REAL-TIME AND DISCRETE PRECIPITATION MONITORING IN MEXICO CITY: IMPLEMENTATION AND APPLICATION

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SUMMARY

This paper presents a real-time system for issuing warnings of intense precipitation events during major storms, developed for Mexico City, Mexico. The system is based on high-temporal resolution (Δt=1min) measurements of precipitation in 6 different points within the city, which report variables such as intensity, number of raindrops, raindrop size, kinetic energy, fall velocity, etc. Each one of these stations, is comprised of an optical disdrometer (OTT Parsivel[2]) to measure size and fall velocity of hydrometeors, a solar panel to guarantee an uninterrupted power supply, a wireless broadband access to internet, and a resource constrained device known as Raspberry Pi[3] for the processing, storage and sharing of the sensor data over the world wide web.

The developed platform follows a component-based system paradigm allowing users to implement custom algorithms and models depending on application requirements. The system is in place since July 2016, and continuous measurements of rainfall in real-time are published over the internet through the webpage www.oh-iiunam.mx. Additionally, the developed platform for the data collection and management interacts with the social network known as Twitter to enable real-time warnings of precipitation events. Key contribution of this paper is the design and implementation of a scalable, easy to use, interoperable platform that facilitates the development of real-time precipitation sensor networks and warnings.

The system was used to issue warnings during the wet season of 2016 in Mexico City, producing timely information to key decision makers in charge of the operation of key drainage infrastructure. The system is easy to implement and could be used as a prototype for systems in other regions of the world.

Keywords: smart monitoring, precipitation, disdrometers, sensor network, urban hydrology, WSN

1. INTRODUCTION

Monitoring and management of freshwater resources has long depended upon on-the-ground measurements. However, there is a documented decline in monitoring networks since the 1980s due to mainly budgetary constraints (Stokstad, 1999; Shiklomanov et al. 2002; Zhulidov et al. 2000). This decline paradoxically has coincided with growing interest in climate change. Monitoring systems *in situ* support water management, as well as serving a range of users and uses (e.g. agricultural and hydraulic operations, environmental planning, etc.). Water managers require accurate *in situ* observations for designing infrastructures and effective management plans, as well as sustained real-time data for operation.

The role that intelligent water networks (IWN), including information/communications technology (ICT), has in terms of the adequate management of hydraulic infrastructure and staff resource optimisation is becoming increasingly recognised by water managers and scientists all over the world (Stewart et al. 2013). Despite their advantages, smart and intelligent metering and monitoring systems are expensive and not yet widely used (Boyle et al. 2013). This is mainly because data is typically not in a user-friendly format, requiring sophisticated data processing for analysis. Therefore, further work is necessary to understand how information form real-time sensor networks can be readily available to decision makers to improve water management.

With the advancement of the digital age and technology of information and communication, it is inevitable for water scientists to transit to the development and use of smart water monitoring systems than allow for a better water management in urban areas. However, there is a limited knowledge of the capabilities of current and future technology in the digital water technology space. In such context, ICT refers to technologies that provide access to information through telecommunications; this includes the Internet, wireless networks, cell phones, and other communication mediums. Presently in the water domain, there is a low level of maturity concerning standardization of ICT solutions to water monitoring (Goubersville 2016).

Indeed, one of the major challenges in hydrologic science and hydraulic engineering is to remotely monitor relevant variables in real-time, in order to provide an instantaneous picture of the system in operation. Within the context of hydrologic science, spatial measurement of hydrologic processes at the catchment, and basin scales is subject to significant constraints in energy, accessibility, sensor coverage area, and cost (Bogena et al., 2010). On the other hand, population growth in urban areas is one trend that has been reported in connection with floods, which has led to more people living in potentially hazardous areas. This trend will keep growing as the world becomes increasingly urbanized with more than 50% of the global population already living in urban areas (Zevenbergen et al., 2010). Unless there are means to reduce the urban vulnerability to extreme weather events, heavy rainfall events endanger the future sustainability of urban environments. This requires adaptation strategies for urban development and drainage infrastructure to a standard that may be greater than the design level originally defined in the construction of current settlements.

Mexico City is one of the largest urban centers in the world, it has been argued that its accelerated growth has given way to the heat island effect, consequently increasing the activity of convective precipitation (Jáuregui, 1997). In such megalopolis, precipitation monitoring is of paramount importance for the adequate operation of key drainage infrastructure. However, current sampling frequency of precipitation is in the order of 15 minutes, which is not sufficient to characterize the convective processes associated to common storm events registered in the city. Therefore, there are more and more concerns on obtaining fine-grained and real-time rainfall information on the micro level in an effective and efficient way. High spatial and temporal resolutions are needed for an adequate measurement of key precipitation processes within the city.

It is well known that for heavy rainfall events, distributions of the rainfall within short terms can vary considerably from day to day, or even from minute to minute. These events are usually measured by networks of rain gauges, although these are often insufficient to support the real-time and large-scale environmental monitoring that needs rainfall information (Colli et al., 2013). Moreover, most of these devices often indicate only the rainfall in a local site of small area. Therefore, a great deal of rainfall-detecting devices need to be deployed in the field, in order to achieve large spatial coverage.

Despite the urgency of having real-time rainfall data at the urban scale, most of the off-the-shelf data-logging components do not allow the acquisition of real time data, as wiring runs are limited by prohibitive cost, signal noise and the need to maintain acceptable levels of current (Kerkez et al. 2012). Recent advances in sensing technology, particularly in the area of wireless sensor networks (WSNs), now enable environmental monitoring in real time, and at unprecedented spatial and temporal scales. The link between real time hydrological information and decision makers, pave the road towards the development of a better operational hydrology (Watteyne et al. 2012). An example of this, was recently provided by Rice and Bales (2010), whom analyzed the performance of a prototype WSN and concluded that the technology could optimize reservoir operation. Monitoring systems in situ support water management and policy development, moreover these type of measurements are essential for calibration and validation of remotely sensed information (Fekete et al. 2015).

Although there are many commercial wireless systems that can transmit data between two points, such hardware generally use relatively high-powered radios and requires substantial energy for transmission. Alternatively, there are advances in hardware technology that make use of open-source software libraries, such as the low cost single board computers known as Arduino and Raspberry Pi. The use of these elements may enable the improvement in data transmission and management.

The work presented in this paper presents a real-time system for issuing warnings of intense precipitation events during major storms in Mexico City. The system is based on low cost devices for data acquisition and management, which enable the development of a platform that is autonomous, scalable, and interoperable, supports efficient sensor data collection, processing, storage and sharing. Moreover, the platform follows a component-based system paradigm allowing users to implement custom algorithms and models depending on application requirements. In our case, this capacity enables the interaction of the system with the social network known as Twitter to allow the dissemination of real-time warnings of heavy precipitation events. The system is comprised of 7 independent stations in Mexico City, all sensor data is transmitted to a central server through a wireless broadband access to internet, and the information is available to all the interested parties through an internet web page.

2. LOCATION AND DESCRIPTION OF THE STAND-ALONE STATIONS

The system monitors precipitation at high-temporal resolution (Δt=1min) in 7 different points within Mexico City. This locations are shown in Figure 1.

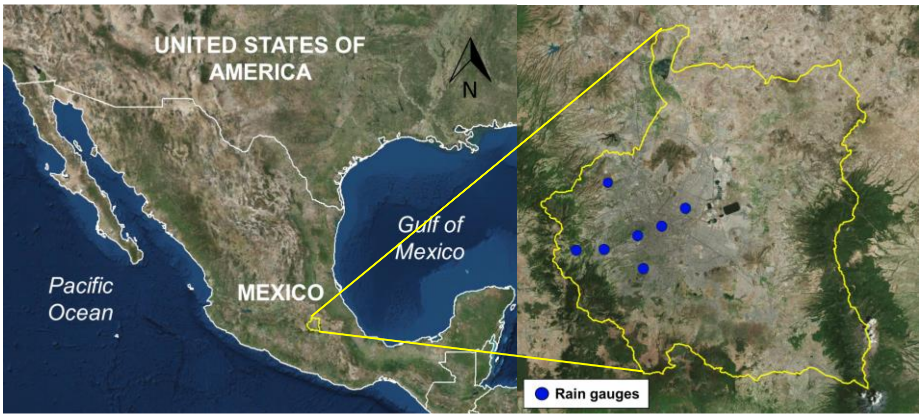

Figure 1. Geographical location of individual stations in Mexico City, Mexico.

Individual stations shown in Figure 1 work independently and are comprised of: a)A laser-optical disdrometer (Parsivel^2, manufactured by OTT Hydromet) to measure precipitation with an accuracy of ±5% for liquid and ±20% for solid precipitation; b) An energy supply system with a 28 amp-hour lead-acid battery and 60W solar panel, that guarantees uninterrupted power supply to the data management system and sensor assembly; c) a wireless broadband access to the internet; d)a 4G mobile router; e) an RS485 Interface Converter and e)an open-source single board computer known as Raspberry Pi3 for the processing, storage and sharing of the sensor data over the internet (see Figure 2). The Raspberry Pi3 uses a LINUX kernel based Operating System and it is fully expandable which means an unlimited number of devices may be integrated into the system. This device is developed in the UK by the Raspberry Pi Foundation with the intention of teaching computer programming concepts in schools. Currently, it is used in many monitoring and accessibility applications (Hernández Marcano, et al., 2016; Parham et al., 2014; Perallos et al. 2015) and little penetration is recognized in the field of hydraulics/hydrology (Hut, 2013). The credit card sized computer does not have a hard disk but uses a Secure Digital card (SD) for booting and persistence storage.

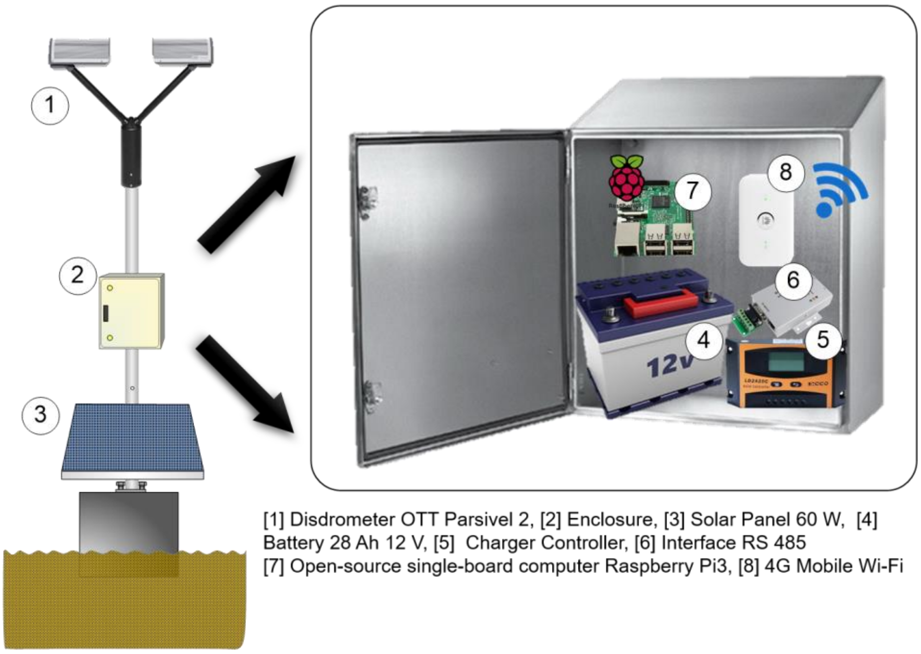

Figure 2. Main components of the system using cloud computing and real-time alerts through Twitter.

One key advantage of the architecture of the individual stations is therefore, that make use of open source electronics that enable the custom-build of the measurement setup. Moreover, the combination of components allows an efficient power consumption of each station. During the day, the entire station is supported by the solar panel, which also recharges the battery; while during the night hours, the recharged battery provides the energy. The system is designed to endure operation during ten strong cloudy days. Table 1 reports power consumption of each component.

Table 1. Power consumption of components in each working with a sampling interval of 1 min.

Component	Voltage (V)	Current Idle (A)	Average Current (A)	Power (W)
Cellular modem	5	0.42	0.44	2.2
Raspberry Pi 3	5	0.24	0.292	1.46
Sensor Parsivel2 OTT	12	0.12	0.12	1.44
Interface RS-485	5	0.14	0.18	0.9

In addition, Figure 3 illustrates a schematic view of the connections between the different components that comprise individual stations located in-situ.

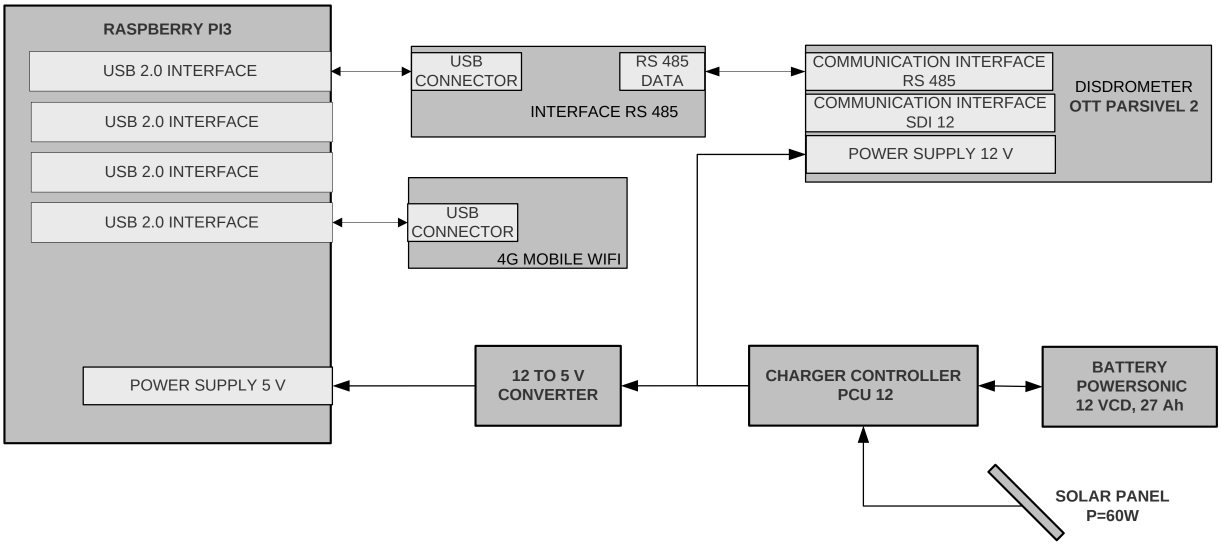

Figure 3. Block diagram of connections between components in each station.

3. DESCRIPTION OF THE INTEGRATED SYSTEM: DATA MANAGEMENT AND CLOUD COMPUTING

The system comprises the application of information and communications technologies (ICTs) to enable a better understanding of rainfall events in Mexico City, making clear use of the field of hydroinformatics (Chen and Han, 2016).

The Hydrological Observatory of the Institute of Engineering of the National Autonomous University of Mexico (UNAM), employs the RS485 communications protocol to send the information from the disdrometer to the RaspberryPi3, the data is stored in-situ in a SD card and also sent to the cloud through a 4G mobile router (using File Transfer Protocol). This is done every minute with custom-made Python codes that manage all data. The wireless data transfer is chosen in terms of the 4G/LTE technology, as it represents the most up to date technology for mobile devices. It provides peak download rates of 300 megabits per second, upload rates of 75 megabits per second and a transfer latency of less than five milliseconds.

The cloud computing part of the system relies on the use of two Virtual Private Servers. The first one is used for the data management, data storage as well as web hosting, enabling real-time publication of the data. The second server is employed for the issuing of real-time public warnings and the emission of automated email alerts to key decision makers. Public warnings are released through the social network known as Twitter using a Python library known as Tweetpy. This is done following the classification of rainfall defined by the World Meteorological Organization in terms of rainfall intensity, illustrated in Table 2. The developed system is able to handle large datasets within tolerable runtime, using for this a commercial cloud computing service, in this case Amazon Elastic Compute Cloud. The commercial cloud has a usage based price policy, making the computing job cost effective in comparison to implementing local clusters. The cloud computing is scalable to suit the job, and does not require extensive knowledge on configuring local clusters.

Table 2. Rainfall classification.

Classification	Intensity (mm/h)
Light rainfall	5 < i < 9.99
Moderate rainfall	10 < i < 15.99
Heavy rainfall	16 < i < 39.99
Very strong rainfall	i>40

On the other hand, a Python script was developed to organize and publish all data through a public web page (www.oh-iiunam-mx) that can be consulted on-line. This process induces a small delay (1 minute) between the real-time measurement and its publication over the Internet; however, this does not represent a major issue. The visualization of the data is programmed in JavaScript, CCS, HTML5 and PHP, which allows the access to the information from multiple platforms and devices with different operating systems.

The automated emails are activated through the definition of a threshold in terms of rainfall intensity, so that when this variable is larger than 40mm/h value an email is automatically sent to a list of key decision makers. This process is implemented making use of a Python script known as sendmail. Figure 4 introduces a schematic view of the architecture of the system and the flow of information.

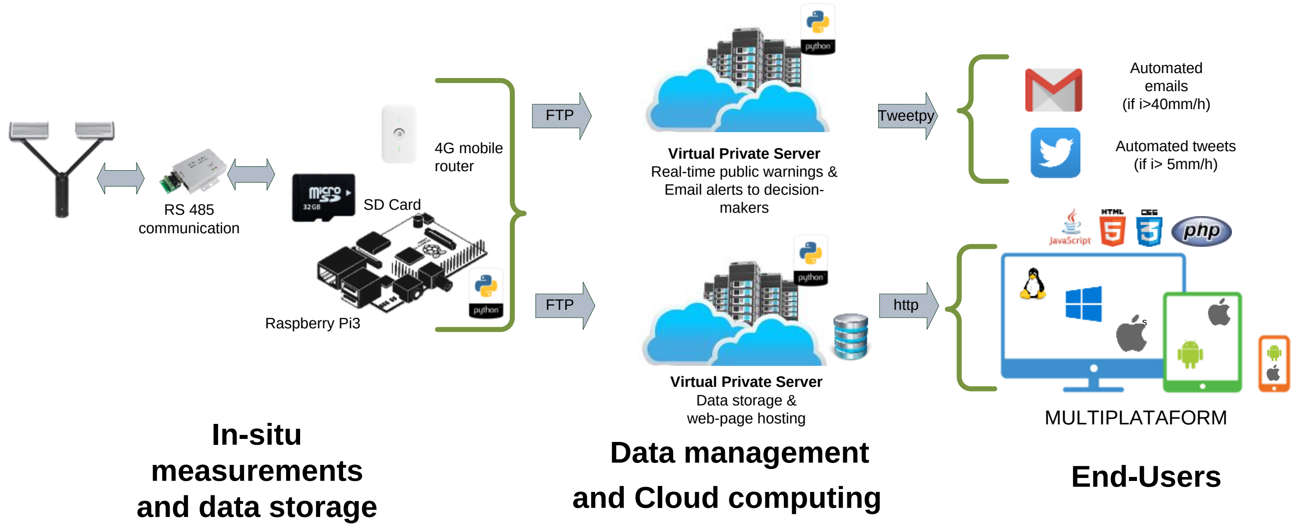

Figure 4. Visual representation of the architecture system.

One of the key features of this initiative is that data will be open to all the public, not only to the scientific community. Following the philosophy of open-source hardware, the data is open to the public and not only to the scientific community. Three of the seven instruments comprising the system are located in Primary Schools, which has greatly increased the interest of children on hydrology and electronic engineering.

4. EVALUATION

There is significant value in leveraging data as it is collected, as it will help us improve the operation of key drainage infrastructure within Mexico City. Nevertheless, even with all the advances in technology and communications that is available today, an appropriate system-level architecture does not exist. This has prevented closing the control loop between the flows induced by natural hydro-meteorological events and the adequate operation of physical infrastructure.

During the wet season of 2016, this was evident in the western part of Mexico City, as twice in July this part of the city was completely flooded, leaving several houses and inhabitants affected by the excess flow of water. The sub-catchments located within this part of the city, have a quick response time of approximately 15 minutes between rainfall and runoff. This leaves a short time for decisions to be made with regards to the drainage operation in downstream points of the catchments.

Figure 5 presents some of the affectations registered in this area, where several houses and streets are shown to be completely flooded. Due to this event, the wireless sensor network presented in this study received a lot of attention. Following conversations within local authorities, the system was expanded with three more stations to measure rainfall in the upper part of these sub-catchments. The system is currently in place and within next year will be tested to revise the overall feasibility of real-time infrastructure operations.

The above challenges are an opportunity for such systems to show their potential to prevent these disasters. There is a clear opportunity in developing countries to use low-cost sensors, open source hardware and freely available data sources to provide hydrologists and decision makers the tools to deal with these hydro-meteorological hazards.

Figure 5. Registered flood affectations in the Western part of Mexico City during July 2016.

5. CONCLUSIONS

The goal of this paper was to illustrate not only the need of a real-time monitoring system in Mexico City, but also its performance and use for different purposes. Although t is acknowledged that before these types of system become the norm, much work remains to be conducted on revising their performance and utility. Real-time monitoring of precipitation in catchments with rapid rainfall-runoff responses has the potential to significantly improve the performance of existing infrastructure and the safety of local residents.

The work presented in this study is still in progress and represents the first documented effort in Mexico aimed at the real-time monitoring of rainfall at a high temporal resolution (1min). It was motivated due to the current situation, in which low-cost sensors, open source hardware, enable the freely availability of data to help to further hydrological understanding.

This effort has encouraged the communication of researchers, engineers, and cities, and its anticipated that in the future the system will be adopted as an important tool to monitor events that pose a high risk to society.

In Mexico, current drainage solutions are still primarily focused on deterministic and static conditions. Sensor driven, real-time monitoring of intense precipitation events presents an exciting new paradigm. Following efforts will involve the modeling of these affected catchments in real –time, which will open the door to the desirable coupling of knowledge with operational hydraulics.

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