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AUTOMATED WATER MANAGEMENT SYSTEM WITH AI-BASED DEMAND PREDICTION

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Abstract: *Access to fresh water has become a headache for many nations around the world today due to water scarcity. Since this aspect is increasing, this paper introduces a system to estimate the households' water needs in a day taking into consideration, the size of the family, zone, temperature, season, working status, location, and religion. By applying machine learning, the system determines the balance of water distribution between the families by these parameters. The predicted values determine the water requirements for each household hence the distribution of water in the households on a particular day. This includes the use of an Arduino microcontroller, water flow meter, and solenoid valves that make the water supply system to be an automatic system. As a result of this, the system helps to control the wastage of water and also ensures that the amount of water required in each home is assessed accurately.*

Keywords: factors influencing water consumption, machine learning model, water distribution control, water wastage control

ZAUTOMATYZOWANY SYSTEM ZARZĄDZANIA WODĄ Z PROGNOZOWANIEM ZAPOTRZEBOWANIA OPARTYM NA SZTUCZNEJ INTELIGENCJI

Streszczenie: *Dostęp do świeżej wody stał się obecnie problemem dla wielu krajów na całym świecie z powodu jej niedoboru. W związku z narastającym problemem, niniejszy artykuł wprowadza system, który szacuje dzienne zapotrzebowanie gospodarstw domowych na wodę, biorąc pod uwagę takie czynniki jak wielkość rodziny, strefa, temperatura, pora roku, status zatrudnienia, lokalizacja oraz religia. Dzięki zastosowaniu uczenia maszynowego, system określa równowagę w dystrybucji wody między gospodarstwami domowymi na podstawie tych parametrów. Przewidywane wartości określają zapotrzebowanie na wodę w każdym gospodarstwie domowym, a tym samym dystrybucję wody w danym dniu. System obejmuje również użycie mikrokontrolera Arduino, miernika przepływu wody oraz zaworów elektromagnetycznych, co sprawia, że system dostarczania wody jest automatyczny. W wyniku tego system pomaga kontrolować marnotrawstwo wody oraz zapewnia, że ilość wody potrzebna w każdym domu jest dokładnie oceniona.*

Słowa kluczowe: czynniki wpływające na zużycie wody, model uczenia maszynowego, kontrola dystrybucji wody, kontrola marnotrawstwa wody

Introduction

The international community is battling numerous challenges as a result of climatic change most of which emanate from the unavailability of resources. Negligence, global actions, preferences, and ignorance majorly share the blame for such disorders. The primary scarce resource essential to all people and most forms of life is water. Nowadays, though, several states experience freshwater scarcity. The United States Environmental Protection Agency estimates that an average household can waste up to 100 liters [43] of water per day, due to water leaks alone which is part of the global issue. Australian, Russian, German, British, Egyptian, French, Brazilian, and Iranian individuals are some of the leading people who waste water [14, 17, 20, 35].

The amount of water that each person uses per day depends on region, season, temperature, location, occupation, and religion. For instance, Middle Eastern people use more water as compared with Americans, Europeans, and Australians; whereas Asian and African people use less water on average. Summer remains the period of high water consumption and in areas where the concentration is felt all year round. Water demands tend to rise when using water for drinking, and since consumers in urban use, more water than in rural areas do. Apart from them, occupations have their part; the physical workers take more water than the office workers, the learners/ students, and the jobless are in between. They include religious activities; patients who practice Islam use more water than those who practice other religions [1, 5, 6, 8, 9, 11, 12, 18, 23, 27–29, 33, 34, 36, 38, 41, 42, 44].

These factors are considered in this paper while establishing a dataset for predicting daily water requirements. Since no organized database is well structured to contain these specific needs the data was obtained from different sources to come up with a sample. Therefore, for the proposed system, random data is created about the identified factors, and the average daily water consumption per person is computed. Subsequently, the data is pre-processed and the Doron's encoder is used to perform one-hot conversion on the table to convert them into a form that is readable by machine. The data set is then divided into training testing datasets and the dependent variable daily water requirement is predicted using a linear regression.

The system is intended to be used in residential areas like apartment buildings but can be expanded for the whole city or even the country. They can input data such as several family members, geographical location, occupation, religion, seasonal conditions, temperature, etc., through the system from the other end. The use of a linear regression model to estimate water required per head of population concerning the above inputs, the total amount of water consumed per family is determined. It provides for the targeted demands of users in their respective homes and does not generalize with equal water distribution.

The final learning and development cycle is the practical application of the design attained by utilizing an Arduino microcontroller. The total predicted water demand for each family is converted from gallons to liters on Arduino C++ and water flow sensors as well as solenoid valves regulate the flow. This control system includes programmers of the maximum volume of water per family and water flow sensors. After a set limit of water has been delivered, an aspect of the solenoid switches off the supply of water for that particular family to prevent the deliberate delivery of excessive water.

This approach rationalizes the use of water in families because they understand that they will only get the amount of water they expect. The system thus covers the need for water management completely, meaning that the wastage of water is minimized. It supplies water by using factors such as the number of people in the house, and not supplying water equally, which would not be fair to some families. The water distribution process is fully automated, and through a machine learning prediction algorithm, this design provides an effective water supply. The process has been modeled in Wokwi software and experience gained from practice indicates that the model is workable.

1. Literature review

Contemporary developments in water supply infrastructure have applied IoT and Machine Learning features regarding water supply effectiveness and utility wastage. Some works have been more centered on the field of driving and controlling water flow as well as reducing leakage. For example, use of IoT solutions is used in water management with a particular focus on leakage management and avoidance [10]. Furthermore, IoT-based systems are used to monitor the equitable distribution of water in areas, and some systems incorporate anti-theft to amplify water protection and distribution [19, 26]. Machine learning is used in estimating water consumption patterns for better demand requirements and billing needs by using data from previous years [30]. Other systems, using microcontroller platforms like Arduino, control fluid flow and keep target fluid levels as well as record water quality parameters including pH and degree of turbidity [2, 22]. application includes a real-time monitoring system where sensors are used to monitor water quality and supply to ensure regular supply and equal portions [15, 24, 31]. In addition, the IoT-related platforms are employed for water pressure, and flow, among other indicators monitoring in smart city supply and demand water systems, providing insights and reviews in real-time [13, 32]. Also, the integration of IoT with other systems such as machine learning algorithms for water usage predictions and categorization enables more efficient use of water resources based on use. They allow for the monitoring, control, and analysis of water usage via telecommunication links and offer the administrators the control option of allowing or denying water uptake depending on real information [7, 21]. Moreover, monitoring in real-time and webserver-based control systems facilitate the pump remote control to guarantee that water delivery is both effective and timely [39]. Wireless smart sensors for leak detection and automatic billing also add to the best value water consumption and easier billing issues [25]. Technological comparisons show how IoT proves useful in real-time water monitoring and the importation of AI for improved leakage and data management [3, 40]. The IoT and AI are also employed in water management in smart cities, regarding the flow, usage, and operating conditions of water systems along with specific concerns with leakage and mitigation [16]. Further, in automatic rooftop water tank filling and consumption measurement systems, factors like power failure and system expansion are overcome to deliver an uninterrupted water supply [2]. Last of all, the use of machine learning to enhance web applications in the water sector allows for the forecast of the water consumption and classification of water consumers to enhance the efficient use of resources for sustainable water usage [37].

The proposed research deals with the development of an advanced structure of an AI system conducted through machine learning algorithms focused on predicting water demand at a household level. Using family size factor, area of residence, temperature, and occupation, this system changes the water supply and distribution and makes sure that the supply is fully and fairly distributed in the households. Compared to the currently used systems this approach offers a certain level of real-time control over the amount and direction of water flow, the best practice for resource allocation and waste reduction, which makes this approach a step forward in terms of efficiency of water management.

2. Methodology

2.1. Dataset preparation

The sequential methodology proposed in this paper is provided in the following Figure 1. One unique characteristic of this analysis is the capability to forecast water needs for households utilizing other factors employed in creating the data set. The dataset divides regions into sub-categories that include North and Central America, Europe, Asia, Africa, the Middle East, Australia, and South America. They are as follows: Seasonal variation is subdivided into winter, spring summer, and autumn while Temperature variation is divided into hot, moderate, and cold. The location is further classified into urban and rural. Variables such as occupation are categorized into office worker, worker, student, or unemployed. Moreover, the denominator of the merges provides data about religious preferences like Islam, Christianity, Hinduism, Buddhism, etc.

Different water consumption rates have been obtained from different reference sources to arrive at daily usage ratings per person. Finally, the average daily water consumption per head count was worked out. To develop the sample dataset, random data was provided to input to the sample structural data frame. This systematic approach explains the procedures used in arriving at the dataset for the study as explored next.

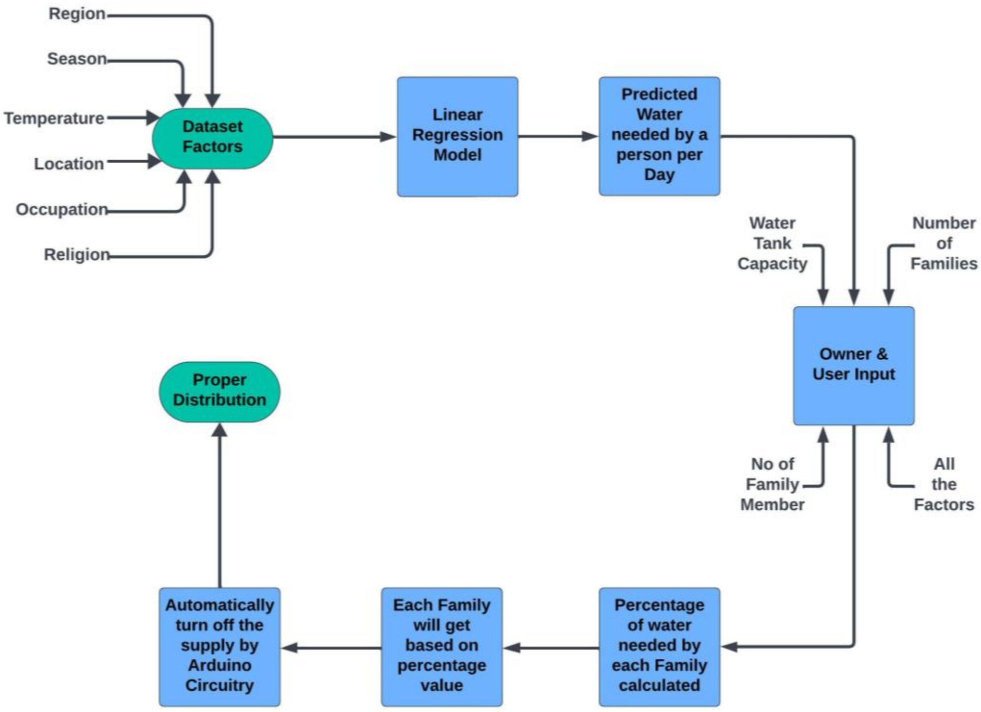

Fig. 1. Block Diagram of the whole process

2.2. Machine learning model

The linear regression model is used to forecast daily water needs per head of population based on the population's geographical locations, time of the year, temperature, places of work, and religion. The daily water requirement for one person is thereafter estimated and this is used to estimate the water requirement for the whole family.

In the context of the proposed system implemented in a residential context, the property owner will input into the system the size of the water tank that is available. They also use the Python code to determine the proportion of water that each family will have from the total capacity of the water tank using the previous estimates. The direct supervision of the program helps to address the problem correctly; it helps to organize the delivery of water properly and finds the household a proper balanced amount of water supply.

The linear regression model can be expressed as:

$$\text{Water Requirement} = \beta_0+\beta_1\times(\text{Region})+\beta_2\times(\text{Season})+ +\beta_3\times(\text{Temperature})+\beta_4\times(\text{Location})+\beta_5\times(\text{Occupation})+ +\beta_6\times(\text{Religion})+\text{error} \quad (1)$$

Here, β_0 is the intercept which means the baseline water requirement. β_1 – β_6 are the coefficients associated with each factor. The coefficients derived from the values of region, season, temperature, location, occupation, and religion are all distinct in terms of their impact on water demand. This research established that region and season exert an influence that positively affects the water demand; regions in the hotter climate or the summer season will demand more water. Concerning occupations, the necessity for water consumption is high if occupations demand intense physical work (labor, for instance), while low if people live in cold climate zones or the country. Water usage usually is higher in urban areas because of the high population density and such things as infrastructure require more water. Also, dictation by religion needs water, some practicing religions may use more water than others, while cold states and students or jobless category use little water as there is less demand for water due to fewer activities. These include the area of residence; a respondent staying in an urban area and having labor-demanding employment in summer will use more water compared to a rural stay plus cold climate plus student employment.

2.3. Arduino code and related circuits

Then, these percentage values will be the input to the Arduino C++ code I mentioned earlier in this paper. Water will be supplied through a water flow sensor and this will also be detected by the same. The water flow sensor shows liters which means that it measures the volume of water that passes through it. But water does not only flow through the water flow sensor, it also flows through the solenoid. Hence water gets to a family through a water flow sensor and a solenoid. The water flow sensor measures the water in liters and the solenoid will be in the off position when the system initially powers up. Maximum water demand is provided as input, so if the maximum turns to the solenoid it will close automatically. That is how water will be properly distributed, and that water wastage can be prevented.

3. Simulation of the proposed design

3.1. Python platform used: Google Colab

The Python scripts used in this study are written and run on Google's Colab platform. Being a service of Google and accessible online the environment resembles the function of Jupyter Notebook where coding can be done within a browser. Google Colab was used for all the programming aspects of the Python code, right from the development of the linear regression model and the inputs that were collected from both the property owner and its users. One can work together and easily access the computational resources that are essential for coding on this platform which makes code even more efficient.

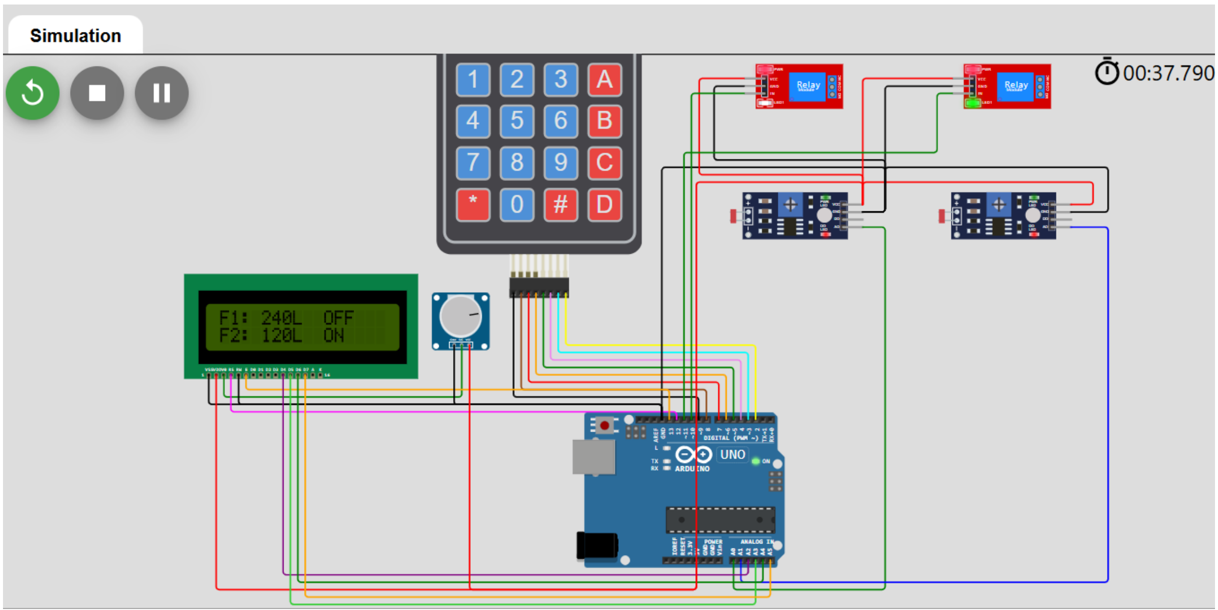

Fig. 2. Simulating Circuit of the proposed design by Wokwi application on the website

3.2. Arduino IDE

The Arduino Integrated Development Environment (IDE) is free and is software that is used to program the board through a computer. In this proposed design, circuitry is engaged using the microcontroller through the Arduino IDE in the development and deployment of the entire system. This platform allows software control and debugging of the design hardware components within an easy-to-use programming environment.

3.3. Wokwi

Wokwi is an online circuit designing software. In this study, Wokwi is used to test and validate the code through modelling and simulation. In the course of circuit simulation, it was possible to use only two analog inputs instead of the water flow sensor; two motors (with relays) instead of the solenoid helped to evaluate the efficiency of the code. The original design of the Arduino UNO R3 was not altered furthermore, no changes were made to the code uploaded into the Arduino board. Through the simulation, the user is shown how the property owner can input the amount of water needed for each family, and the circuit's reaction to these inputs.

From the simulation represented in the figure above, it is clear that Family 1 has exceeded the allowed ratio of water; therefore, the solenoid that has been stimulated by a motor in the simulation is deactivated. On the other hand, the water supply in Family 2 does not exceed the maximum limit enabling the solenoid to remain open. This suggests that the circuit simulation is working optimally while providing an accurate representation of the operating characteristics of the system. The other exciting part of the code is that we used a keypad to give the maximum demand from outside so the code of the Arduino needs not upload and run again and again so it will reduce the hassles of the user means it is user-friendly.

4. Result, performance, and discussion

4.1. Predicted result

In Figure 3 below is the predicted percentage of the water requirements that shall be met for every family in consideration to the figuring by the machine learning model. This predictive modeling enables the right distribution of water supply and reduces the possibility of wastage of this important resource.

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Water Distribution:
Family 2: 292.94 liters (58.59%)
Family 1: 207.06 liters (41.41%)
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Fig. 3. Predicted Water Values in Liters

4.2. Model evaluation by residual analysis

Regression analysis is a statistical tool used to assess the predictive model against the data. Residual values are calculated using the following formula:

$$\text{Residual} = \text{Observed} - \text{Predicted} \tag{2}$$

The residual analysis for the linear regression model used in this research is presented in Figure 4 below. The performance of the residuals is then evaluated using the distribution of the graph. The ideal model means that the model performing well will have residuals with the noise within the chart refusing to be easily aligned on the horizontal zero line or be easily grouped into trends or patterns. This lack of association makes it possible to by inference deduce that the model's predictions are neutral and are not influenced by any other factor. This is also true across the board for each of the five tests, the scattered residuals evidenced in Figure 4 support this assertion of the model used in the proposed design as a good fit for prediction purposes.

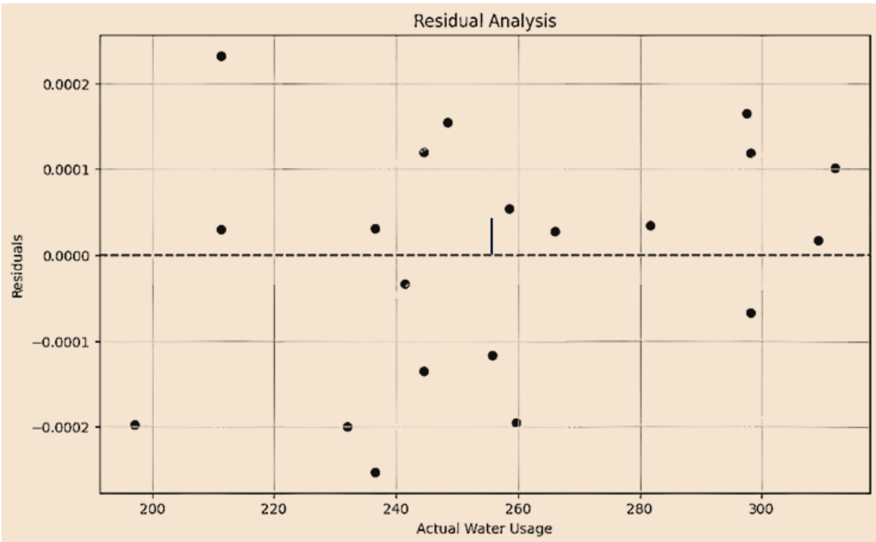

Fig. 4. Residual analysis of the model

5. System implementation, accuracy, affordability, and security

We tested the code practically with a water solenoid valve and Arduino. The code worked well for the solenoid as the practical implementation of the circuit highly relies on the solenoid operation. So easily we can implement the design for the broader application.

We know some multitasking delays are happening in the Arduino. But for our application, this issue will not be a big issue and the system will work well for the household work. Our design applies to the city and the broader area of a country. In that case, the multitasking accuracy may be a concern. We can use Raspberry Pi for accuracy but the concept of our design and the application will be the same as well.

We should consider the cost of the implementations as well, especially for the lower economy country. The owner of the house should be capable in any country to apply this implementation. For applying the broader areas, this should be a concern for the government. The cost will not be as much as big for a government to implement in any country.

The users can give input from their home about their number of family members, area, season, and other factors but the main circuit and control will be the hand of the owner of the house or the government employee of the specific of the areas. So, security will be maintained. In the future design, we can use the live website to see the status of everything and statistics of the water supply and demand.

6. Conclusion

This research seeks to fill the existing gap in the global problems related to water conservation and supply and the management of water resources. There is no wonder that these appear to be rather urgent problems, and the proposed design seems to present potential solutions to them. The result shows stability and the effectiveness of the real implementation of the proposed system. The approach of predicting water usage employed in the current paper offers a new idea and a perspective to approaching this research area. The input of machine learning into the water consumption prediction and the calculation of the water percentages given the various forms of input was done successfully, secondly, there was a practical application using the Arduino microcontroller.

The overall performance of the linear regression model was evaluated which also showed very good results. Nevertheless, when using the feature importance graph some of the values were negative that must be addressed during the next iterations. Thus, the method under consideration in the present paper is more effective in comparison to the existing approaches and contributes to the development of the corresponding field, which still requires further investigation.

7. Future work

The proposed work has a lot of value in the field; however, attention must be paid to the following important limitations to pave the way for other works in this regard. To improve the quality of the forecast it is necessary to increase the sample with a larger amount of data taken from other geographical locations and take as many factors as possible into account.

This has made the inclusion of a water flow meter sensor in this study to allow for the integration of a billing system that will suit the real use of water making the project more applicable. Even though the design centers on the private residential and family domain, it is adaptable to the national domain based on the same principles.

Since the management of water remains one of the key challenges, new ideas are likely to be found in future studies that would enhance the management, distribution, and preservation of water resources as a way of making the world safer and more sustainable.

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