An Automated Irrigation System for Smart Agriculture Using the Internet of Things

Conference Paper · November 2018

DOI: 10.1109/ICARCV.2018.8581221

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2018 15th International Conference on
Control, Automation, Robotics and Vision (ICARCV)
Singapore, November 18-21, 2018

An Automated Irrigation System for Smart Agriculture Using the Internet of Things

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Abstract— **Water is a vital and scarce resource in agriculture and its optimal management is emerging as a key challenge. This paper presents an automated irrigation system to reduce water utilization in agriculture by combining the Internet of Things (IoT), cloud computing and optimization tools. The automated irrigation system deploys low cost sensors to sense variables of interest such as soil moisture, pH, soil type, and weather conditions. The data is stored in Thingspeak cloud service for monitoring and data-storage. The field data is transmitted to the cloud using Wi-Fi modem and using GSM cellular networks. Then an optimization model is used to compute the optimal irrigation rate which are automated using a solenoid valve controlled using an ARM controller (WEMOS D1). The variables of interest are stored in the cloud and offered as a service to the farmers. The proposed approach is demonstrated on a pilot scale agricultural facility and our results demonstrate the reduction in water utilization, increase in data-availability, and visualization.**

I. Introduction

Sustaining agricultural productivity, guaranteeing food-security, and enhancing economic growth in the face of climate variability, diminishing labour force, and changing soil conditions requires innovation in agriculture. In India, agriculture contributes 18% of the country's Gross Domestic Product (GDP) and employs more than 50% of the population [1]. Notwithstanding these contributions, the sector is under stress and the recent economic survey of the Indian government has pointed out the need to extract "more crop per drop" which indicates exploiting technology and good practices to enhance productivity per drop of water. While this is largely dependent on the irrigation system, recent developments in technology are being touted as solutions [2]. The real-time environmental parameters such as temperature, soil moisture, humidity, evapotranspiration, cropping cycles, and others influence the crop lifecycle. Resource utilization can be optimized by real-time monitoring of these parameters and taking corrective actions based on sensed information.

In this backdrop, the Internet of Things (IoT) with has emerged as an enabler of agriculture automation [3], [4], [5]. The IoT uses recent advances in sensing, networking, and computing technologies to enable novel applications and services. The use of IoT for crop monitoring has been studied in [6]-[9]. Fusing crop statistical information and agricultural environmental information was studied in [10]. However, control functionalities were not studied in these investigation. The investigations in [11] and [12] proposed a framework with limited control functions. The role of IoT for controlling the water consumption in irrigation has been studied by many scientists as well. A simple irrigation system was studied in [13]. An advanced system was proposed in [14] that aims to transform traditional farming to modern one. The investigation in [15] proposed using wireless sensor networks for managing irrigation in agricultural farms. The framework proposed allowed user to interact with the data and consult in a comfortable way. An IoT based smart farm irrigation system was proposed in [16] wherein Zigbee was used for communication between sensor nodes and base station. While data was collected and processed in these investigation, combining cloud computing with IoT was not fully explored. This provides additional opportunities due to the service delivery models of the cloud.

Recently significant efforts have been devoted to combine IoT and cloud computing [17], [19], [20] showed that the IoT benefits can be enhanced by combining it with cloud computing. The role of cloud-based IoT scheme for precision agriculture was studied in [18]. However, the final control aspect has not been considered. Similarly, optimization models for irrigation have been studied in [21] without discussions on monitoring and control. A review of the literature reveals that existing approaches on using IoT are restricted to monitoring and data-aggregation. Final control including optimization of resources has not been studied in the literature to our best knowledge. In this paper, we combine the IoT sensing and networking capability with cloud interfaces, use the data to study the optimal irrigation rates, and finally implement the computed flow rates by commanding a solenoid valve. Consequently, a comprehensive solution including sensing, networking, control, and optimization is proposed. Such a methodology has not been proposed for agricultural irrigation purposes to our best knowledge. The main contributions of the paper are:

1) A smart irrigation system that uses IoT and cloud-connectivity to aggregate and store information, an optimization model to compute the optimal irrigation parameters, and final control implemented using solenoid valves.
2) Design aspects of IoT hardware, software, and their integration along with networking as well as cloud connectivity are discussed.
3) Demonstrate the control methodology and hardware

This research is funded by the DST through the Initiative to Promote Habitat Energy Efficiency Project title: Energy Savings Through IoT and Nonlinear Model Predictive Controller (TMD/CERI/BEE/2016/088)

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using experiments/simulations.

The rest of the paper is organized as follows. Section II presents the system architecture and design which describes the various components of the system. The optimization model for irrigation control is presented in Section III. Results and observations are presented in Section IV. Conclusions are drawn from the obtained results and analysis in Section V.

II. System Architecture and Design

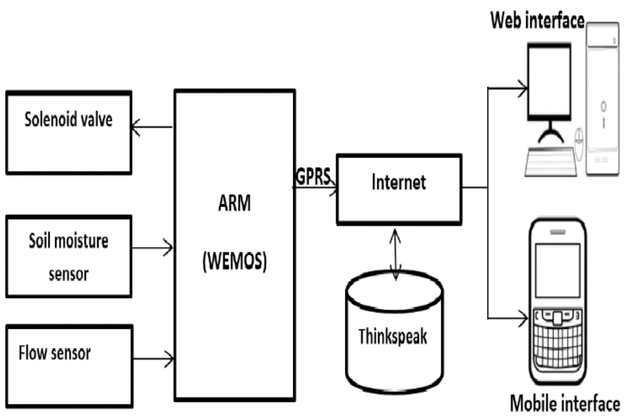

Fig. 1: IoT Architecture of the Smart Irrigation System

The IoT architecture used for implementing the precision irrigation system is shown in Fig. 1. The components of the architecture are listed in Tab. I. The components are selected based on cost-reliability analysis. While the low-cost sensors lead to reliability issues, they perform reasonably well for the application considered. In this work low cost soil moisture and flow sensors are used. The sensors send the data to the WEMOS D1 controller and the controller controls the flow using sensed information. The controller controls the solenoid valve through which the field is irrigated. The controller also controls the DC motor on/off state since the motor has to be on only when any one of the valve is in open state. The controller is connected to the internet through the GSM GPRS module. The internet connectivity is provided through GSM as broadband is not feasible in many rural agricultural areas, whereas more than 70% of the land in India is feasible with GSM based cellular network. The information retrieved from the field is used to control the irrigation system, and it is also stored in the cloud (Thingspeak) for further analysis. Remote monitoring of the field was provided through web interface and mobile interface. The farm is split into several sectors as depicted in Fig. 2, the water flows through different valves for each sector which are deployed with a set of sensors for monitoring and a solenoid valve as an actuator.

The sectors are sort of control regimes for which the water can be irrigated. This helps organizing the irrigation and monitoring to meet the needs of the individual sectors, thereby better management can be achieved. Having

Device	Specifications
WEMOS D1 Controller	ESP-8266EX
Soil Moisture Sensor	YL69
Solenoid Valve	1/2 Inch, 12V
Gardening sprinkler	4-hole female
Drip irrigation hose	4 mm, 2 meter (length)
Water Flow Sensor	YF-201
Humidity & Temperature sensor	DHT 11
pH sensor	pH meter probe (0-10)

TABLE I: Components of the Architecture

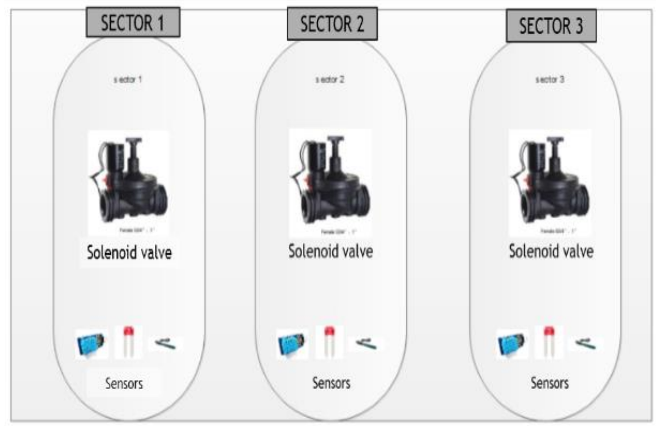

Fig. 2: Organization of Agriculture Land as Sectors

described the architecture, we provide a succinct description of the different components used in the hardware.

1) WEMOS D1 Controller: The D1 is an ESP8266 (Wi-Fi) based controller which is compatible with the Arduino IDE. The functions are same as the Arduino Uno controller, whereas the WEMOS has the ESP8266 module by default on the board hence reducing the complexity of interfacing an ESP8266 with Arduino Uno. ADCs(Analog to Digital convertors) were used to interface multiple analog sensors to the controller.

2) Solenoid Valve: The traditional valves are replaced with solenoid valves to control the flow. The valve is operated either in ON/OFF mode and a pulse-width modulation approach is used to control the flow, i.e., the amount of flow is proportional to the time-period for which the valve remains in ON state over a given time period. A 24 V relay is used to turn ON/OFF the solenoid valve.

3) Soil Moisture Sensor: In our design, YL69 series soil moisture sensor or probe measures the volumetric water content in the soil. Determining soil moisture is considered as an important task in agriculture to assist farmers manage the irrigation systems more effectively. Compared to other low cost sensor such as gypsum block sensors, these probes tender a rapid response time. Due to this reason the sensor is chosen and used in the proposed design. Placing the soil moisture sensor in the right place is very important, since a sector's irrigation is controlled by the value of the soil moisture sensor deployed for that sector. The soil moisture sensor works between 3.3V and 5V power supply. The output value of the sensor is between 0 ohms to 1000 ohms. Based

Soil Type	Resistance value range
Dry	0- 300 Ω
Humid	300-700 Ω
Wet	700-100 Ω

TABLE II: Resistance range of Soil Moisture Sensor

on the sensor reading the soil can be classified into Dry, Humid and wet. The soil moisture sensor used is connected to the analog pin of the controller through wire. The sensor range for determining the soil type is shown in Tab. II.

4) Flow Sensor: In this system flow sensor (YF-201) is used to measure the amount of water utilized in the process of irrigation. The amount of water utilized has to be measured in the experimental setup for the traditional and automated irrigation methods so that comparison can be easily carried out. The water flow sensor is aligned in parallel with the water line, and a pinwheel inside the sensor is used for measuring the water irrigated through it. The water flow is measured in litres/second.

5) Data Transmission: Transferring the collected information from the farm to the Internet is a major issue as internet connectivity through broadband to agricultural area is still an infeasible solution in more than 50% of the agricultural lands across India. In this work the data is transmitted using the GPRS internet connectivity available through the cellular network providers. The cellular network covers majority of the agricultural lands in India and with the emergence of 3G and 4G technology it is possible to transmit data quickly. Instead of using a GPRS module along with the controller, we have used a Wi-Fi hotspot device for data transmission from the controller to the internet as the transmission speed is high when using hot spot as compared with a GSM GPRS module of the controller. The use of WEMOS controller has reduced the complexity in interfacing an ESP8266 when compared to Arduino. The GSM module is used to send messages from the controller regarding the status of the field.

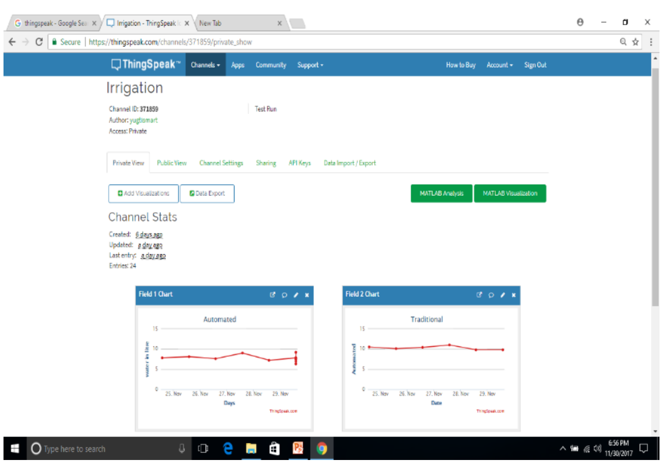

Fig. 3: ThingSpeak Web Interface

Time stamp	Entry Id	Soil Moisture in ω	Flow in $\frac{\ell}{s}$
2018-03-26 10:38:51 UTC	94	310.00	6.12
2018-03-26 10:39:12 UTC	95	316.00	6.21
2018-03-26 10:39:33 UTC	96	330.00	6.29
2018-03-26 10:39:54 UTC	97	345.00	6.39
2018-03-26 10:40:15 UTC	98	368.00	6.51
2018-03-26 10:40:36 UTC	99	382.00	6.62

TABLE III: Sample Data Stored in Thingspeak

A. *Cloud-based Remote Monitoring*

The Irrigation system is initiated based on the soil moisture sensor value. The field is irrigated automatically using the solenoid valve or sprinkler. The solenoid valve and the sprinkler were connected to the controller using relay switch. The data from the controller is transmitted to the Thingspeak cloud, and the data can be viewed using Thingspeak website. The user interface is a simple monitoring interface which shows the readings from the sensor, the solenoid valve status and the amount of water used. The screen shot of the ThingSpeak web interface is shown in Fig. 4 and the snippet of the data displayed is shown in Table III.

Similarly the PH value of the soil, Humidity and temperature were also stored in cloud. Thingspeak cloud service is an easy to access service and has inbuilt lab view functions. Fig. 4 shows the Thingspeak Cloud Service Interface for a smart phone wherein the data are represented in charts. The data feeds can be stored in the Thingspeak along with the timestamp for further analysis and for providing real-time data visualization.

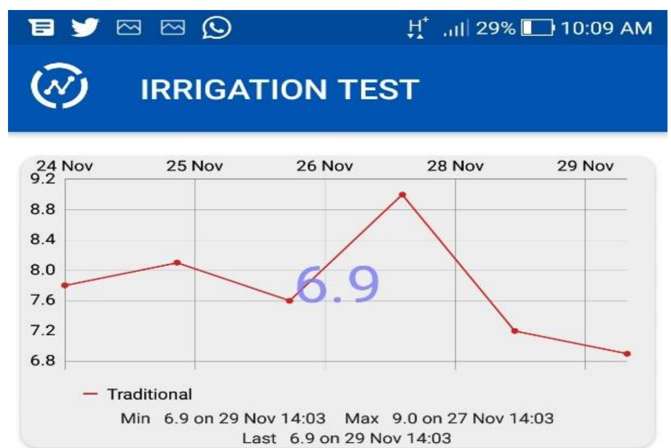

Fig. 4: ThingSpeak Interface for Smart Phone

III. Optimization Model

Computing the minimum irrigation rates based on sensed information is a decision making problem requiring help of optimization tools. Therefore, we model the optimal irrigation problem as an optimization problem. We define the following:

Definition 1: The difference between the planting and harvesting time is denoted as the irrigation period.

Definition 2: Maximal rainfall over the irrigation period denoted by R_{max} is the upper bound on the rainfall during the period.

Our objective is to minimize the irrigation of the water over a 24 hour horizon which is given by $\mathcal{I} = \sum_t = Q\Delta t$ where Q denotes the flow and Δ unit time step used in the analysis. In addition, we aim to exploit the use of rain water, and soil moisture content. The objective is modelled as:

$$\mathcal{J} = w_1(t)S_t + w_2 r_t + w_3(t)Q(t)\Delta \qquad \forall t \in \{t+\Delta, t+2\Delta, \ldots, t+T\Delta\} \tag{1}$$

where w_1, w_2 and w_3 are weighing factors, S_t soil moisture content at time t, and the weights are selected depending on the crop or soil conditions.

Limits on the rainfall r are given by

$$R_{min} \leq r_t \leq R_{max} \qquad \forall t \in \{t+\Delta, t+2\Delta, \ldots, t+T\Delta\} \tag{2}$$

where R_{max} and R_{min} denote the maximum and minimum values of the rainfall during the period. The upper limit on the irrigation is given by

$$\sum_{t=t+\Delta}^{t+T\Delta} Q(t)\Delta \leq I \tag{3}$$

Following [21], the irrigation at time periods is limited by

$$\begin{aligned} Q(t) &\geq \frac{(e_t - r_t - S_t + d_t)}{\Delta} \\ Q(t) &\leq \frac{WR_{max}(t) - r_t - S_t + d_t}{\Delta} \end{aligned} \tag{4}$$

where e_t is the threshold on water use, d_t water drained, and WR_{max} maximum water reserve, respectively. In addition, the evapotranspiration rate is constrained by

$$EP(t) \leq r_t + S_t + Q(t)\Delta - d_t \qquad \forall t \tag{5}$$

In addition, the rainfall, soil moisture, flow-rate, and drain are all positive real-values and this is expressed as

$$r_t, S_t, d_t, Q(t) \geq 0 \tag{6}$$

The optimization model for reducing the irrigation is given by:

$$\begin{aligned} \mathcal{M} : & \\ & \min_{Q(t)} \quad w_1(t)S_t + w_2(t)r_t + w_3(t)Q(t)\Delta \\ s.t. & \\ & R_{min} \leq r_t \leq R_{max}, \\ & \sum_{t=t+\Delta}^{t+T\Delta} Q(t)\Delta \leq I \\ & Q(t) \geq \frac{(e_t - r_t - S_t + d_t)}{\Delta} \\ & Q(t) \leq \frac{WR_{max}(t) - r_t - S_t + d_t}{\Delta} \\ & EP(t) \leq r_t + S_t + Q_i(t)\Delta - d_t \\ & Q_{min} \leq Q(t) \leq Q_{max} \\ & r_t, S_t, d_t, Q(t) \geq 0, \\ & w_1 + w_2 + w_3 = 1 \\ & \qquad \forall t \in \{t+\Delta, t+2\Delta, \ldots, t+T\Delta\} \end{aligned}$$

The optimization model $\mathcal{M}$ is a linear programming problem and can be solved with open source solvers such as Gnu Linear Programming Kit on single-board computers such as BeagleBone Black. However, in our analysis, the problem was solved in a computer using MATLAB's *linprog* routine.

IV. Results

A. Real-time Experiments

In our experiments, a pilot having four land sectors each 2×2 square feet were taken to test the method. One sector was irrigated using traditional method in which the water flow was controlled manually, and the other three (Automated Irrigation, Drip Irrigation, Sprinkler Irrigation) were irrigated with the automated method using sensors and actuators (solenoid valve, sprinkler, and Drip). The spinach named Amaranthus tricolor seeds was sown in even quantity and grown in the entire four land sector. Water flow sensor, soil moisture sensor, soil PH sensor, was installed in all the sectors. Weather sensors like humidity, temperature Sensor and rain sensor were deployed in common for all the four sectors. The actuators were connected to the controller using wired connection. The input to the sprinkler was given using a low pressure water pipe as the land sector taken for irrigation is small. The irrigation was done based on the moisture sensor value. Different moisture values are set for different crops, in the experimental set up the value was set to less than 300 ohms to 950 ohms, if the value drops below 300 ohms then the solenoid valves were opened and the field is irrigated and if the value was greater than 950 ohms then the solenoid valves were closed. For drip irrigation automation, the solenoid valves were used to supply water to the drip irrigation tube. In the sprinkler irrigation system sprinkler is supplied with a low pressure water input as the experimental prototype is for demonstration purpose. The soil moisture metric used to automate the irrigation makes sure that the land is not dry at any point of time. The data is uploaded to the things speak cloud using write API key. The experiments were conducted for a period of 3 weeks. To test the effectiveness of the optimization approach, we first propose a moisture based control as shown in Fig. 5.

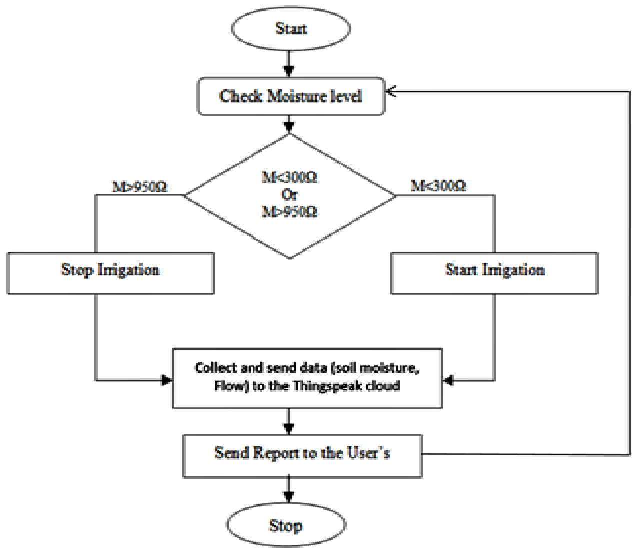

Fig. 5: Moisture-based Control

The following two scenarios were compared:

- Flow control based on moisture level with valve control, sprinkler control, and drip irrigation;
- Flow control using optimization approach with valve irrigation, sprinkler control, and drip irrigation;

In the optimization model, the change in irrigation conditions correlate to change in the limits of the flow-rates $Q(t)$.

B. Results with Heuristic Control

The flows for a period of 3 weeks were used to study the effectiveness of the flow-based control. The results of all three automated irrigation methods were compared with conventional method. In Drip irrigation method the system is highly efficient saving around 24%, compared to 20% in sprinkler and 16% in Solenoid valve based automated irrigation. In this experimental prototype, deficient watering condition was eliminated as the water resources were sufficient throughout the experiment. Water deficit might occur when the system is implemented in the real agricultural field due to water scarcity. The data is stored in cloud with ease using the API funtions in thingspeak. The flow control over for a period of six days with flow-based control is shown in Fig. 6 shows that the drip irrigation the flow is relatively lower than other irrigation systems.

C. Simulation Results with Optimization Based Control

The flows for a period of 1 week with optimization based control was used to study the effectiveness of optimization based control for the three irrigation schemes. In drip irrigation method the method provided 31.2% over conventional

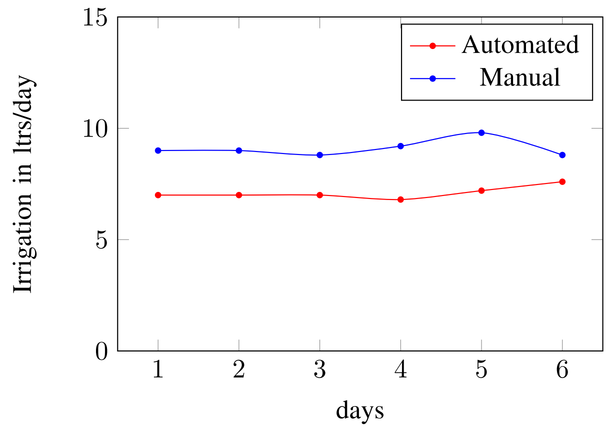

Fig. 6: Automated versus Manual Control with sprinkler system for flow-based control

method and an increase in 7% savings over flow-based control. Similarly, in sprinkler irrigation, the savings were 26% and 22% in solenoid valve based control. Our simulations shows that optimization based control outperforms the flow-based control in terms of water savings.

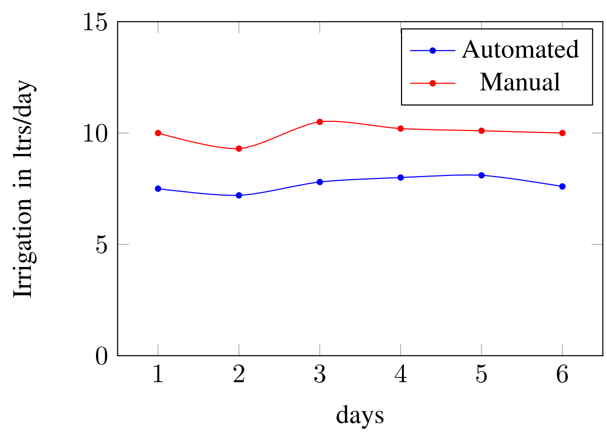

Fig. 7: Automated versus Manual Control with Sprinkler System for optimization-based control

D. Observations

- It was observed that the pH value of the soil decreases with an increase in moisture levels.
- The IoT and cloud-connectivity enhanced the data-aggregation and visualization capability significantly.
- Combining IoT, cloud-connectivity, and optimization models will help enhance water efficiency of the agriculture systems.
- The irrigation system was automated by connecting solenoid values which helped increase the agility of the control.

V. Conclusions

This investigation presented an automated irrigation system to reduce water utilization in agriculture by combining

Internet of Things (IoT), cloud computing, and optimization. The automated irrigation system is realized by deploying low-cost sensors to sense variables of interest such as pH, temperature, humidity, soil type and weather conditions. The data is stored in Thingspeak cloud service for monitoring and storage. Then an optimization model for reducing the water usage was proposed and constraints modelling the physical conditions were included. The optimal flow rate was determined solving the optimization model and it was shown that the flow rate can be automated using solenoid valves. The optimization-based control was compared with flow-based control and our results demonstrated that optimization models help in reducing the water consumption. Improving the optimization models and enhancing the IoT prototype are future course of this investigation.

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