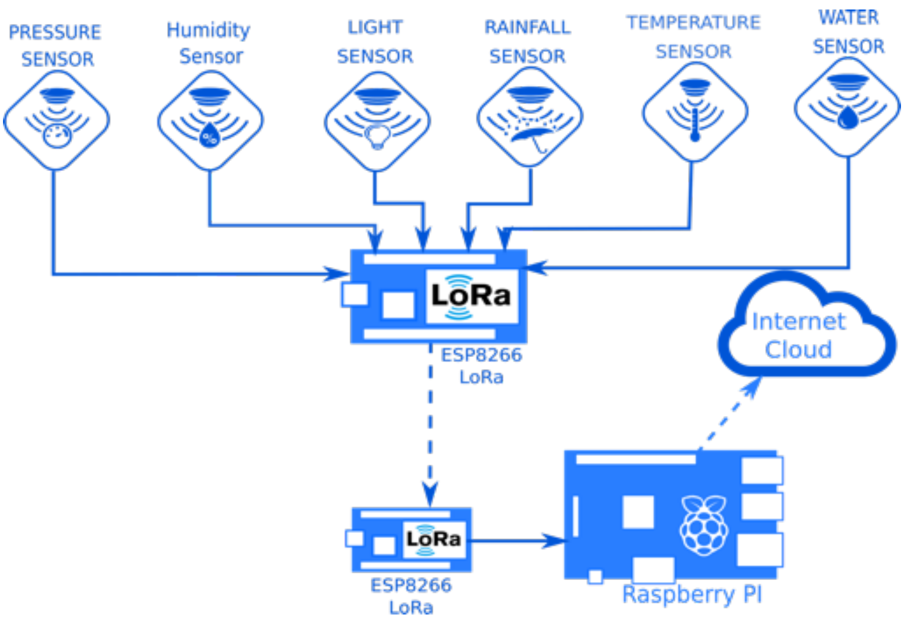


Figure 10. Prototype Scheme for flooding monitoring system

The fog computing system brings the cloud applications closer to the physical sensor devices at the network edge. For instance, analysing data closer to where it is collected minimizes latency, offloads gigabytes of network traffic from the core network, and also keeps sensitive data inside the network. On the other hand, less delay sensitive data is sent to the cloud for historical analysis, big data analytics, and long-term storage. In addition, cloud infrastructure has more storage, computing and network resources, and it can control a specific set of edge devices and access to clouds.

Figure 11 shows the workflow for flooding monitoring system considering fog node development, where the fog node receives the collected data, processes them, and gives as a result flooding warning and precipitation prediction, as well as send the collected data to the cloud. To this end, fog node consists of four modules, namely, sensor data formatting, offline warning, machine learning models, and internal database. In this scenario, all the data generated by the sensor nodes are received by the TTN LoRa Gateway, and forwarded to the fog node, which formats the data into a CSV file and stores them in an internal database. The fog node has a machine learning model responsible for predicting the possibility of rainfall. To this end, it is analysed the weather and the daily precipitation, because of local properties that act in the local flood, such as, the period of more rainfall. In this sense, the machine learning model was trained using a local dataset considering weather characteristics, such as, temperature, humidity, precipitation, and insolation, in order to predict the possibility of flood, it analyses the weather and the daily precipitation. Furthermore, the machine learning model can be periodically updated to improve accuracy, due to the possibility of using the new data obtained by the sensors in the long term. The output is the warning of a possibility of flood occurrence based on the precipitation. Based on the possibility of flooding, offline warning model could send warning notifications, such as SMS messages, to subscribed users with low delay, since the data is processed at places closer to end users in order to reduce the damages in the populations flooded in high precipitations.

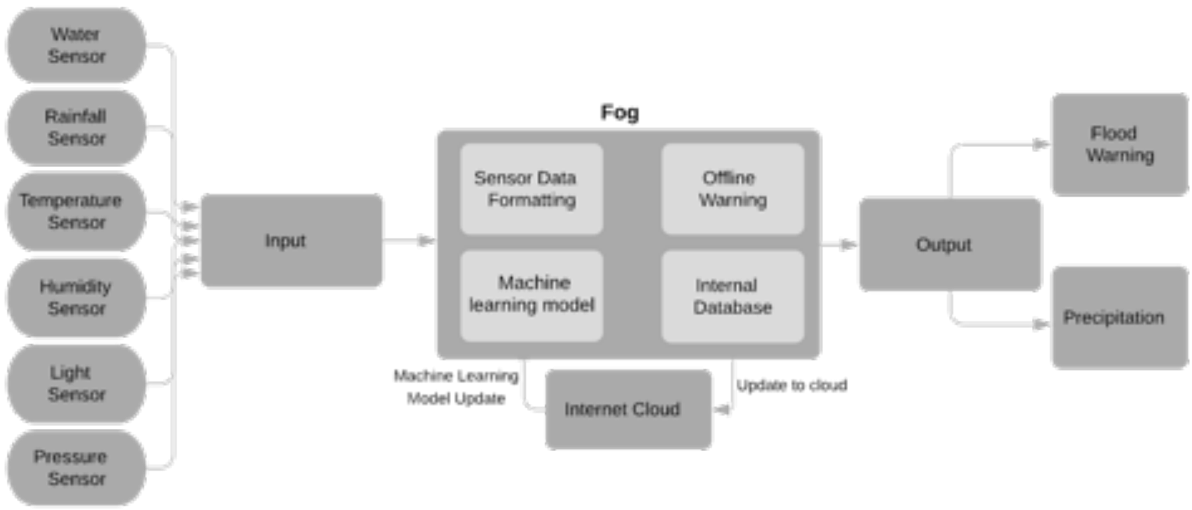
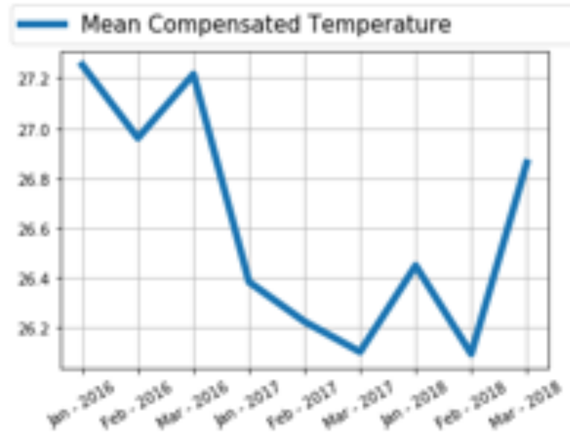
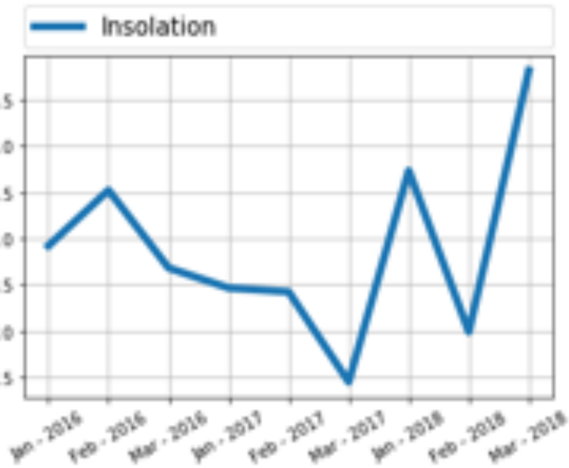


Figure 11. Flooding monitoring workflow

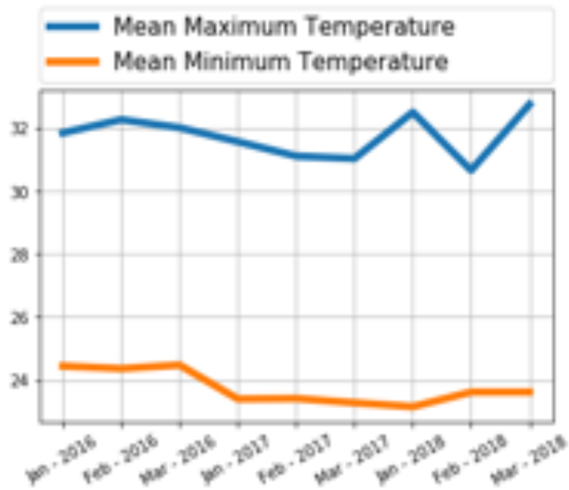
A Random Forest (RF) algorithm predicted the daily precipitation using past weather data. RF is a low complexity machine learning technique to correlate Insolation, Temperature and Humidity. RF works with the concept of forming smaller selections of a tree, informing different results in these smaller trees, and counting the most chosen solution (i.e., majority tree) as the answer to a question, which is the predicted rainfall and flooding risk. RF was selected because it is an efficient general-purpose classification method and does not perform pruning (in contrast to single decision trees), and the search is faster. To train the model, we consider a public dataset found at INMET [1], which is a national meteorology institute from Brazil. The dataset has historical data from Belém between Jan. 2016 to Mar. 2018 for compensate temperature, Insolation (i.e., the amount of solar radiation reaching a given area), mean maximum and minimum temperatures, and mean Humidity, as shown in Figure 12.



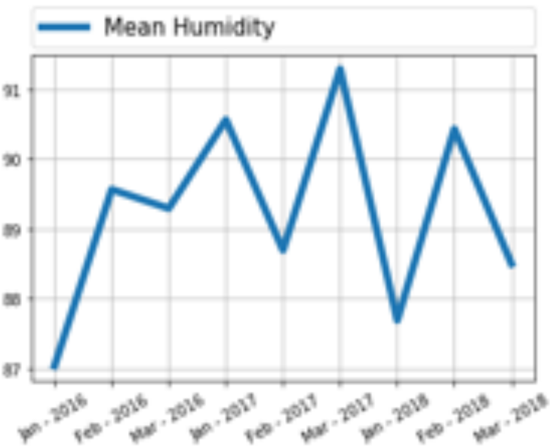
a)



b)



c)



d)

Figure 12. Two years input data from INMET dataset. a) compensate temperature, b) Isolation, c) mean maximum and Minimum Temperatures, and d) Mean Humidity.

Figure 13 shows the rainfall occurrence in the dataset, and the predicted value. The RF model predicted the precipitation with a 88% accuracy with a 9.52 in standard deviation, that indicates that the values are spread out over a wider range. This RF model can run on the fog node within 300 Milliseconds, which is acceptable in order to predict rainfall, and afterwards flooding.

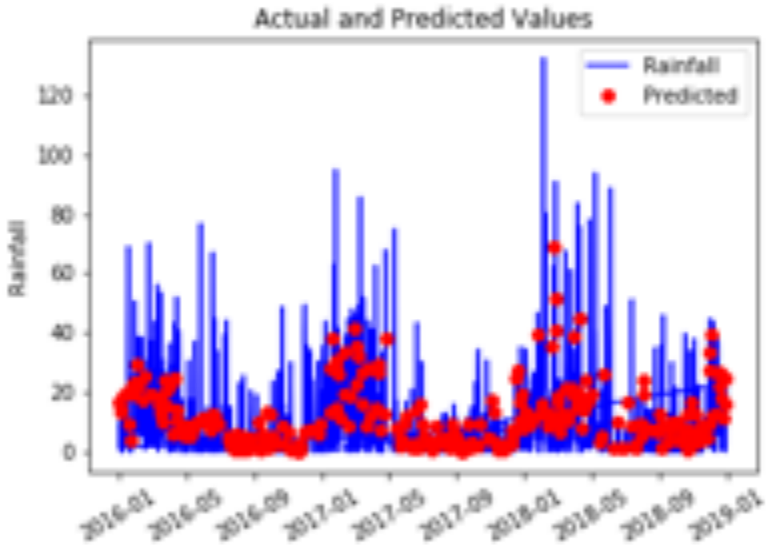


Figure 13. Actual and predict values

2.5 List of project related publications

Please list ALL the publications produced in this project.

1- Carrera-Villacrés, D. C., Carrera Villacrés, J. L., Braun, T., Zhao, Z., Gómez, J., & Carabalí, J. Q. (2020). Fog Harvesting and IoT based Environment Monitoring System at the Ilalo volcano in Ecuador. International journal on advanced science, engineering and information technology, 10(1), 407-412. DOI: http://dx.doi.org/10.18517/ijaseit.10.1.10775

2.6 Expected institutional impact and further steps (collaboration activities, teaching activities, exchange, initiated or concluded agreements, etc.)

The impact on the Universidad de las Fuerzas Armadas ESPE in Ecuador is positive because the fog collector systems and installed infrastructure will serve as a laboratory for students. It will also be a model to replicate it in other places that do not have water in South America.

Currently, the fog collector system square section is generating meteorological information and how much water is collected every 4 hours, which will serve to generate predictive models with a greater degree of accuracy. In February 2020, students from Argentina, Perú and Chile visited the fog collectors systems and this project will probably be replicated in those countries as their thesis of engineering civil and environmental. The place where the fog collector system square section was installed is an experimental agro-ecological farm and is constantly visited by students from all over the world who come to volunteer and learn sustainable agricultural techniques. Students are impressed by our work. The fog collectors systems provide water, meteorological information and also generate a positive visual impact without distorting the environment. The idea is to build a fog collector system that is removable and that also controls its own internal climate so that it forces more condensation. We are working on it. The Universidad de las Fuerzas Armadas ESPE hopes to continue working with the University of Bern and Federal University of Pará on new projects. The LoRa network infrastructure deployed at UFPA is available to the UFPA community, such as students, professors, and startups. The infrastructure is also available for future projects related to the Internet of Things or environmental monitoring applications. As a concrete example, some students used such infrastructure during two classes, i.e., Urban Computing and Computer Network, in the second semester of 2019 (July to December, 2019).

As a result of our collaboration, we submitted two projects with collaboration between UFPA and UniBern to an open call from the São Paulo research foundation, Brazil, where each project has a budget of R$ 100.000,00. The projects are entitled: "VeiAut: Framework for Providing Data Analysis, Vehicle Cloud Computing and Mobility as a Service for Connected Autonomous Vehicles", and "Management of Real-Time Services in Computing on the Edge and Extreme Edge".

2.7 Expected patents, commercial potential and private partners

No.

3 Assessment of the program

3.1 Your evaluation of the funding instrument

Do you have any feedback on the funding instrument and its organization and management? What worked well? Where did you encounter difficulties? What could be improved?
Do you have any suggestion for a next call?

This program provides a good opportunity to join the research interests of both Switzerland and Latin-America institutes to conduct research activities that can be beneficial for all partners.