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The analysis and deployment of a fully open monitoring system in the Sri Lankan Deduroya basin: the 4onse project

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1. Introduction

According to the 2017 report of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), Asia and the Pacific region are heavily affected by natural disasters. In 2016, hazardous phenomena killed 5 thousand people and caused about USD 77 billion of damages. The greatest loss and the damages were due to flooding and droughts. In this context, the monitoring of hydro-meteorological parameters supports several activities such as the mitigation of natural disasters, the management of the water resources and the forecast of the weather conditions. Thanks to the recent technological developments (Internet of Things, big data, ubiquitous of Internet, etc.), "non-conventional" monitoring systems based on open software, open standards, open hardware and low-cost sensors could represent a complement to official monitoring networks or a main source of weather information in regions where traditional networks are in decline or totally missing. In fact, in low income and developing countries there is still a lack of dense monitoring systems due to: high costs related to conventional solutions; low accessibility to the hardware and software components; missing of data interoperability; closed source of data format, hardware and software solutions.

In this framework, the 4onse project (www.4onse.ch) (analysis of Open, Non-conventional, Sustainable and Effective monitoring systems), funded by the Swiss National Science Foundation (SNSF), aims at evaluating if a fully open solution could be a viable solution to build an environmental monitoring system in a sustainable and "effective way". Such a system was implemented during the first year of the project. The system is composed by weather stations which are connected through the GPRS 2G to the istSOS software hosted on a server dedicated (Figure 1).

This article presents the results of the weather station prototype validation and the ongoing deployment activity that aims at setting-up the 4onse monitoring system in the Deduroya Oya river basin. Once the 4onse weather stations network installation will be finalized the whole system can be verified from a socio-economic and scientific point of view.

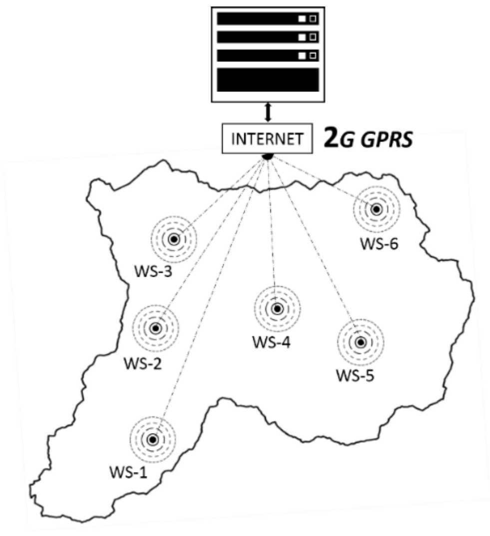

Figure 1 - 4onse system schema.

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2. The study area

The Deduroya Oya river basin (Figure 2) was selected for the deployment of the 4onse monitoring system. The catchment area of 2 687 km^2 collects an annual amount of rainfall which can reach 2 600 mm in the wet districts of Kurunegala and Puttalam. From the annual rainfall about 50% is received during the monsoon months (March-April & October-November) (Sampath et al., 2015). The basin has a tank system to mitigate the flood risk and to provide water for crops, however a management system that is based on hydrological models and is capable to support operational tank management and facilitate water downstream lamination is still missing. Additionally, the ability of rise timely alerts and warnings is undermined by the absence of real time, dense and continuous meteorological data.

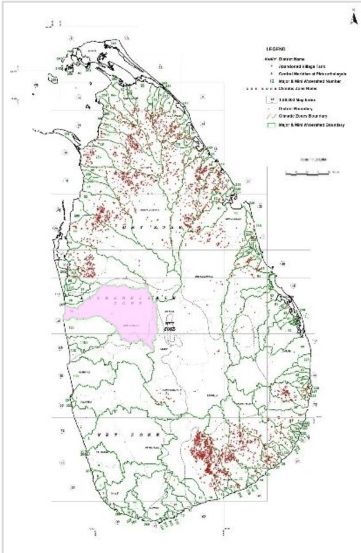

Figure 2 - Deduru Oya river basin, case study area of the project.

Currently, 22 locations were selected to install the weather stations for testing the 4onse experimental monitoring system (Table 1) according to the following criteria:

- proximity to the sub-basins' centroids;
- registration of high rainfall events;
- accessibility – closer to a main road;
- at least one station for sub-basins;
- sites inside religious places, police stations, hospitals, post offices etc.;
- outreach to young population.

Total stations	22
N^o of selected schools	18
N^o of selected temples	2
Other places	2

Table 1 - Selected locations for the weather stations deployment.

3. Material and methods

The 4onse system is composed by three main layers (Figure 3) (Cannata et al., 2017): the hardware layer is individuated by the weather stations, nodes, to observe the environment; the communication layer has the role to transmit data from the node to the server through adopted protocol and media; finally, the service layer archives, manages and processes data to create and exploit the information thanks to a number of chained web services. In the following paragraphs, the description of the methods and materials used for the deployment of each layer is presented.

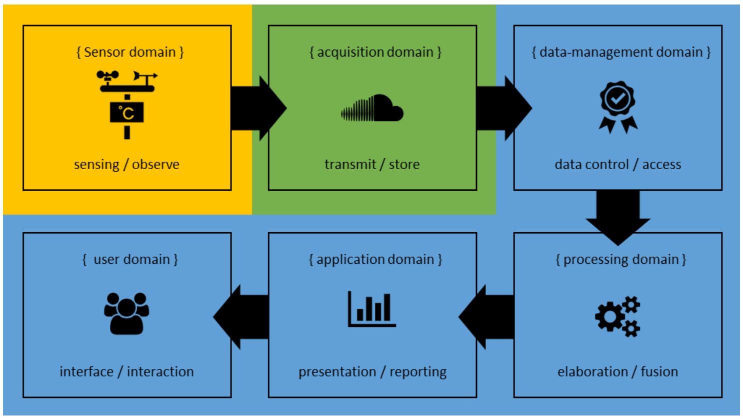

Figure 3 - 4onse Environmental Monitoring System architecture and its component's domains grouped in hardware (yellow), communication (green) and service layer (blue).

3.1 The hardware layer

Since these type of networks are located in large areas with long distances between nodes, a multi-node network composed by independent weather stations was planned in order to have a one-to-one communication between the node and the server which works as a collector of the requests. At the time of writing (June 2018), 14 weather stations were installed in the basin following some rules concerning the sensors and control unit set-up. In Table 2, the main requirements are listed and summarized.

Sensor	Altitude	Location (suggestions)
Temperature/humidity	from 1.7 to 2 m	A green field at least 10 meters away from any kind of obstacle (buildings, trees, etc.)
Pluviometer	from 1.5 to 2 m	10 meters away from any kind of obstacle which can prevent the rain to fall inside the bucket
Solar radiation	2 m	At the top of the pole, pay attention to possible shadows which can make shade on the sensor
Anemometer	2/2.5 m	At the top of the pole and at least 10 meters away from possible obstacles

Table 2 - Weather station deployment restrictions in sub-urban area.

In agreement with the project philosophy of building at low cost a station highly replicable, two weather stations (4onse-mod and 4onse-pcb) were developed with the same hardware components but with different building strategies for different needs. 4onse-mod uses only components widely available on the market and thus maximizes the reproducibility of the system while requiring long assembly time; 4onse-pcb, is based on a Printed Circuit Board (PCB) which minimizes the building time increasing the difficulties in the reproducibility since the PCB should be specifically created.

To evaluate the durability and the costs related to the maintenance of the stations, a system to keep track of the issues and the operations performed on each station along the testing period was developed. The ODK suite was used to provide on the server side a system to store the information and on the client side an Android application which works both as a checklist and as an issue tracker for the maintainers. The collected data will be analysed to better realize which are effectively the costs of maintenance and the durability of the components.

3.2 The service layer

A data warehouse capable to handle and process data providing reports and information to stakeholders needs a server infrastructure and software. The 4onse backend is composed by a Debian based distribution (Ubuntu 16.04 LTS) hosted on machine with two CPUs of @ 2 GHz 64 bits, 2 GB of RAM and 200 GB of Hard Disk SSD. istSOS (Cannata et al., 2013) together with its dependencies (PostgreSQL, Apache and Python 2.7) are installed to offer services for data storing, sharing and management that are totally compliant with Sensor Observation Service (SOS) standard of the Open Geospatial Consortium (OGC).

3.3 The communication layer

Each station is directly connected with the server thanks to a GPRS 2G mobile connection enabled by a SIM800 (http://simcomm2m.com) module. Since a SIM card is mounted on the Simcomm module, the mobile provider was selected considering and balancing two main factors:

1. good mobile signal to guarantee a stable connection to the Internet;
2. price of the flat plan.

The free android application OpenSignal (https://opensignal.com/) was useful to get and analyse the signal strength stats of the providers available at the station's location. To guarantee a good and stable connection to the nearest phone cell the RSSI must be up to -80 dBm (Table 3).

RSSI dBm	**Condition**
From -109 to -95	Marginal
From -95 to -85	OK
From -85 to -75	Good
From -75 to -53	Excellent

Table 3 - Classification of signal quality based on RSSI.
(http://m2msupport.net/m2msupport/atcsq-signal-quality/)

Once the device is connected to the GPRS network, the device-to-server data transmission uses a RESTful style architecture over HTTP/HTTPS which guarantees a request/response pattern. The standard SOS *InsertObservation* XML request is not used because it comes with many meta information increasing the time and bandwidth needed. Thus, a faster and lighter data messaging technology, called *fastInsert*, was implemented within the istSOS software to reduce issues during the insertion of observations (Strigaro et al., 2017).

3.3 The weather station validation

A 4onse-mod weather station was compared with a nearby authoritative weather station of the hydro-meteorological network of the Cantone Ticino in Switzerland to validate and analyse the correlation between the time series of the parameters measured (air temperature, air humidity, air pressure, cumulated rain, etc.). The following methods were used to get an estimation of the data quality:

- visual comparison of the recorded data;
- time series goodness-of-fit calculation trough the coefficient of determination by Pearson;

- coherence of aggregated values (daily mean, max and min values);
- scatter plots to evaluate the general behaviour of the 4onse weather sensors.

Many are the tools available to perform time series analysis. During the project activities and for this article, to follow the Openness principle of the project. The authors selected:

- Observations Analysis Tools (OAT) (Cannata et al., 2017)
- Pandas (https://pandas.pydata.org/)
- Matplotlib (https://matplotlib.org/)

4. Results and discussion

The installation of the stations follows the tests performed on the 4onse-mod station to scientifically validate the weather station. Six months of data collected by the 4onse-mod for the temperature, pressure, humidity and rain parameters were compared with the time series provided by the Canton Ticino Trevano station.

The mean residual of the temperature parameter is +0.26°C with a standard deviation of 0.10. The R-squared is 0.99 which indicates a very high correlation of the values (Figure 4).

In Figure 5, the humidity daily mean values of the two stations show slightly different results. Even if the R-squared is 0.99, the mean error is -1.60% with a standard deviation of 2.90. The scatter plot confirmed the greater dispersion than the results of the previous parameter considered and the increasing of the overestimation trend with higher values of humidity (>70%). However, the 4onse humidity values are totally acceptable for the purpose of the project since almost all the values fall inside an interval of +/-4%.

The comparison analysis of the pressure parameter, as for the temperature, shows very good results with high values of correlation. According to the scatter plot in Figure 6, basically all the values are on the identity line, in fact the mean error is 0.38 hPa and the standard deviation 0.16 with a R-squared of 0.99.

Table 5 briefly summarizes the amount of rain collected by the two tipping-buckets. The total amount or rain recorded in six months is 632.4 mm for the 4onse station and 672.8 mm for the Trevano one. The difference of 40.4 mm represents an error of 6%.

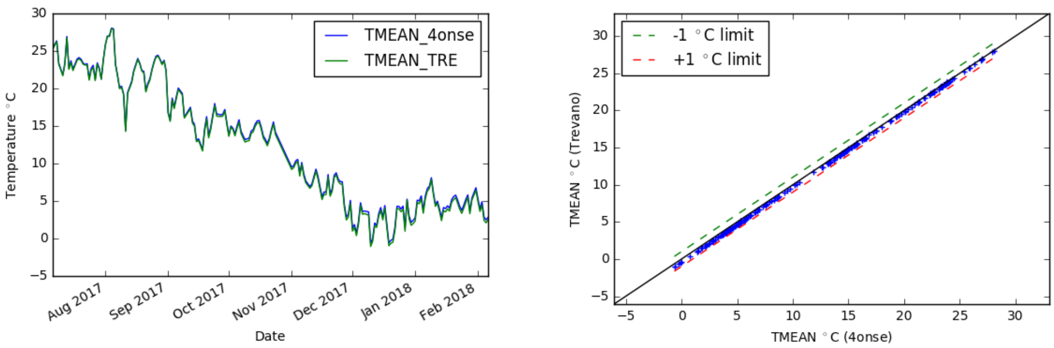

Figure 4 - Temperature daily mean time series overlapping of 4onse and Trevano stations (left); Scatter plots between the 4onse and Trevano daily mean temperature values (right).

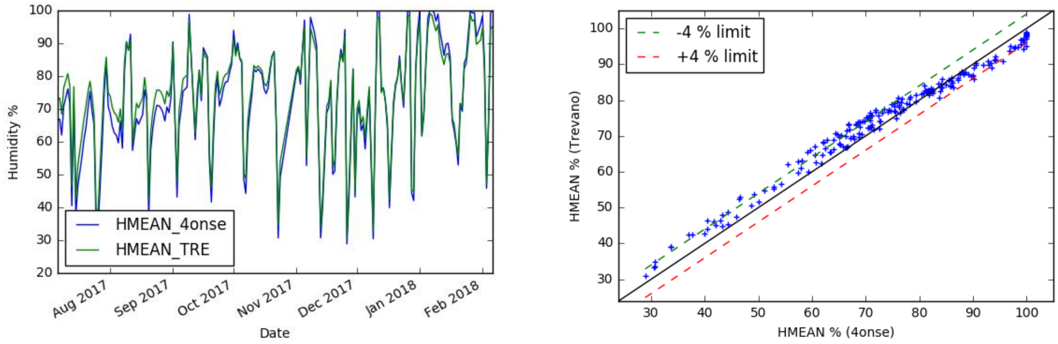

Figure 5 - Humidity daily mean time series overlapping of 4onse and Trevano stations (left); Scatter plots between the 4onse and Trevano station.

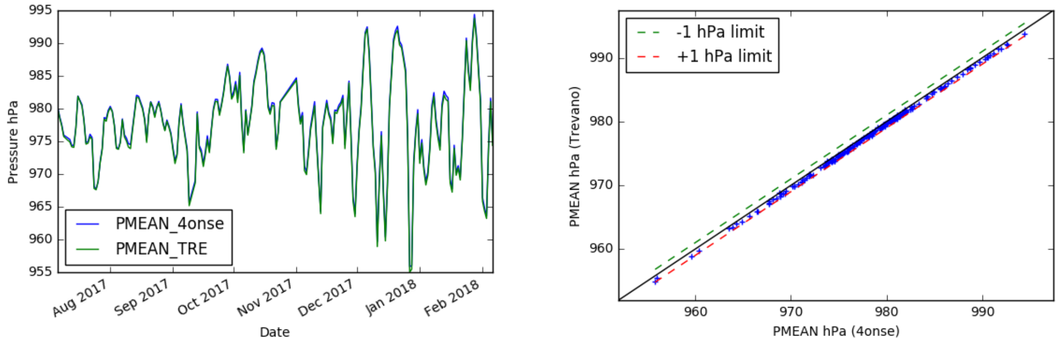

Figure 6 - Pressure daily mean time series overlapping of 4onse and Trevano stations (left); Scatter plots between the 4onse and Trevano station.

Rain max	4onse (mm)	Trevano (mm)	Δ (mm)
24h	29.8	24.8	+5
1h	66.6	74.6	-8

Table 4 - Comparison of the 1h and 24h rain max.

4onse total rain (mm)	Trevano total rain (mm)
632.4	672.8

Table 5 - Total amount of rain measured (6 months).

The implemented prototypes confirmed their replicability demonstrated by the local creation of 14 installed stations. Market accessibility to components were not a problem in the building stations to be deployed. However, during the starting phase of the deployment we have experienced that shipment charges can sensibly influence the total costs and delivery time can produce delays in accessing the components up to one month.

5. Conclusions

The 4onse system aims at offering an alternative solution particularly interesting for the developing and low-income countries, for the installation of dense sensor networks at low-cost to monitor environmental parameters that are useful for natural risk management and nowcasting. Toward this goal, during the first year of the project the system prototype, composed by hardware, service and communication layers, was designed, developed and tested.

In this article, the results of the testing phase on the 4onse-mod weather station were described. Thanks to the Trevano weather station of the hydro-meteorological network of the Canton Ticino in Switzerland, it was possible to validate the 4onse-mod using six months of both stations' data. The results of this analysis show very high values of correlation between the two stations for the temperature, humidity, pressure and rain environmental parameters.

After the validation of the prototype the system deployment in a large size basin started. The Deduroya Oya river basin was selected to host a total amount of 30 stations due to the high relevance in terms of climatic and logistical factors. 22 locations were selected and, at this state, 14 4onse-mod stations were set-up in the field collecting real-time data. During the system deployment the maintenance activity began. The ODK suite is used to compile a checklist and to track the incoming issues which can affect every parts of the stations.

The research and the validation activity performed on the prototype system shows very good and promising results. The deployment phase conducted so far demonstrated the high level of reproducibility of the designed system. However, only a final analysis on data collected during the monitoring of the fully deployed network for a period of one year will scientifically verify if the 4onse system is a viable solution (quality and socio-economic sustainability) to effectively support decision makers in managing natural disasters and risks.

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