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Remote-Controlled Affordable Solenoid Valve Design and a Web-Based Approach to Its Implementation

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Abstract

Irrigating agricultural lands remotely using automated irrigation systems can mitigate water and energy wastage, reducing it to a minimum. This study aims to design an agricultural irrigation system that operates by remotely opening and closing solenoid valves. The envisioned solenoid valve comprises a wireless microcontroller, a power circuit, and a basic valve mechanism. The remote and automated irrigation system can monitor and receive commands for the connected solenoid valves through web services and a web interface. After every operation executed by the system, interfaces displaying the real-time status or historical operational states of the controlled solenoid valves are presented to the users. This system is orchestrated using a web server operating on a cloud server, serving as the system control center. Solenoid valves positioned at ten different points are integrated, facilitating real-time and programmable use based on user requests. The system uses a secured website, accessed via user passwords, as a communication interface to receive irrigation control requests. It offers the capability for multiple users to control the system simultaneously through the same interface. Ultimately, this research seeks to establish a secure, remote, and automated irrigation system based on the control and scheduling of low-cost solenoid valves via a web page.

Keywords: “Remote irrigation system, solenoid valve, wireless microcontroller, web services, energy efficiency, automated irrigation.”

1. Introduction

The rapidly increasing global population necessitates the continuous evolution of the agricultural sector to meet nutritional needs[1]. Projections suggesting that Turkey's population will exceed 106 million by 2050 further amplify this imperative [2]. However, current global food production levels are not equipped to support this growth trajectory [3], [4]. Traditional agricultural methods, despite expansive farmlands, remain limited in enhancing productivity, leading to reduced crop yield [5], [6].

To overcome these challenges, there's an imperative to use water and energy resources in the agricultural sector more effectively and sustainably[7]. Remote and automated irrigation systems hold the potential to make water and energy usage in agricultural fields more efficient[8]. Especially in recent years, technological advancements have significantly reduced the installation and operational costs of such irrigation systems [9].

Internet connectivity today facilitates almost universal access to myriad information. Moreover, the rise of Internet of Things (IoT) technology has revolutionized many sectors, from smart homes to agricultural fields [10]. Particularly in agriculture, IoT holds significant potential to optimize irrigation processes.

When considering traditional irrigation methods, farmers are often confronted with a labor-intensive process that demands constant attention [11]. Not only is this time-consuming and exhausting, but it also escalates energy and water consumption. In contrast, automated irrigation systems ensure water is used in the right quantity, at the right time, and at the right location. Current market-available automated irrigation systems are typically high-cost and complex [12], posing challenges to farmer adoption.

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This research focuses on the development of automated irrigation systems, underpinned by low-cost and energy-efficient solenoid valves. The establishment of such systems will guide water and energy usage in the agricultural sector towards a sustainable and efficient future. Additionally, this study aims to provide farmers with more effective irrigation management tools, contributing significantly to increased agricultural production and the preservation of natural resources.

2. Material Method

The study was conducted on an agricultural land located 35 km away on the Tokat-Turhal highway. This plot spans an area of 3,688 square meters and exhibits hillside characteristics with a 25% slope. An aerial view of the land can be accessed in Figure 1. The land encompasses 22 distinct sections. These sections cultivate a variety of agricultural produce including apple and peach trees, grapevines, and crops such as tomatoes and peppers. Historically, this area employed a flood irrigation technique.

Figure 1. Aerial view of the land

Located in the lower section of the land is a water pump with a power of 3 kW and a capacity of 4 HP, which fulfills its water requirements from underground sources. Constructed at the highest point of the land is a water reservoir with a capacity of 12 tons and dimensions of (5x5x1.2) meters.

Water is transferred from the pump to the reservoir through an irrigation pipe with a diameter of 63 mm. The distribution of water from the reservoir to ten different sections of the land is accomplished via an irrigation pipe with a diameter of 32 mm. Both electricity and water lines have been laid out to the irrigation site, upon which the developed irrigation system has been installed

2.1. Web of Things Architecture (WoT-TR)

In this study, the preference for web-based methods within the context of Internet of Things (IoT) technologies has been primarily addressed. While these methods frequently emerge in applications such as e-commerce and smart city implementations, they remain relatively unexplored in precision agriculture applications[13], [14]. In this context, a user-friendly, cost-effective, and easily learnable Web of Things (WoT) architecture has been designed. Due to the independently developed hardware and software components, this architecture has been designated as WoT-TR.

The WoT-TR architecture is conceptualized as a web-interface and cloud-based platform. The primary objective of this platform is to promote sustainable and efficient water usage in agricultural irrigation applications.

The architecture comprises the following core components:

Actuators: Employed in the agricultural field to control the irrigation system.

Network Connection: Facilitates communication and control of the actuators through wireless communication protocols.

Cloud Server: Provides a centralized platform where collected data is stored and processed. It also offers users access to data and the capability to control the system.

Web Interface: A user-friendly interface that enables users to access data and exercise control over the system.

2.2. Web of Things (WoT) Communication Protocol

The HyperText Transfer Protocol (HTTP) has been selected as the fundamental communication protocol for the WoT architecture. HTTP operates as a request-response-based communication protocol between the client and the server. The two most prevalent methods of this protocol are GET and POST. While GET is employed to request data from a specific resource, POST is utilized to create or update a resource. In this study, the statuses of the actuators are retrieved using the GET method, whereas notifications regarding the current status of the device are conveyed via POST.

GET Method: This method is employed to request data from a specific resource. In this study, the query string (actuator name) is sent in the URL through a GET request. For instance, the following URL is used: http://www.******.com/test/aktuator.php?actuatorname=value1. The response provided to this URL comprises a sequence like "1,1,0,1". This sequence symbolizes the status of the solenoid valves. A "1" indicates that the solenoid valve is open, while a "0" signifies its closed status. There are a total of four comma-separated values, allowing the control of four distinct solenoid valves from a single point.

POST Method: The POST method is utilized to create or update a resource. The data sent is housed in the body of the HTTP request. For example, the following URL is utilized:

POST http://www.******.com/test/demo_form.php HTTP/1.1

actuatorname=value1&valve1=1&valve2=1&valve3=1&valve4=1

With the message sent via this URL, the "actuatorname" variable specifies which actuator's status will be notified. Information about which valves on the solenoid valve have had their statuses altered is conveyed through the "valve" variables. In this manner, information is simultaneously sent to four valves.

These two methods contribute to the effective and efficient execution of irrigation management and control.

2.3. Wireless Solenoid Valve Control Unit (WSVAU)

The WSVAU has been designed to address the water needs of agricultural fields and to regulate water distribution. This unit facilitates irrigation control using ¾-inch solenoid valves. These valves typically operate with a 220 V AC voltage and offer a variety of output options. Core components of the WSVAU include a microcontroller with wireless communication capabilities, mini solid-state relays, and solenoid valves.

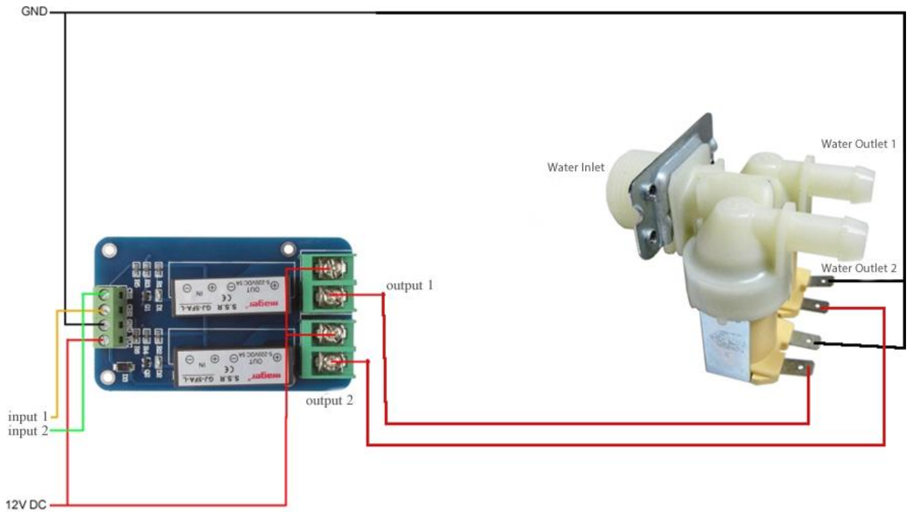

Figure 2: Wireless Solenoid Valve Control Unit (WSVAU)

2.4. Microcontroller Communication Software

This software operates on the ESP8266 microcontroller, enabling the device to connect to the internet. Additionally, it manages the device's state through HTTP GET and POST methods, reporting any necessary modifications. The software has been developed using the C++ programming language. As outlined in Algorithm 1, the system persistently monitors the actuator's status and makes requisite adjustments based on the retrieved status.

Algorithm 1: Monitoring and Controlling the Actuator

```
Function establishConnection(SSID: string, password: string) -> bool:
   // This function attempts to establish a connection to the given SSID using the provided password.
   // Returns true if connection is successful, false otherwise.

   try:
      connectToNetwork(SSID, password)
      return true
   except ConnectionError:
      return false

Function monitorAndControlActuator():
   // This function continuously monitors the actuator status via HTTP requests.
   // If any changes are detected in the actuator state, it sends an update using HTTP POST.

   while True:
      currentStatus = httpGetRequest(aktuator_url)

      // Control the actuator based on the retrieved status
      actuatorResponse = controlActuator(currentStatus)

      if actuatorResponse != currentStatus:
         httpPostRequest(aktuator_url, actuatorResponse)

// Main Execution
if establishConnection(mySSID, myPassword):
   monitorAndControlActuator()
else:
   print("Connection failed!")
```

2.5. User Interface Software

The user interface facilitates the operation and programming of the actuator node. It has been developed using HTML5, PHP, JS, and CSS. This interface is made compatible with the Bootstrap 3 CSS framework. Authorized users can access the device and modify its configuration. All changes are recorded in the database, with the latest entry reflecting the device's most recent state.

3. Results and Discussion

Based on the WoT-TR architecture, this study focuses on a real-time, programmable agricultural irrigation management system prioritizing energy and water efficiency. The developed system not only supports inter-object communication using HTTP protocols but also presents wireless solenoid valve control units (WSVAU) and a user-friendly web interface, simplifying the irrigation management of agricultural areas.

Throughout the research process, an integrated system for agricultural irrigation management has been established. This system contributes to energy and water savings, adding a valuable dimension to sustainability and efficiency standards in the agricultural sector. Constructed using HTTP protocols for the Web of Things (WoT), this model proposes a strategic approach for the effective management of water in agricultural areas, taking into account the direct relationship between crop diversity, growth, location, and quality with optimal water management.

In the experimental phase, data collected from each actuator node were analyzed. The web interface enables users to monitor irrigation zones in real-time and to plan their irrigation schedules using geographic mapping tools (Figure 3).

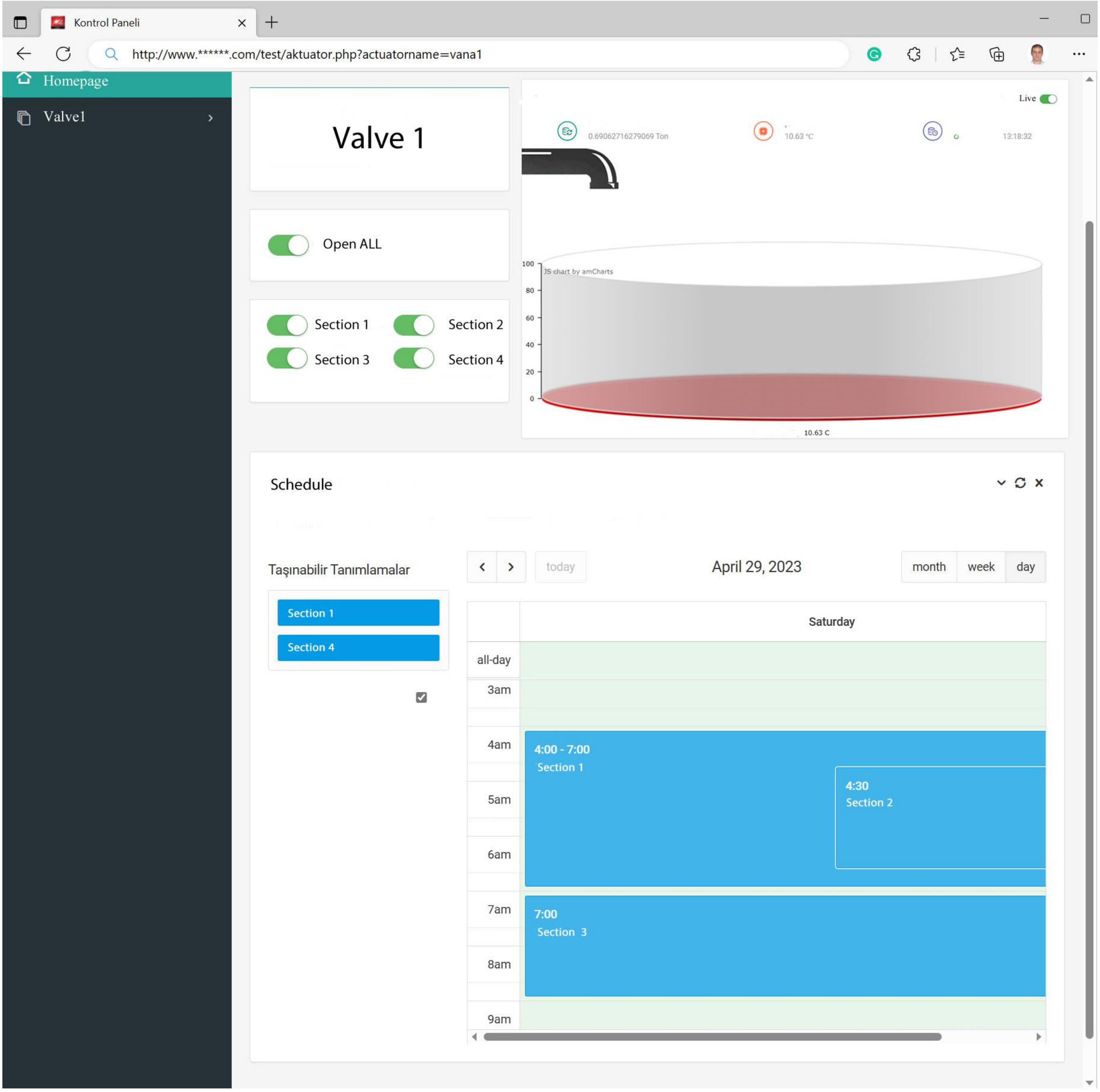

Figure 3 WoT-TR Web Architecture

The findings of this research are regarded as a significant step in optimizing agricultural irrigation management and limiting energy consumption. When compared with the literature, it is observed that this approach has the potential to ensure energy and water efficiency. From an economic perspective, the developed model appears to offer a more cost-effective solution compared to existing irrigation systems.

The integration of the user interface allows for the real-time adaptation of irrigation strategies and more conscientious use of water resources, representing a critical stride towards the sustainable management of global water resources.

In conclusion, this study presents a revolutionary step in agricultural irrigation management by enhancing energy and water efficiency. Future research is anticipated to focus on larger agricultural areas and different climatic conditions. The widespread adoption of the approach proposed by this study could positively influence global agricultural production and water management standards

4. Conclusion

This study focuses on the development of a real-time and programmable system aimed at achieving energy and water savings in agricultural irrigation management. The results obtained point to a potential for significant increases in sustainability and efficiency within the agricultural sector, accompanied by reductions in energy and water consumption. Particularly, the success of the Web of Things (WoT) architecture in irrigation management paves the way for its broader adoption in agricultural irrigation applications. These findings possess the potential to shape and enhance the future of precision farming practices, offering the scientific community a valuable contribution towards the adoption of innovative and sustainable solutions in this domain. The system developed provides a framework for managing agricultural irrigation processes in a more economical, effective, and environmentally friendly manner. This not only contributes to the sustainable utilization of water resources but also elevates agricultural productivity. In summary, this research delivers a pivotal contribution to science on how modern technologies can be effectively integrated into agricultural irrigation management.

Authors' Contribution

Both authors contributed equally to the study.

Conflict of Interest Declaration

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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