INTERNET OF THINGS (IOT) APPLICATIONS: FEASIBILITY OF A REMOTE LIMNIMETER BASED ON ULTRASONIC SENSOR

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ABSTRACT

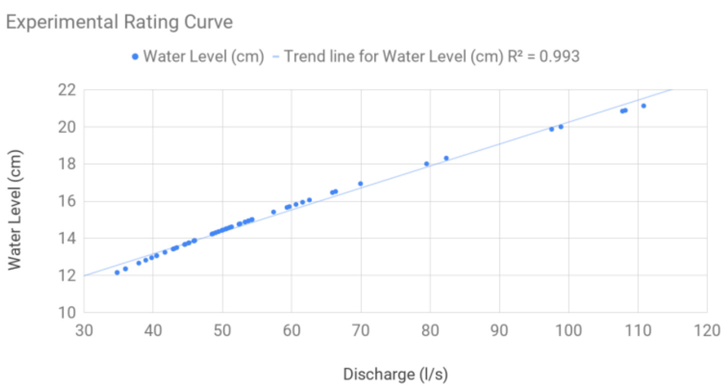
Discharge monitoring is crucial for calibrating hydrological models, studies on water quality, or warning of flood events. Difficulties related to hydrological monitoring include: specialized knowledge and availability of technicians, high cost of standard measurement equipment, and high measurement frequency. The Internet of Things (IoT) technology can help to develop monitoring systems, by providing an automated data collection process and allowing data remote access. The objective of this study is to verify the feasibility of an IoT solution to develop a remote limnimeter for a canalized river. Since the flow occurs in a cylindrical tube with a constant slope and free surface (gravity-driven flow), a rating curve in the section was calculated based on classical hydraulics relations. Experiments have shown good accuracy in the ultrasonic sensors to measure water level (Nash–Sutcliffe efficiency = 0.99 and R^2 = 0.99). The conversion of water level data into discharge, by applying Manning's equation, also presents satisfactory results when compared to the float method (R^2 = 0,993). The IoT technology enhances the storage, visualization, and processing of monitored data, facilitating information sharing, strengthening its application in environmental monitoring.

Keywords: low cost sensors; internet of things (IoT); hydrological data; remote monitoring; limnimeter.

1. INTRODUCTION

Water regime monitoring has been carried out both to warn of flood events and to provide data for hydrological models that assist in watershed planning (Powar et al., 2019; Cruz et al., 2018). For example, in numerical hydraulic modeling, which is often used for delimiting boundary conditions (Domeneghetti, et al., 2012). However, monitoring hydrological data is often a costly and complex process that requires time, financial resources, and skilled labor, resulting in a quantitative and qualitative shortcomings database (de Lima Moraes, 2020; Pandeya et al., 2020). Measurement automation is proposed as a way to optimize data acquisition and measurement automation (de Paula & Velásquez, 2020). Fortunately, Internet of Things (Iot) technology has proven to be a great tool to achieve better hydrological monitoring and has been widely applied. (Liu, et al., 2019; Sahphrom & Korkua, 2019; Wong, Chen & Lin, 2020). In this perspective, considering that depth rate measurements can create a simplified estimate of flow discharges, measuring the water level is essential to build a rating curve, and adjust it throughout the monitoring as the measured data increases, further cyclically refining the water regime analysis. (Abdolvandi, et al., 2020; Liu & Moriarty, 2020).

Considering both, the gap in hydrological monitoring and the wide availability of IoT approach, the objective of this research is to verify the feasibility of an IoT solution to obtain a remote hydrological monitoring system in



order to build a rating curve in the section studied. It has been proposed the automation of collection and transmission of measurements made with sensors installed in the stream, which allows the integration of this monitoring data with an online platform that stores and processes the data.

2. SYSTEM ARCHITECTURE AND IMPLEMENTATION

All equipment is connected to measure the distance between sensor and water surface, relating this value to the flow level, and also to transmit data obtained by sensors to some remote server. To program the commands a code was developed in the IDE interface. The code has the task of activating the sensors at 15-minute intervals, saving the data on an SD card, and sending them to a server. For data acquisition, all hardware framework was plugged using an ESP32 microcontroller, an AM2302 module, and an HC-SR04 ultrasonic sensor. Also, a Shield data logger with an SD card was attached. To allow remote access to measured data, a GSM/GPRS Arduino shield based on the SIMCom SIM900 module was attached to the monitoring system. Thus, using the coverage of GPRS (General Packet Radio Services) and a chip Machine-to-Machine (M2M), the system is allowed to access the Internet. For server-side software, Software as a Service (SaaS) and self-hosted solutions have been evaluated. A wide range of options offer differences in features such as data analytics, data transformation capabilities, integration with other services, creation of user interfaces, security, and price. SaaS solutions have the advantage of easy setup, high scalability, high availability, the low need for maintenance and monitoring (IBM Cloud Team, 2020). Self-hosted solutions have the advantage that they can be completely modified to adapt to the specific needs of the project. The most important features of this project on software development are security and data transformation capabilities, so it is essential to use a SaaS option. All the big tech companies offer products specially tailored to IoT applications. Amazon has AWS IoT, Microsoft Azure and Google Cloud also has their solution to easily collect, display and analyze IoT data (Larry Dignan, 2021).

An essential data mining was required to organize the monitored data. For instance, outlier filtering and calculation of daily and hourly averages. With the level data already treated, an empirical method for the flow calculation proposed by Manning (1889) has been applied. This method is widely used to obtain rating curves in streams where the acquisition of the flow values is not very accessible (Abdolvandi, et al., 2020; Liu & Moriarty, 2020). The calculation is based on the relationship of the water level in a closed duct with the partially filled flow, the slope of the flow, and the roughness of the channel. The calculations for less than half the full pipe flow value at each level are done by applying the following equations.

$$Q = \frac{□}{□}.\ □h^{2/3}.\ □^{1/2} \qquad \text{[Eq. 1]}$$

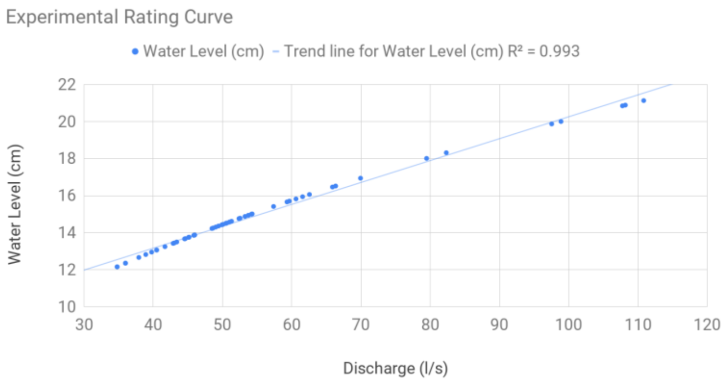
$$\theta = 2\ \arccos.\left(\frac{□ - h}{□}\right) \qquad \text{[Eq. 2]}$$

$$A = \frac{□^2.(□ - □□□□)}{2} \qquad \text{[Eq.3]}$$

$$P = r.\theta \qquad \text{[Eq.4]}$$

$$□h = \frac{□}{□} \qquad \text{[Eq.5]}$$

Equation (1) represents Manning's formula. *Q* is the volumetric flow rate passing through the channel reach (m^3/s), *A* is the cross-sectional area of flow normal to the flow direction (m^2) (3), *n* is a dimensionless empirical constant called the Manning Roughness coefficient, *Rh* is the hydraulic radius (5), *S* is the bottom slope of the channel in m/m (dimensionless), *P* is the wetted perimeter of the cross-sectional area of flow (4), θ is the angle (2), formed between the water surface and the center of circumference, and *h* is the water level.



3. EXPERIMENTAL SET-UP AND RESULTS

Before the water level data acquisition starts on the field, the hardware was tested and calibrated in the laboratory. The measured distances from two ultrasonic sensors were compared to measurements with a measuring tape. The performance of the proposed sensor was also evaluated by two statistical methods: the Nash–Sutcliffe model efficiency coefficient (NSE) (Nash & Sutcliffe, 1970) and the Coefficient of determination (R^2). The NSE is broadly used to evaluate the predictive capacity of hydrological models, and the R^2 measures the adjustment of a generalized linear statistical model, both vary between 0 and 1, the latter being the best result. Sensor I, presents, NSE=0.99 and R^2=0.99, by applying the linear equation ($y = 0.9969*x +0.5531$), and sensor II presents, results as NSE=0.99 and R^2=0.99, by applying the linear equation ($y = 0.9952*x + 0.5377$). Both sensors tested resulted in a very good performance with mean values of NSE = 0.99 and R^2 = 0.99. After calibrating the sensors, the system was installed in the stream. The system was installed inside a shackle, powered by a 100 V outlet. The fixation location remained the most parallel to the flow and a level was used to help align the sensor. The assessed monitoring period started on 05/08/2020 and ended on 30/09/2020. The average daily flow for the monitored period is shown in figure 1.

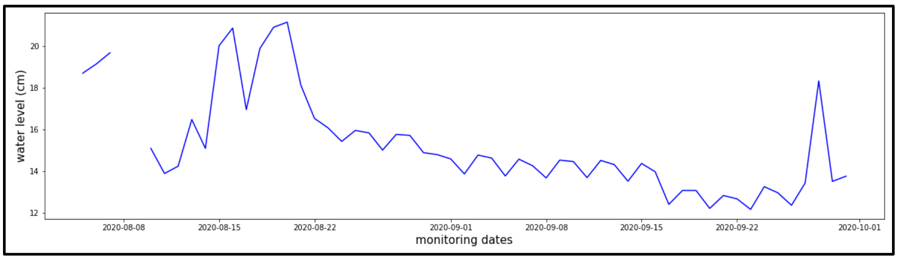
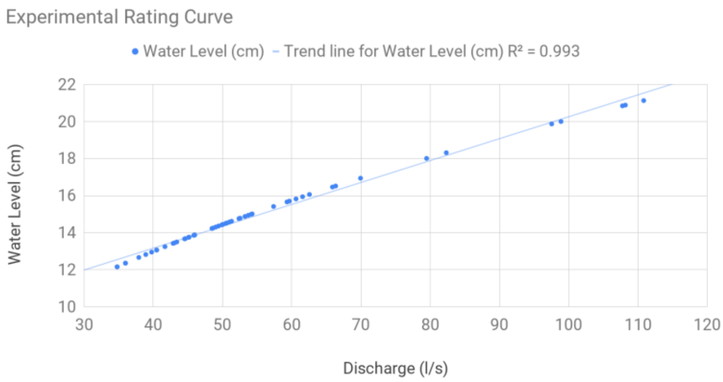


Fig. 1.: Daily average of water level during the monitoring period

To transmit the data to a server, the "TinyGSM" software library was used (Shymanskyy, 2020). This library provides a set of routines to facilitate the use of several GSM modems including the SIMCom SIM900. The Hypertext Transfer Protocol (HTTP) will be used to send data to a remote server. The methodology to obtain a rating curve has been tested on a code developed in Python. The purpose was basically: To organize the measured data obtained from ultrasonic sensors, by finding outliers and calculating daily and hourly averages; To calculate Manning's equations; To build a rating curve. For the flow calculation, based on fieldwork, it was defined that the stream is channeled in a shackle of 1.50 meters in diameter, and the slope is 1.31%. According to the roughness classification proposed by Chow (1959) the value used for the flow duct material was 0.04. With the level measurements for the period between 05/08/2020 and 30/09/2020 a rating curve was built (figure 2), to validate the application of the manning equation. The flow data modeled with the application of the manning equation were validated based on direct flow measurement. Procedures were done by using the measurement procedures proposed by the British Standard Hydrometry - Measurement of liquid flow in open channels using current-meters or floats (2007). By applying the floats method, it was obtained a flow rate of 28 l/s considering a 12 centimeter water level, while the flow modeled for the same water level, with the Manning equation resulted in 34 l/s. The variation of 6 l/s is considered satisfactory for this stage of initial tests.



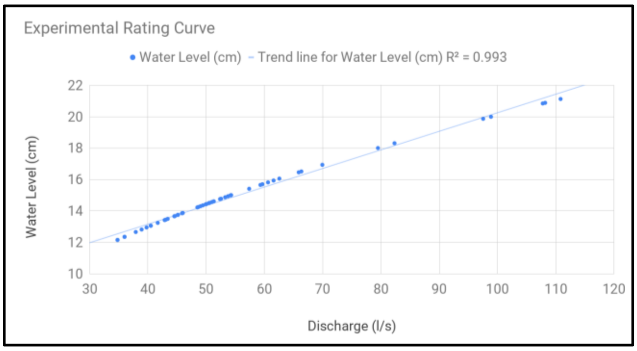


Fig. 2.: Daily average of water level during the monitoring period

4. CONCLUSIONS

Based on the research that has been carried out so far, it is assumed that the facility proposed by the IoT technology, by allowing remote access to the monitored data, can bring several benefits. Examples of benefits are: assisting in the identification of equipment failures, optimizing the maintenance of the data collection system, increasing the temporal and spatial density of observations of the water regime, reduction of human resources expenses, among others. Besides, IoT technology enhances the storage, visualization, and processing of monitored data, facilitating the organization of the database and the sharing of information. It was clarified that to select the cloud platform to be used, there are some caveats, like transmission security, data processing capacity, results from visualization, and price.

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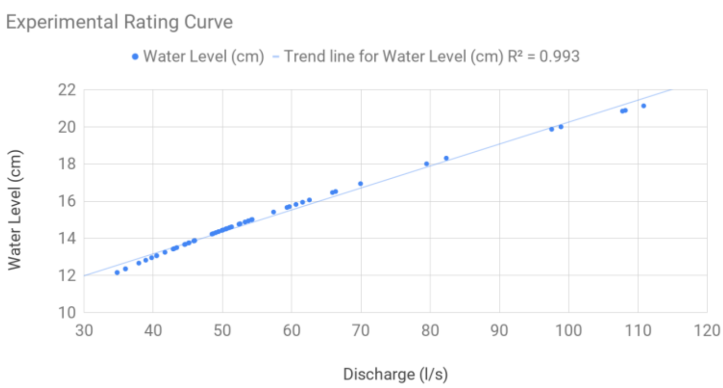

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