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THESIS REPORT

DEVELOPMENT OF A SMART AUTONOMOUS IRRIGATION SYSTEM USING IOT AND ARTIFICIAL INTELLIGENCE

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ABSTRACT

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B.Sc. Thesis, Electrical & Electronics Engineering Department

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Agricultural irrigation ensures that the water required for plant growth is delivered to the soil in a controlled manner. However, uncontrolled management can lead to water waste while reducing agricultural productivity. Drip irrigation systems, which have been one of the most efficient methods since the 1970s, are modernised with IoT and artificial intelligence in this study, aiming to both increase efficiency and prevent water waste.

The developed system is designed to be applicable to different agricultural production areas and tested with a prototype consisting of 3 rows and 3 columns. The project will start with the transfer of environmental data via the Wi-Fi module of the ESP32 microcontroller, the data will be processed with the LSTM model and learning and prediction processes will be carried out. The user will be able to control the system manually or delegate it to artificial intelligence through the Blynk application. The system includes ESP32 microcontroller, rain and soil moisture sensors, DHT11 temperature and humidity sensor, relays, solenoid valves and 12V power supply.

The system aims to increase labour productivity and contribute to the conservation of water resources by enabling agricultural and greenhouse workers to focus on processes other than irrigation. In addition, the developed autonomous irrigation system will support the spread of sustainable agricultural practices and increase agricultural productivity.

Keywords: Autonomous Irrigation, IoT, Artificial Intelligence, Agriculture, Water Management

ÖZET

IOT VE YAPAY ZEKÂ KULLANARAK AKILLI OTONOM SULAMA SİSTEMİ GELİŞTİRİLMESİ

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Lisans Bitirme Tezi, Elektrik & Elektronik Mühendisliği Bölümü

Tez Danışmanı: Dr. Öğr. Üyesi Hayriye Serra ALTINOLUK

2024, 66 sayfa

Tarımsal sulama, bitki büyümesi için gerekli suyun kontrollü şekilde toprağa verilmesini sağlar. Ancak kontrolsüz yönetim, tarımsal verimliliği azaltırken su israfına yol açabilir. 1970'lerden bu yana en verimli yöntemlerden biri olan damlama sulama sistemleri, bu çalışmada IoT ve yapay zekâ ile modernize edilerek hem verimliliğin artırılması hem de su israfının önlenmesi hedeflenmiştir.

Geliştirilen sistem, farklı tarımsal üretim alanlarına uygulanabilir şekilde tasarlanmış ve 3 sıra, 3 sütundan oluşan bir prototip ile test edilmiştir. Proje, ortam verilerinin ESP32 mikrodenetleyicisinin Wi-Fi modülü üzerinden aktarılmasıyla başlayacak, veriler LSTM modeli ile işlenerek öğrenme ve tahmin süreçleri gerçekleştirilecektir. Kullanıcı, Blynk uygulaması aracılığıyla sistemi manuel olarak kontrol edebilecek veya yapay zekâya devredebilecektir. Sistem, ESP32 mikrodenetleyici, yağmur ve toprak nem sensörleri, DHT11 sıcaklık ve nem sensörü, röleler, solenoid valfler ve 12V güç kaynağı içermektedir.

Sistem, tarım ve sera sektöründe çalışanların sulama işlemleri dışındaki süreçlere odaklanmalarını sağlayarak iş gücü verimliliğini artırmayı ve su kaynaklarının korunmasına katkıda bulunmayı hedeflemektedir. Ayrıca, geliştirilen otonom sulama sistemi, sürdürülebilir tarım uygulamalarının yaygınlaşmasını destekleyerek tarımsal verimliliğin artırılmasına olanak tanıyacaktır.

Anahtar Kelimeler: Otonom Sulama, IoT, Yapay Zekâ, Tarım, Su Yönetimi

ACKNOWLEDGEMENT

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We are especially grateful for her dedication and the knowledge she generously shared, which helped us overcome challenges and achieve our project goals.

We also acknowledge the resources and facilities provided by Muğla Sıtkı Koçman University, which played a vital role in enabling the successful realization of this study.

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LIST OF ABBREVIATIONS

WUE	Water Use Efficiency
IoT	Internet of Things
AI	Artificial Intelligence
BC	Before Christ
AD	Anno Domini
LSTM	Long Short-Term Memory
Wi-Fi	Wireless Fidelity
SPI	Serial Peripheral Interface
I2C	Inter-Integrated Circuit
UART	Universal Asynchronous Receiver Transmitter
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
Arduino IDE	Arduino Integrated Development Environment
ESP-IDF	Espressif IoT Development Framework
VCC	Positive Supply Voltage
GND	Ground
GPIO	General purpose input/output
LED	Light Emitting Diode
MOSI	Master Out Slave In
MISO	Master In Slave Out
SCK	Serial Clock
CS	Chip Select
SDA	Serial Data
TX	Transmit
RX	Receive

CAN	Controller Area Network
PWM	Pulse Width Modulation
RTC	Real-Time Clock
DHT11	Temperature and Humidity Sensor
DC	Direct Current
ML	Machine Learning
DL	Deep Learning
CNNs	Convolutional Neural Networks
RNNs	Recurrent Neural Networks
MSE	Mean Squared Error
MAE	Mean Absolute Error
SSID	Service Set Identifier

1. INTRODUCTION

Today, population growth, industrial activities, agricultural activities, global climate change, and warming-related evaporation increase put great pressure on clean water resources. When water consumption is taken into consideration, the biggest share in this is agricultural water use, accounting for approximately 75%. This significant proportion underscores the critical role of agriculture in the global water crisis and highlights the necessity of sustainable water management practices in this sector [1]. The studies in the field indicate that increasing pressure on water sources due to industrial and domestic water consumption will be critical in the near future. Figure 1 and Figure 2 shown below indicates this critical increase year by year [2,3].

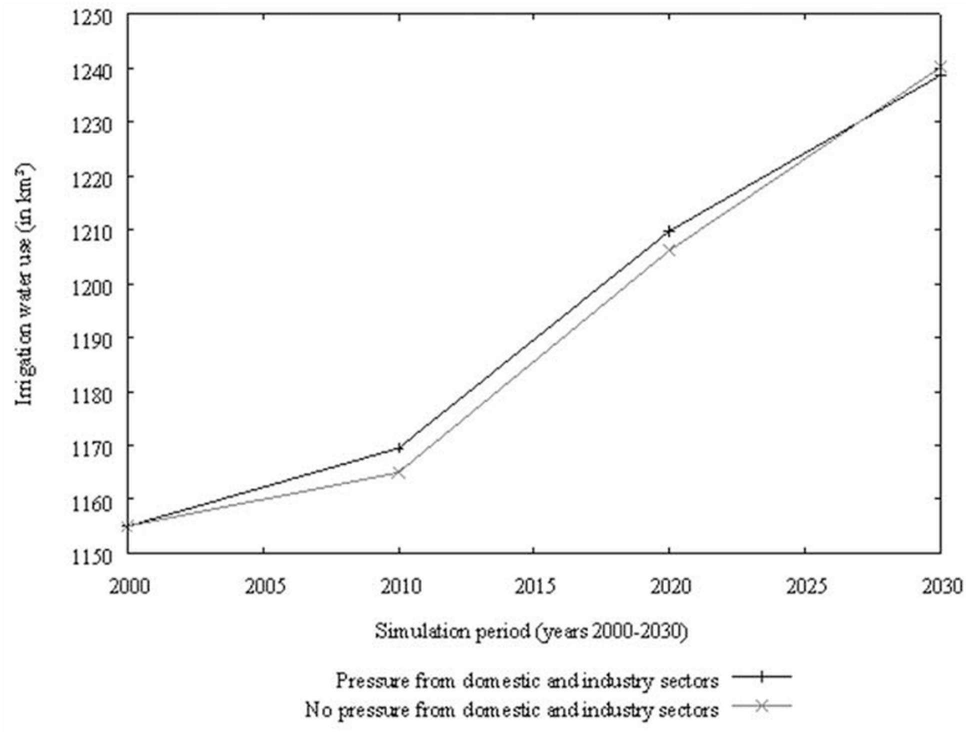


Figure 1. Global water consumption in irrigation between 2000-2030 [2]

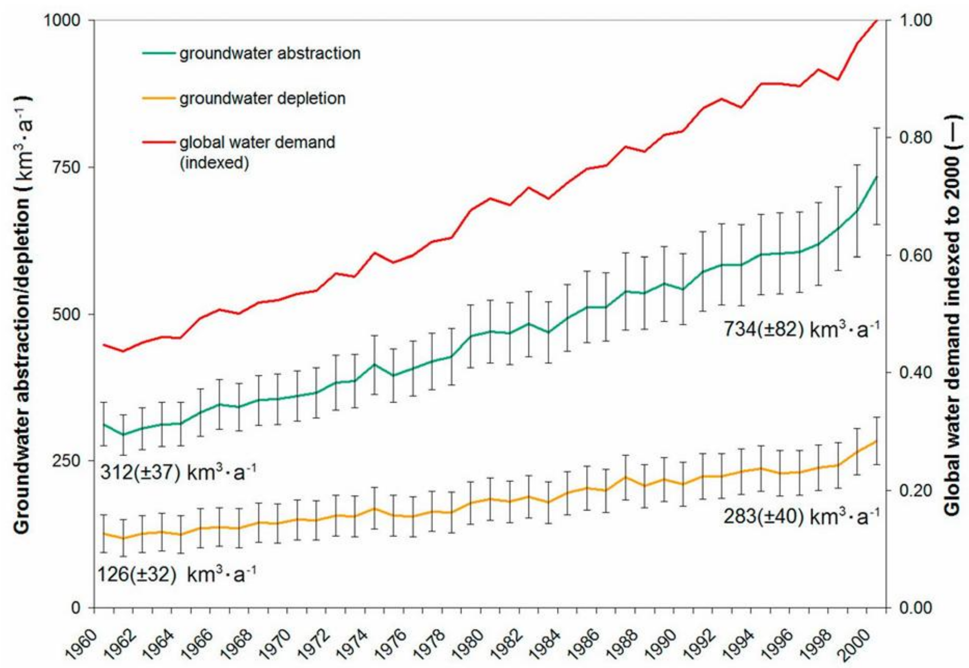


Figure 2. Groundwater depletion and increasing global water demand [3]

The reason for such a high level of water consumption takes root from the water used in plant-based and animal-based production to meet the increasing demand for agricultural products driven by the growing human population. For instance, while plant-based food production requires considerably less water compared to animal-based food production, the total annual water consumption for both sources still reaches almost a significant value of 1600 m^3 per capita. This emphasizes the immense impact of agricultural practices on water resources and the urgent need for sustainable management strategies to mitigate this pressure [1].

Water is not only essential for human survival but also serves as the backbone of environmental stability. Its sustainable management is crucial to meet current demands while preparing for the future needs of a growing population. The substantial contribution of irrigated agriculture to water consumption—especially in semi-arid regions, where per capita irrigation water requirements can reach 785 m^3 annually—highlights the necessity of adopting more efficient and water-saving agricultural practices [1]. Table 1 shows the water requirements for foods per capita.

Table 1. Water requirements for food per capita[a] [1]

Food	Plant-based	Animal-based	Total
Daily amount (kcal)	2300	400	2700
Daily water required per 1000 kcal (m^3)	1	5	–
Daily actual water requirement (m^3)	2.3	2.0	4.3
Annual water requirement (m^3)	840	730	1570
Assume 50% irrigated production (m^3)	–	–	785

[a] Source: FAO (see Falkenmark, 1997).

Prioritizing plant-based agriculture, which requires less water, can play a pivotal role in conserving water resources while simultaneously supporting ecosystem sustainability. This approach aligns with broader sustainability goals and ensures that water is used efficiently to meet both environmental and societal needs.

All problems have been tried to be addressed globally and from every angle so far. However, the situation in our country should also be taken into consideration.

1.1. An Overview of Agricultural Water Use in Turkey

Considering the findings of Ertek and Yilmaz (2014), it can be observed that Turkey's water resources face significant threats if immediate measures are not implemented. According to same report, in Turkey, surface irrigation methods account for 80% of irrigation practices, with only 20% relying on pressurized systems [4]. A considerable amount of water is lost due to evaporation in surface irrigation and open-channel systems. Therefore, transitioning to pressurized irrigation methods for all cultivated crops has the potential to reduce water consumption by nearly 50% [5].

Turkey has a suitable structure for growing various agricultural products, considering its geographical conditions, climate, location, soil type diversity, etc. Table 2 shows different types of plants which widely harvest among Turkish provinces.

Table 2. Different Plant Types and Water Consumption of Crops [4]

Plant type	**Region**	**Evapotranspiration (mm)**	**Yield (kg/ha)**	**WUE (kg/ha mm^{-1})**
Cotton	Menderes basin	602	3510	5.83
	Cukurova basin	850	4110	4.84
Maize	Cukurova basin	756	8610	11.39
	Konya basin	510	8160	16.00
	Menderes basin	640	9950	15.55
Wheat	Konya basin	516	2010	3.90
	Cukurova basin	525	4040	7.70
	Menderes basin	700	4020	5.74
	Harran plain	727	5070	6.97
Citrus	Cukurova basin	687	85 **(kg/tree)**	0.12 **(kg/tree mm^{-1})**
	Antalya basin	710	79 **(kg/tree)**	0.11 **(kg/tree mm^{-1})**
	Menderes basin	1155	48 **(kg/tree)**	0.04 **(kg/tree mm^{-1})**

Evapotranspiration, Yield, and WUE of Different Plant Types in Various Regions

WUE stands for 'Water Use Efficiency,' which indicates how efficiently a plant utilizes water. Effective water management systems can increase this value; however, a high WUE value does not necessarily imply that the system is highly efficient. Because ‘water use efficiency’ is not solely determined by the presence of an irrigation system but also by the plant's ability to use water efficiently. Table 3 shows the WUE values for different irrigation methods. It is evident that the WUE values reach their highest point when the drip irrigation method is used for the same crop.

Table 3. Crop types and different irrigation methods and WUE values [4]

Crop	Irrigation method	Irrigation water (mm)	Yield (t/ha)	WUE (%)
Strawberry (Tarsus)	Furrow	400–650	12–13	0.3–0.2
	Drip	300–400	13–15	0.4
Orange (Adana)	Furrow	460–575	24.5–36.7	0.5–0.6
	Drip	151–299	20.1–37.3	1.3–1.2
	Sprinkler	344–430	31.0–42.4	0.9–1.0
Orange (Tarsus)	Furrow	115–445	5.9–7.6	0.5–0.2
	Sprinkler	670–844	13.6–13.3	0.2–0.16
Lemon (Mersin)	Furrow	1002–1336	2.2–2.8	0.02
	Drip	184–277	2.2–2.5	0.10–0.09
	Sprinkler (over tree)	1001	2.5–3.4	0.02–0.03
	Sprinkler (under tree)	1064–1463	2.5–2.8	0.02–0.01
Tomato (Mersin)	Sprinkler	130–330	29–67	2.2–2.0
	Drip	80–250	30–64	3.7–2.6
	Perforated pipe	90–270	30–64	3.3–2.4
Banana (Mersin)	Drip	984–1528	18.7–22.5	0.2–0.15
	Conventional	2407–2784	16.2–22.5	0.07–0.08

Irrigation water use and yield with various irrigation methods in Turkey (Tekinel and Kanber, 2002).

As observed, the drip irrigation system currently offers the highest water efficiency for the crop. However, this method is costly and lacks an optimal electrical and electronic control system. This thesis explores strategies to enhance the efficiency of drip irrigation systems through the integration of modern IoT and AI technologies.

Until the first integration of the drip irrigation system in the 1970s, activities in the field were carried out in a haphazard manner and far from being productive. However, with the drip irrigation system, water is given to the plant roots with the help of a pipe laid under the plant from the soil, and water flow is provided systematically. Thus, the system provides water to the plant with a high efficiency rate by minimizing water evaporation at certain intervals. Detailed information is visually shown in Figure 3.

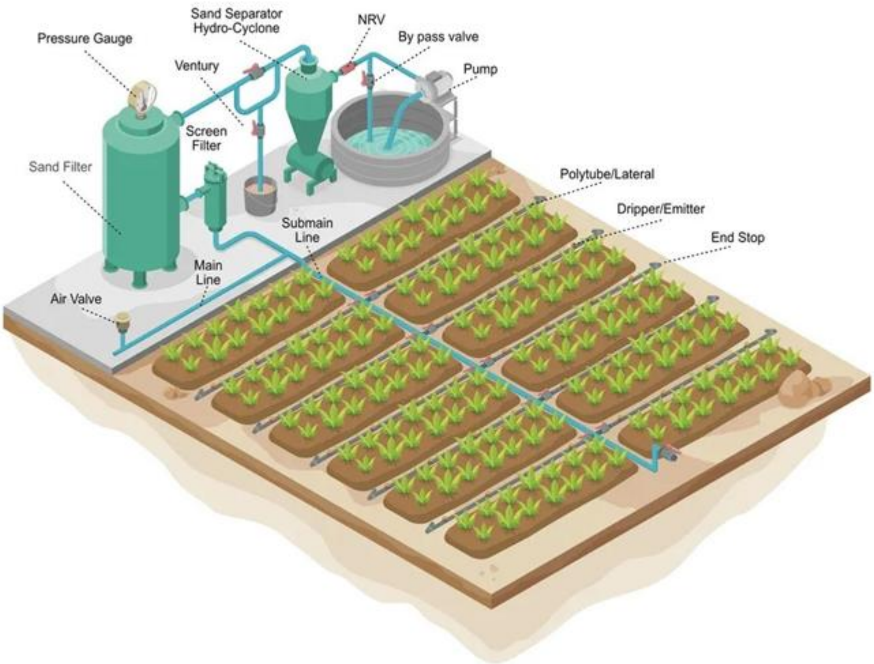


Figure 3. Drip irrigation process [6]

Before moving on to the work to be done to increase the effectiveness of the system, it was deemed useful to take a brief look at the historical process in order to understand how people approached this problem in the past.

1.2. Historical Process of the Agricultural Irrigation Systems

(3000-2000 BC) Sumerians (Mesopotamia): The first organized irrigation systems developed around the Euphrates and Tigris Rivers. They built canals, ditches, and dams to divert the river waters to the fields, increasing grain production and prosperity for the Sumerians [7]. Figure 4a illustrates an artistic representation of these ancient irrigation systems.

(1000 BC - 500 AD) Roman Empire: Aqueducts and drainage systems were used to transport water for both cities and agricultural areas. The Romans developed screw pumps and water wheels to pump underground water sources [8]. The aqueduct bridge in Segovia is shown in Figure 4b.

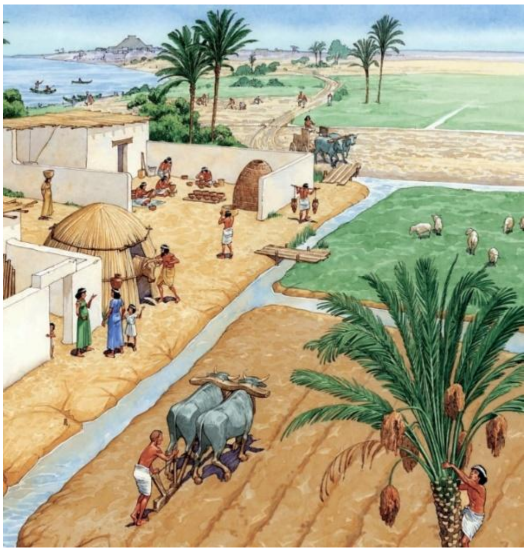


Figure 4a. Ancient irrigation system [9]   b. The aqueduct bridge in Segovia [10]

(500-1500) Andalusia (Spain): The Islamic world developed advanced techniques for the efficient use of water. Innovative methods such as water wheels (noria) and terraced irrigation systems increased agricultural production, especially in arid regions [11]. Figure 5 illustrates a schematic representation of the *noria* system, showcasing its design and functionality.

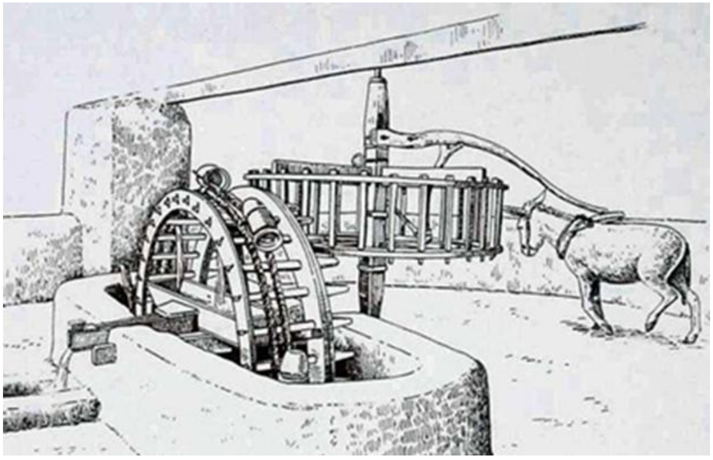


Figure 5. A schematic representation for noria system [12]

(1500-1900) Renaissance and the Industrial Revolution: During this period, irrigation engineering developed and scientific approaches were applied to irrigation projects. In particular, Leonardo da Vinci developed a system of paddle wheels and water lines that could provide different flows depending on the water pressure. This system, which can be given as an example of the first autonomous irrigation system, was used in some regions of Italy at the time and spread from there to the world [13].

Also during this period, a system called the 'Archimedes Screw' was used as an innovative solution. This system acted as a mechanical elevator, lifting the water to where it needed to be carried. This place was usually a water tank or a cistern [14]. Figure 6 shows Da Vinci's design for efficient water management in agriculture.

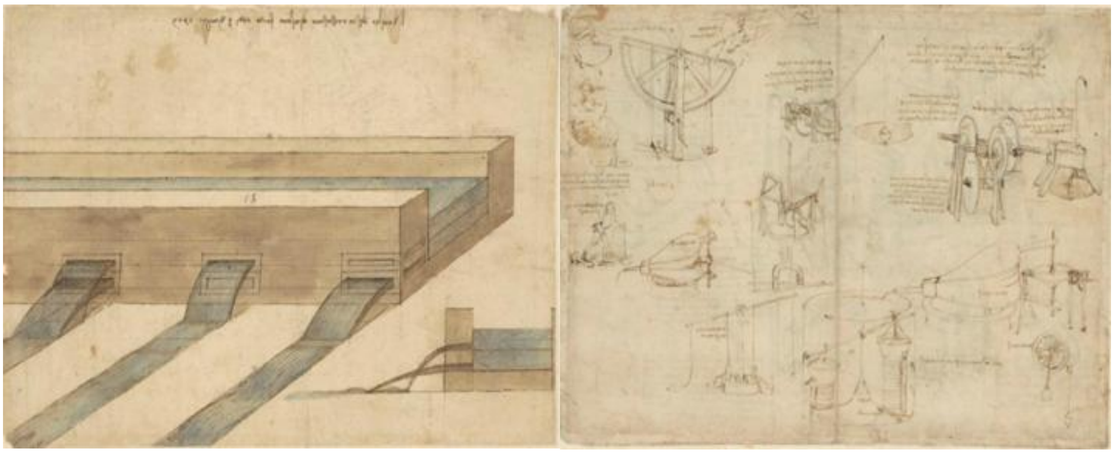


Figure 6. Water Management System Design of Da Vinci for Agriculture [14]

Mechanical Irrigation: Water pumps and steam engines were introduced. This allowed more areas to be irrigated. Water pumps are mechanical structures that create a pressure difference that can draw water from places such as wells, ponds and streams. In the 1900s, thanks to these steam-powered mechanisms, water could be delivered from a certain source in a relatively fixed amount without human power [15]. Figure 7 shows a steam-powered water pump that was widely used during this period.

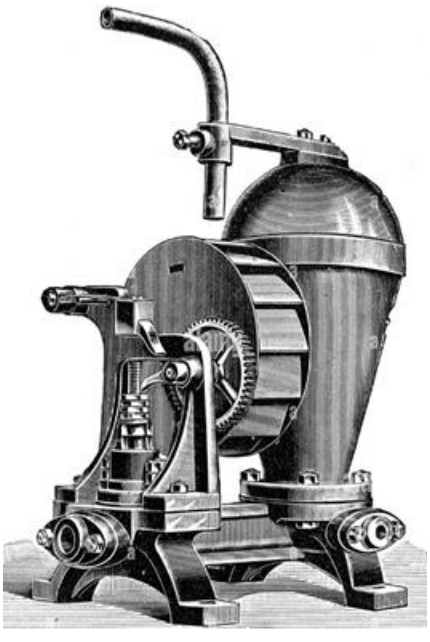
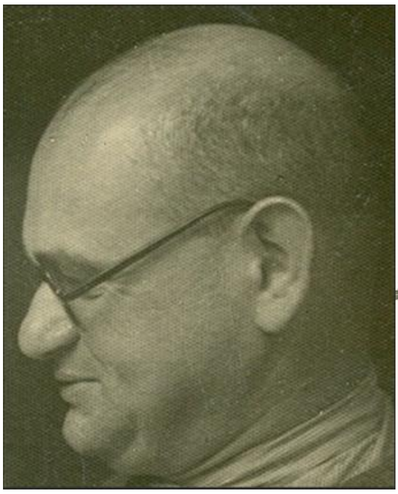


Figure 7. Steam Powered Water Pump [16]

20th Century

Drip Irrigation (1960s): Developed in Israel, this innovative system saves a significant amount of water by delivering it directly to the root zone of plants. Figure 8a shows Simcha Blass, who, together with his son Yeshayahu, paved the way for efficient irrigation agriculture in Israel despite limited water resources. They founded the company Netafim, which revolutionized irrigation and marketed this technology globally [17]. Figure 8b illustrates the drip irrigation system, showcasing its components and functionality.



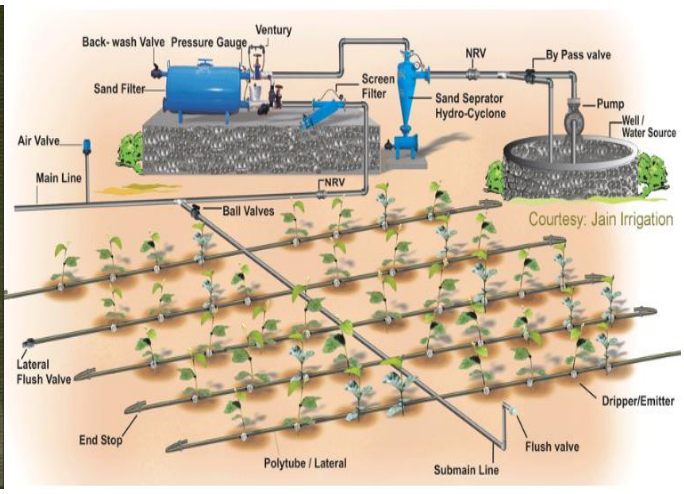


Figure 8a. Simcha Blass [18]   Figure 8b. Drip Irrigation System [19]

Sprinkler Systems: Irrigation pipes and sprinklers are used to distribute water evenly over large areas. The system includes a pump unit, main and side pipelines, rotating heads called sprinklers and an electronic card for the control mechanism. The spray area can be changed via this card [20]. Figure 9 illustrates a typical sprinkler irrigation system in action.

Figure 9. Sprinkler Irrigation System [21]

Modern Systems

IoT and AI Based Systems: Using sensors and AI, the moisture status of the soil is analyzed in real time, ensuring the most efficient use of water. The project planned to be carried out uses this approach to determine soil moisture, air temperature and humidity, water flow rate, etc. It will control the irrigation system by making predictions by evaluating important data such as.

Solar Irrigation: Running water pumps with renewable energy sources reduces energy costs. Such systems consist of two separate parts.

1. **Photovoltaic panels where energy is produced:** Reduce the cost of energy and can be used safely forever as a clean energy source.
2. **DC pumps:** Sends water to desired areas with pressure difference using electrical energy.

2. METHODOLOGY

2.1. Aim and Goals

By challenging the effectiveness of current irrigation methods, this study seeks to create a more adaptable, independent, and data-driven system. The suggested solution seeks to more precisely forecast irrigation needs by combining AI and IoT technologies, which will save water and time.

Within the scope of the study, the following objectives are planned to be achieved:

1. Collection of environmental data such as soil moisture, temperature, rainfall and water flow rate through sensors.
2. The collected data is transferred to a cloud-based database using the wireless connection feature of the ESP32 microcontroller and stored regularly.
3. Developing a mobile application for users to easily access the system and monitor environmental data in real time.
4. Estimation of irrigation needs based on historical data using LSTM model and optimisation of irrigation process in line with these estimates.
5. Designing a system that supports manual, automatic, and AI-based irrigation control options.
6. In case of any problem, the system stops the irrigation process and informs the user.

Particularly in areas where water is scarce, this study seeks to guarantee more economical and social benefits from agricultural operations and to guarantee more effective use of resources. In addition, by reducing farmers' workloads, it is anticipated to support sustainable farming methods.

The stages of the study are supported by the work flow diagram in Figure 10.

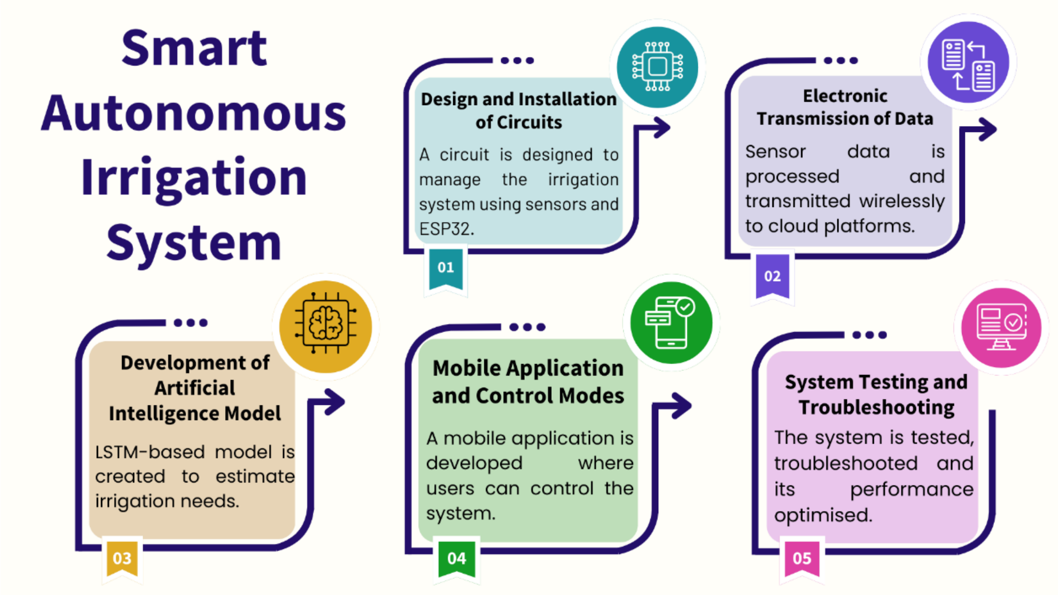


Figure 10. Work Flow Diagram

The study consists of five stages:

First Stage: Design and Installation of Circuits

To gather environmental data and manage the irrigation system, a circuit board will be created. Using the ESP32 microcontroller, the circuit board will incorporate the following parts: a water flow sensor, a DHT11 sensor, a rain sensor, and a soil moisture sensor. These elements will serve as the system's foundation for measuring environmental factors to determine irrigation requirements and guarantee that the right amount of water is sprayed.

Second Stage: Data Transmission

The code will be written to process the sensor data and move it to cloud computing platforms like Blynk or Google Firebase. The ESP32's wireless communication capabilities will be used to send data in real time to the electronic environment and enable users to access it remotely.

Third Stage: Development of AI Model

Using the information gathered, the LSTM algorithm—a machine learning model—will be created to estimate irrigation requirements. Through learning from past data, this model will optimize irrigation operations and make recommendations based on user behavior.

Fourth Stage: Mobile Application Development

To make it easier for users to monitor and manage the system, a mobile application will be created. In addition to managing irrigation in three modes—manual, automated, and AI-based—the app will show sensor data. Full user control is available in manual mode, sensor data is used in automatic mode, and an LSTM-based model is used in AI mode to optimize irrigation by analyzing user behavior and environmental data. This method uses an intuitive interface to provide effective and flexible control.

Fifth Stage: System Testing and Troubleshooting

To confirm the system's operation and address any issues, extensive testing will be done. During this process, the system will adjust to its surroundings and function efficiently with little assistance from humans.

2.2. Materials and Methods

The materials and techniques used to develop and deploy an intelligent, self-sufficient irrigation system utilizing AI and the IoT are thoroughly covered in this chapter. While techniques are created to optimize system performance and accuracy, materials are carefully chosen to guarantee compatibility, efficiency, and dependability.

1. **ESP32 (Wi-Fi + Bluetooth Development Module)**

ESP32 is a low-cost, high-performance microcontroller module developed by Espressif Systems, widely used in IoT and embedded system projects. The dual-core Xtensa LX6 processor offers a flexible and powerful solution for applications requiring wireless communication with integrated Wi-Fi and Bluetooth features. In addition, its low power consumption and large developer community make ESP32 popular among developers and in projects requiring energy efficiency [22].

Key Features of ESP32

Important features of the ESP32 that enable it to be used in a wide range of applications are:

- **Dual-Core Processor:** Its dual-core structure based on the Xtensa LX6 processor allows multitasking and provides high performance [23].
- **Wireless Connection Support:** ESP32 enables IoT devices to connect to the internet and communicate with other devices with integrated Wi-Fi 802.11 b/g/n and Bluetooth 4.2 features [23].
- **Low Power Consumption:** ESP32 supports various sleep modes and power management features to provide energy efficiency. This provides a great advantage especially in battery-powered applications [24].
- **Integrated Peripherals:** The ESP32 offers a rich input/output interface including digital and analogue peripherals such as SPI, I2C, UART, ADC and DAC. This feature enables easy integration of sensors and other peripherals [23].
- **Security Features:** ESP32 ensures data security in IoT projects by supporting security mechanisms such as hardware-based cryptography, secure boot and flash encryption [23].
- **Programming Flexibility:** ESP32 supports various development tools such as Arduino IDE, MicroPython and Espressif's ESP-IDF. This flexibility appeals to developers of different experience levels [22], [23].

1.1. Pin Structure and Functions of ESP32 Microcontroller

The ESP32 microcontroller has a versatile pin structure designed to meet a variety of application needs [23]. These pins fulfil many functions from power connections to communication interfaces. The pin structure and functions of the ESP32 are shown in Figure 11.

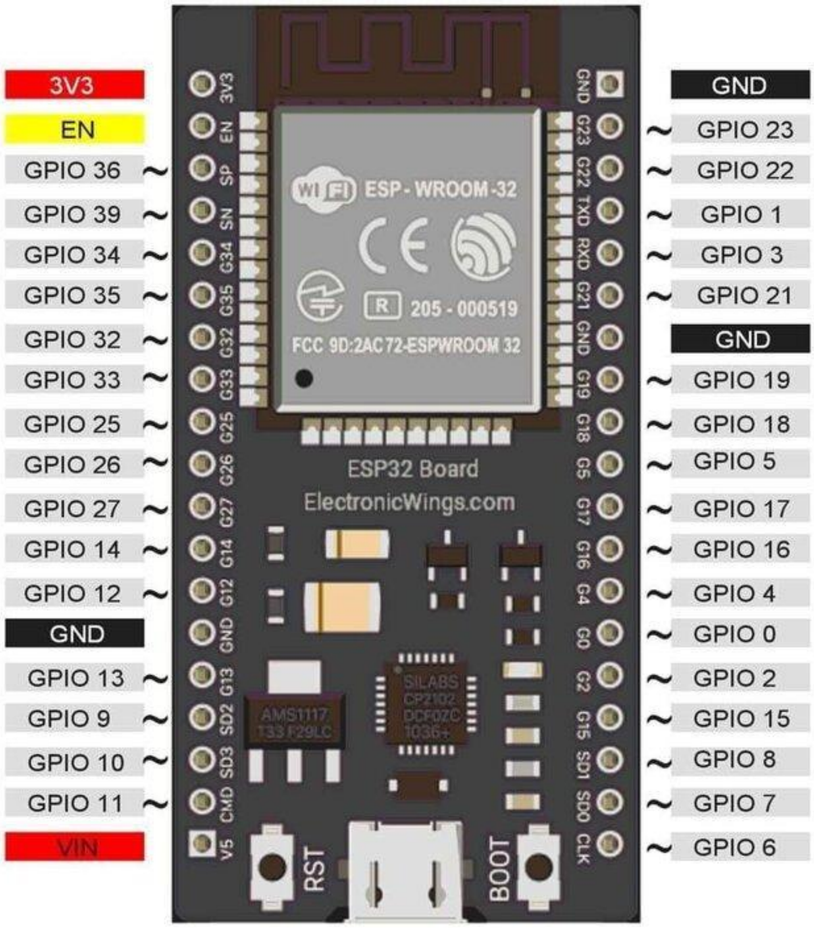


Figure 11. PIN Description of ESP32 [23]

1. **Power Supply Pins**

- **VCC:** This pin is usually connected to a 3.3V power supply to meet the energy needs of the system.
- **GND:** It is the earth connections that provide the reference voltage for the system.

2. **Digital Input/Output Pins**

- **GPIO Pins:** Both digital inputs and outputs can be set up on GPIO pins. Sensor connections, LED control, and external device administration are just a few of the many uses for it. Numerical identifiers such as GPIO0, GPIO2, or GPIO26 are used to identify the pins.

3. **Analog Input Pins**

- **ADC Pins:** A group of pins on the ESP32 can convert analog to digital. Analogue voltage levels from sensors can be read using these pins, which are designated ADC1_0 and ADC2_4.

4. **Communication Interface Pins**

- **SPI Pins:** These pins support SPI communication and include MOSI, MISO, SCK and CS connections.
- **I2C Pins:** I2C pins including SDA and SCK lines support inter-device communication.
- **UART Pins:** The UART pins are designed for serial communication using TX and RX connections.
- **CAN Pins:** Some ESP32 models have dedicated CAN pins that support CAN communication.

5. **PWM Pins**

PWM pins enable the generation of analog-like signals with programmable duty cycles. It is used in tasks such as motor control, LED brightness adjustment and sound reproduction.

6. **Internal Component Pins**

- **RTC Pins:** These pins are reserved to work with the internal RTC module.
- **LED Control Pins:** Some ESP32 models have special pins for controlling the on-board LEDs.

7. **Special Function Pins**

- **Touch Pins:** Designed for touch sensitive applications, these pins have labels such as T0, T1.
- **Multifunctional Pins:** Some pins can fulfil more than one function, depending on the configuration.

The ESP32's broad pin layout and wireless connection capabilities (Wi-Fi and Bluetooth) make it easier to integrate sensors and actuators. For our investigation, we decided to use ESP32 to interpret sensor data and send it in real time to cloud platforms. This platform satisfies our requirements for programmability and connectivity.

2. Rain Sensor

The rain sensor allows the system to adjust irrigation programmes by providing instant updates according to current weather conditions. It stops irrigation when it rains, prevents plants from getting unnecessary water and warns the user [25]. The sensor contributes to water and energy savings by monitoring the weather and optimising irrigation according to rainfall. An example of the sensor is shown in Figure 12.

Figure 12. Rain Sensor [26]

3. Soil Moisture Sensor

Moisture is an important factor in plant growth. Soil moisture sensors measure the moisture content of the soil and inform users when to start or stop irrigation. In this way, the timing of irrigation is optimized, ensuring efficient use of water resources. Moisture has a critical role in agricultural production as one of the three main factors affecting plant growth [27].

A total of six soil moisture sensors will be used, placed at the beginning and end of each row. Strategically placed in a 3x3 matrix, these sensors provide essential data to assess irrigation requirements and enable the artificial intelligence model to accurately analyze moisture levels [25]. These sensors, positioned at the beginning and end of each row, allow continuous monitoring of the soil moisture level, ensuring uniform irrigation throughout the rows [28]. By means of regulation, ideal irrigation conditions are guaranteed by providing the correct irrigation control according to the specific needs of each row of plants [29]. Thus, plant health and productivity are increased by maintaining appropriate moisture levels in the root zones of the plants, and at the same time, water and energy savings are achieved by irrigation only in the areas where it is needed [30]. An example of the sensor is shown in Figure 13.

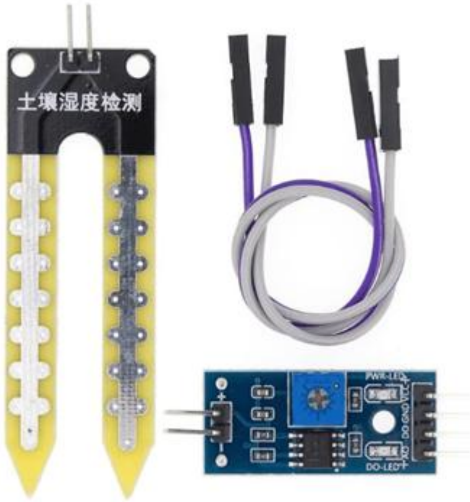


Figure 13. Soil Moisture Sensor [27]

4. **DHT11 Sensor**

The DHT11 sensor provides a critical layer of environmental data for the irrigation system by measuring ambient temperature and humidity. This sensor enriches the overall dataset, providing important inputs to the AI model to optimise water use. In particular, temperature and humidity data improve the performance of the system by contributing to more accurate estimation of irrigation needs [25]. An example of the sensor is shown in Figure 14.

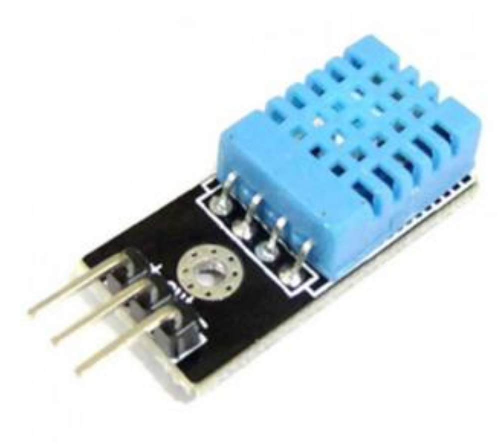


Figure 14. DHT11 Sensor [27]

5. YF-S201 Water Flow Sensor

In smart irrigation systems, precise and effective water management is essential for both water conservation and plant health protection. Water flow sensors are among the system's essential parts in this regard.

The YF-S201 water flow sensor is a sensor used to determine the amount of water transported through the pipe by measuring the flow rate of water. This sensor is connected to the pipe of a submersible water pump and has an operating flow rate from 1 to 30 L/min. Furthermore, the water pressure capacity of this sensor is below 1.95 MPa. The YF-S201 improves efficiency by enabling precise management of water in irrigation systems [31].

These characteristics of the YF-S201 ensure that plants get the water they require while preventing wasteful water use. As a result, it was chosen as a crucial component of the irrigation system for the study. An example of the sensor is shown in Figure 15.

Figure 15. YF-S201 Water Flow Sensor [32]

6. Solenoid Valve

A solenoid valve is an electrically controlled valve, consisting of a solenoid—a coil with a moveable ferromagnetic core (plunger) at its center. In its rest position, the plunger closes a small orifice, which can be opened by creating a magnetic field through an electric current passing through the coil. The magnetic field pulls the plunger upward, opening the orifice. This principle is employed to open and close solenoid valves, which are used to start, stop, dose, distribute, or mix the flow of gas or liquid in a pipe. In this study, the solenoid valve is utilized to control the flow of water to the desired field for a specified duration [33].

A total of three solenoid valves will be placed, one per row [25]. Depending on the amount of irrigation zones that need to be managed, a relay module with four channels will be used to control these valves, enhancing the system's adaptability and economy. The ability to regulate each row separately makes it possible to precisely meet the water needs of several plant species or the same species at various phases of growth. As a result, waste can be avoided and water resources can be used as efficiently as feasible. Plant health and crop productivity can be enhanced by irrigating plants spread out across the field according to local soil structure and climate.

Solenoid valves are planned to be operated with 12V DC power supply. By sending a 5V signal to the relay modules, the ESP32 microcontroller will be able to control the valves. This method offers a dependable control mechanism and minimal power consumption, which improves the system's sustainability and efficiency.

The flexible and expandable structure of the proposed system offers the ability to easily adapt to different irrigation needs in the future. An example of the sensor is shown in Figure 16.

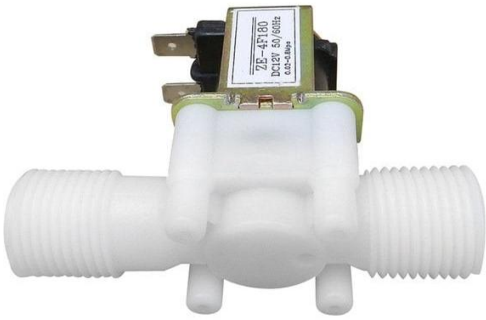


Figure 16. Solenoid Valve [34]

2.3. General Diagram of the Proposed System

For effective water management, this study describes the design and implementation of an intelligent, autonomous irrigation system that makes use of ML and IoT technology. Figure 17 shows the total process flow of the system, showing how each step is integrated and operates to produce an effective and completely automated irrigation solution.

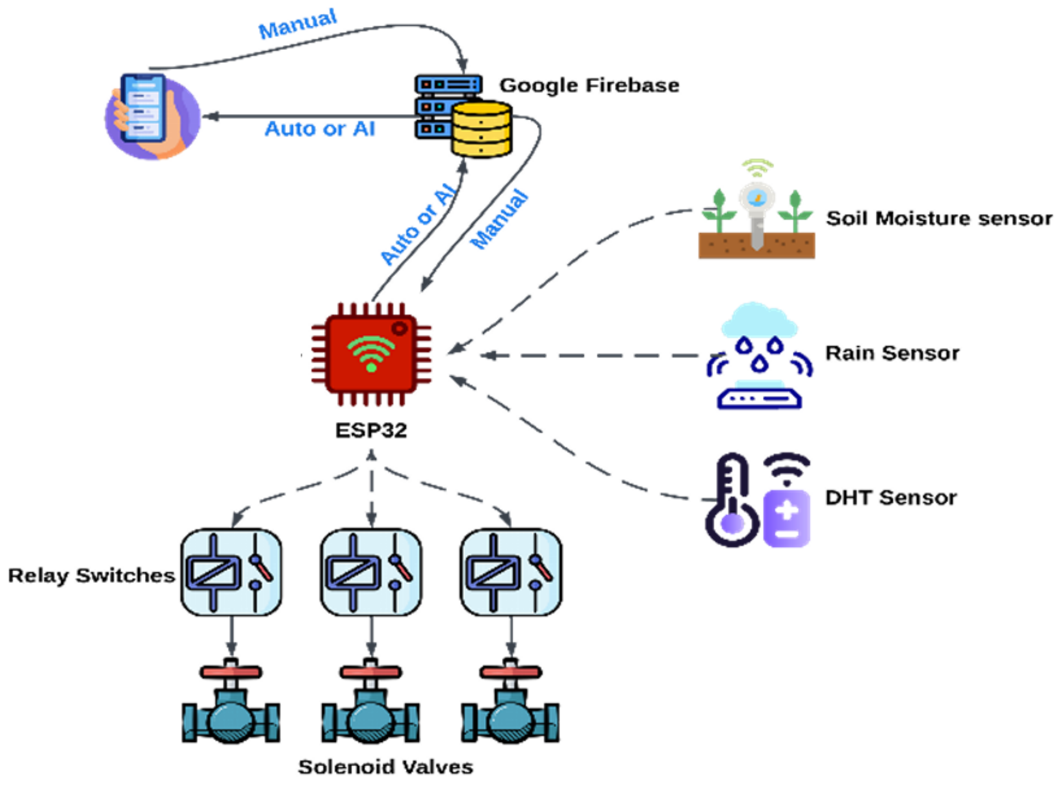


Figure 17. General Diagram of the Proposed System [25]

Step 1: System Design and Circuit Board Construction

The first stage of the project is designing a circuit board that will control the watering and data collection processes. Several sensors will be included into this board to monitor environmental conditions and manage the irrigation system. The circuit board's primary components are:

- **Soil Moisture Sensor**: Measures soil moisture to determine irrigation requirements. If the soil moisture level falls below a pre-set threshold, the system initiates the watering process.
- **Rain Sensor**: Detects rainfall in the area and automatically stops watering when rain is detected, ensuring efficient water use and avoiding over-watering.
- **DHT11 Sensor**: Monitors ambient temperature and humidity, helping the system to assess the overall climatic conditions that affect irrigation requirements.

These sensors work together to provide continuous monitoring of environmental conditions, which is essential for determining irrigation needs.

Step 2: Data Transmission and Cloud Storage

The ESP32 microcontroller will be used to send the sensor data to a cloud-based platform, like Google Firebase or Blynk. Real-time data transmission to these platforms, where it will be stored and examined, is made possible by the ESP32's wireless capabilities. This makes it possible to remotely monitor and control the system, allowing users to view the data from any location at any time.

Rain, temperature, humidity, and soil moisture sensors will all send data to the cloud continuously. In order to automate the irrigation process and enable users to modify the system as necessary, this real-time data is essential.

Step 3: System Control Modes

The system will offer three control modes to manage the irrigation process effectively:

1. **Manual Mode**: Users have full control over the irrigation system and can start or stop the irrigation process through a mobile application. This mode provides complete flexibility for users to manage the irrigation manually.
2. **Automatic Mode**: The system functions independently in this mode, starting or stopping irrigation in response to sensor inputs. For example, the system will start irrigation if the soil moisture falls below a certain threshold and stop if enough moisture is found or if it rains.
3. **AI Mode**: In this mode, ML algorithms, specifically an **LSTM model**, will be used to predict irrigation needs based on historical data. The system will collect and store environmental data (e.g., temperature, humidity, soil moisture) and water consumption data from the user. This data will be used to train the **LSTM model**, which will predict irrigation requirements and optimize the process. The AI mode will analyze past irrigation behavior and provide a more personalized and efficient watering schedule.

Step 4: Irrigation Mechanism

The ESP32 microcontroller will manage the irrigation operation by controlling the solenoid valves via relay modules. To guarantee that each zone of the irrigation system receives the proper amount of water, the solenoid valves will distribute water to designated locations. The system will allow for precise control of irrigation in different zones based on the moisture content in the soil.

The sensors, relays, and microcontroller will all operate steadily thanks to the system's steady 5V DC power source. The system will be able to operate continuously without requiring manual intervention thanks to its unbroken power source.

Step 5: System Monitoring and Data Storage

For ongoing monitoring and analysis, all sensor data and system control activities will be saved in the cloud. Users will be able to assess the system's performance over time and make the required modifications to maximize its effectiveness thanks to the saved data. Based on current circumstances, this data will also be utilized for system performance improvement and troubleshooting.

Step 6: System Expansion and Adaptability

The system's extendable and adaptable architecture makes it simple to adjust to various environmental factors and agricultural requirements. The system will be able to improve its irrigation procedure as it gains knowledge from user behavior and environmental changes. Because of its versatility, the system can be applied in a range of agricultural contexts with a minimal amount of human involvement and the highest possible water efficiency.

Artificial Intelligence (AI)

Artificial Intelligence is defined as the replication of human cognitive processes in machines designed to mimic human reasoning, learning, and decision-making abilities. It involves a diverse set of functionalities, such as solving complex problems, making informed decisions, understanding natural language, and recognizing patterns. Artificial Intelligence has two fundamentally different sub-disciplines [35].

Machine Learning (ML): Refers to algorithms capable of learning from data, improving their performance over time without requiring explicit human intervention.

Deep Learning (DL): A subset of machine learning that leverages large datasets and artificial neural networks to enable complex learning processes.

Differences Between Machine Learning and Deep Learning

Artificial Intelligence (AI): Serves as the overarching domain that aims to emulate human-like decision-making.

Machine Learning (ML): A subset of AI focused on algorithms that learn from data to improve their performance.

Deep Learning (DL): A specialized branch of machine learning that utilizes multi-layered artificial neural networks to tackle more intricate and sophisticated problems.

This hierarchical framework highlights the relationship between AI, ML, and DL, demonstrating their interconnected yet distinct scopes and methodologies, as shown in Figure 18.

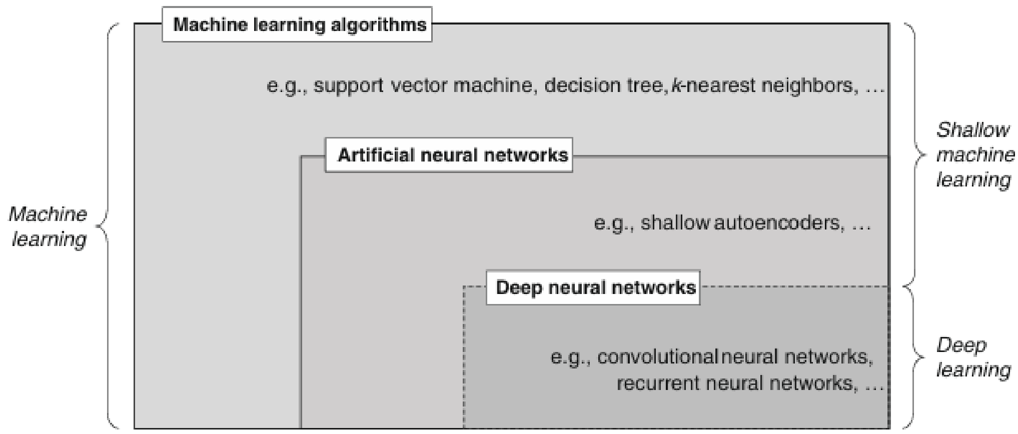


Figure 18. Hierarchy of Machine Learning Algorithms and Neural Network Architectures [36]

CNN and RNN Architectures

Convolutional Neural Networks (CNNs):

CNNs are a type of neural network specifically designed to process visual data. They are widely employed in tasks such as image classification, object detection, and image segmentation.

Recurrent Neural Networks (RNNs):

RNNs are models that operate on sequential or time-series data, making them particularly suitable for language modeling and temporal data analysis.

These architectures exemplify the tailored application of neural networks for distinct data modalities and tasks, highlighting their versatility in machine learning.

The LSTM, a variant of RNNs, was selected as the optimal model for analyzing sensor data in time series format within the system and for forecasting future states [37].

Irrigation Prediction Process with LSTM Model

Forecasting Process with ML Models

In this project, **LSTM** algorithm, one of the machine learning methods, will be used to estimate the irrigation requirement. LSTM is an improved version of RNNs designed to effectively learn complex dependencies and long-term relationships in time series data. While traditional RNNs face problems such as **gradient fading** and **gradient bursting** in time-delayed data sequences, LSTM has a unique cell structure to solve these problems. This cell structure is equipped with **input**, **forget** and **output gates** that control the flow of information and thus effectively learns both short and long-term dependencies in data sequences [38].

One of the most important advantages of LSTM is its high performance on time series data, where not only past events but also the order of occurrence of events is critical. This feature is extremely useful in situations where environmental data is constantly changing and time dependent, such as irrigation systems. In the proposed study, the irrigation requirement will be estimated from variables such as soil moisture, temperature and precipitation using the LSTM algorithm and the system will be enabled to manage water resources efficiently.

Data Collection and Preparation

In the first stage of the LSTM-based prediction process, environmental data will be collected using the **ESP32 microcontroller**. The ESP32, with its low power consumption and integrated Wi-Fi, will gather data from sensors such as the **soil moisture sensor**, **DHT11 sensor**, and **rain sensor**. The data will be collected at regular intervals and transmitted wirelessly to a centralized platform.

The collected data will be stored in **Excel files** for pre-processing. Data pre-processing steps, including cleaning, handling missing values, and anomaly detection, will be performed using Excel. After pre-processing, the data will be divided into **training** and **test sets** for use in training and evaluating the LSTM model.

LSTM Model Design and Training

The pre-processed data will be uploaded to **Google Colab** for the design and training of the LSTM model. Google Colab provides a powerful environment for machine learning tasks, especially those requiring high computational power. The LSTM model will be designed to predict irrigation requirements based on environmental data.

In the training stage of the model, **the hyper-parameters** (e.g. learning rate, number of cells, number of layers) will be tested with various values to determine the best performing structure. **The Adam Optimisation function** will be used to improve the accuracy of the model.

Adam (Adaptive Moment Estimation) is an optimisation algorithm used in deep learning models and helps the model learn faster and more accurately. Adam Optimiser provides a faster and more stable learning process by automatically adjusting the learning rate of the model [39].

MSE loss function will be used. MSE is a loss function that helps the model to minimise the prediction errors. Since this function increases the error values quadratically, larger errors are given more weight. Thus, the model performs a more precise and careful learning process [40].

After the training process is completed, the performance of the model will be evaluated on test data and the prediction accuracy will be measured. **The error rate of the prediction** will be evaluated using **the MAE** metric and this value **between 0 and 0.5** is the range considered successful by artificial intelligence developers. The algorithm planned to be coded is aimed to have MAE values in this range.

Forecasting and Continuous Learning Process

After the model training is completed, the prediction process will be started using real-time data from **the Wi-Fi module of the ESP32 microcontroller**. The LSTM model will predict the future irrigation needs from these data and enable the system to irrigate automatically. **Relays and solenoid valves** will be controlled according to the estimated values and irrigation systems will be activated.

The process will not only react to the current environmental conditions, but also enable the system to continuously learn and improve its prediction accuracy. Since the LSTM model has the ability to make predictions by learning from past data compared to other RNN models, the system will tend to continuously learn and produce new predictions. The model will also be updated periodically with new data from the sensors so that it can make even more accurate predictions over time. The proposed approach is of great importance both in terms of saving water and determining the optimal amount of irrigation required by the plants.

In conclusion, this project aims to provide a solution to make irrigation management in agriculture more efficient and sustainable, by exploiting the strengths of the LSTM algorithm for the analysis of time series data. The general schematic of the irrigation prediction process using the LSTM model is shown in Figure 19, illustrating how each step in the process is interconnected.

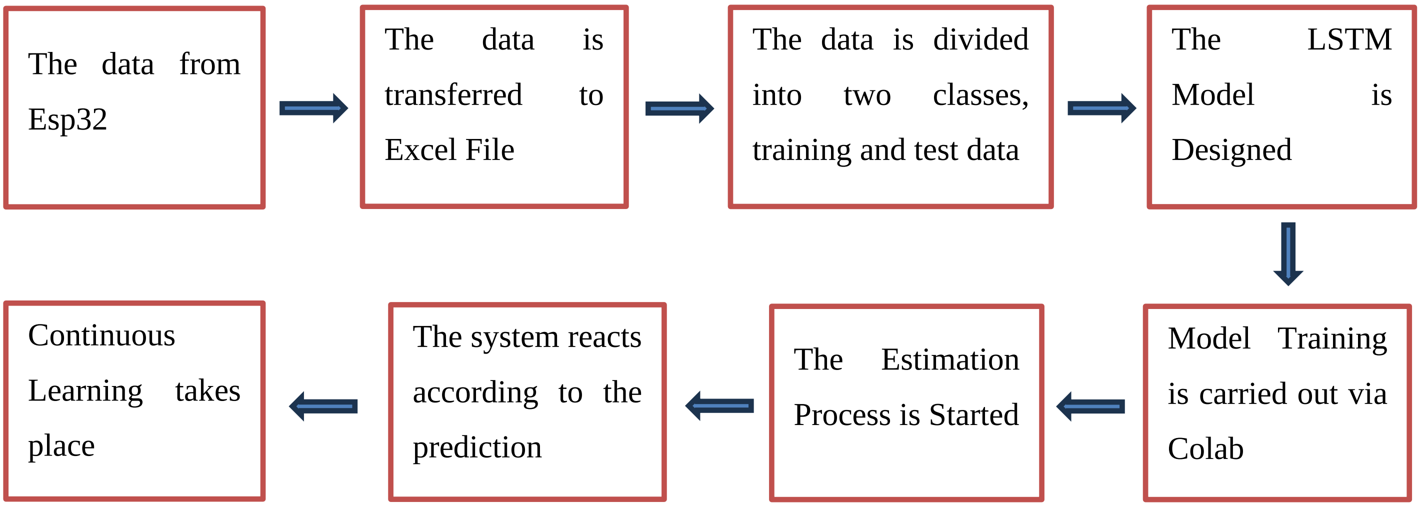


Figure 19. Prediction and Continuous Learning Process of AI Model

User Interface and Mobile Application

Blynk IoT Platform

Blynk is an **IoT** platform that enables users to interact with the system. In this project, **Blynk mobile application** will be developed to enable users to view sensor data in real time and control the system [41].

Why Blynk IoT?

- **User-Friendly Interface:** With Blynk, users can create **customized IoT dashboards** and **apps** with little to no coding experience. Both **iOS** and **Android** smartphones can use these apps.
- **Wide Hardware Compatibility:** The platform works with widely used hardware, including the Raspberry Pi, Arduino, ESP32, and ESP8266. This offers a versatile solution for various sensors and microcontrollers.
- **Cloud Connectivity:** Blynk's **cloud infrastructure** enables **remote device access** and **control**. As a result, users can oversee and control their systems from any location in the world.
- **Virtual Pins:** These provide an alternative to real pins for communication. This makes it possible for the application and hardware to have a more adaptable structure.
- **Customization and Open Source:** Because Blynk is open source, users can design and modify their systems to suit their requirements.

Functionality of the System

Real-time sensor data will be shown on the Blynk app, which also provides remote control over the system's irrigation operations. Furthermore, the application's data may be examined in the past, and system settings can be readily changed as needed.

Visualisation and Control of Data

The Blynk mobile application, developed within the scope of the project, enables users to:

- **Soil moisture sensors,**
- **DHT11 sensors,**
- It will allow the user to easily monitor data from devices **such as rain sensors**.

At the same time, irrigation system relays and valves can be controlled directly from the Blynk, offering the user maximum flexibility.

The design of the Blynk mobile and web dashboard is presented in detail in Figure 20 and Figure 21.

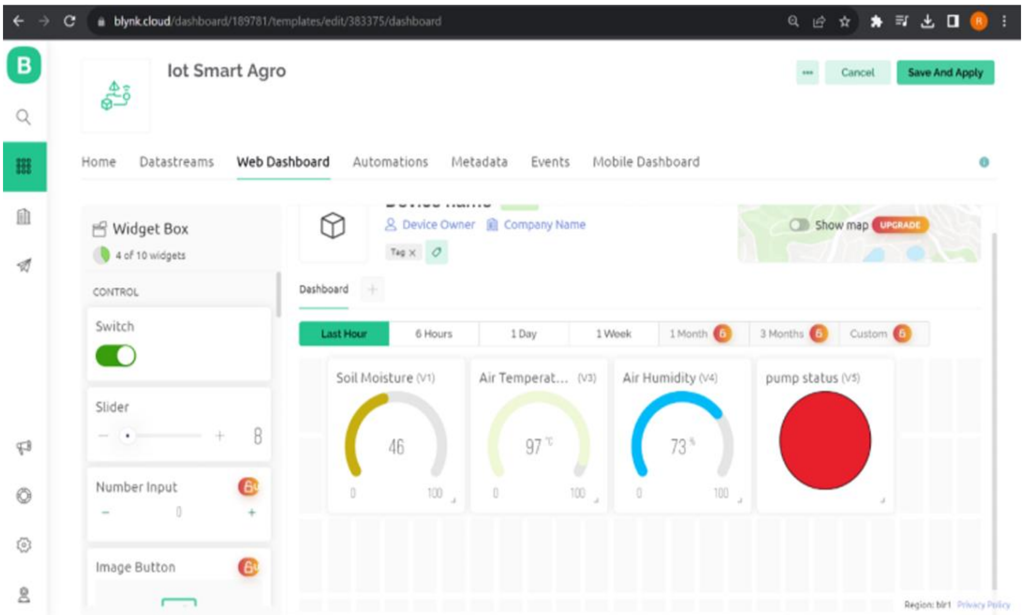


Figure 20. Blynk web dashboard installation [41]

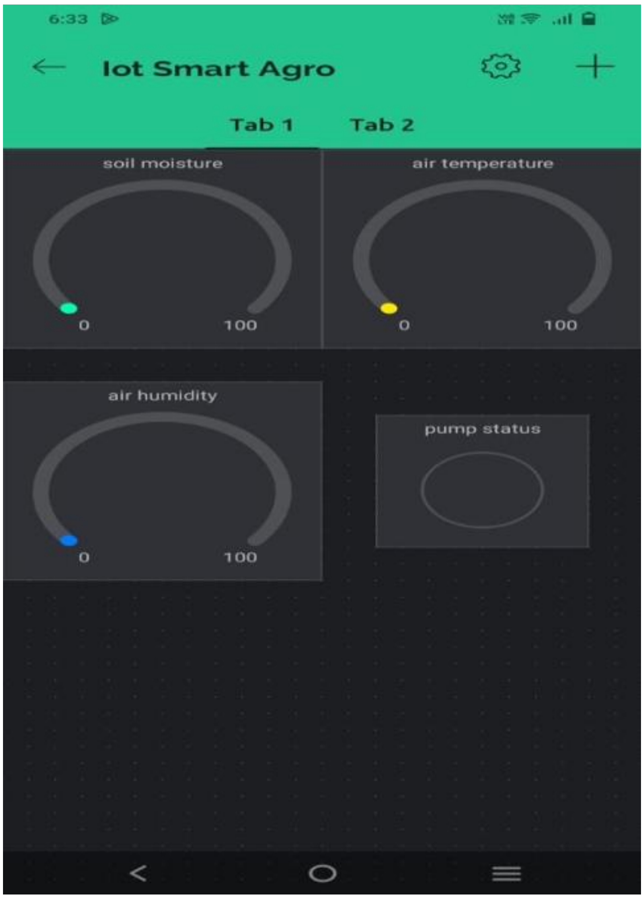


Figure 21. Blynk Mobile Dashboard [41]

The Blynk authentication token (auth token), Wi-Fi ID (SSID), and Wi-Fi password must be entered into the system before the Blynk application can grant remote access to the system. This information is essential for a good link between the hardware and the application.

Following the completion of the connections, **the ESP32 microcontroller** is loaded with the relevant software code. Before they may begin utilizing the system, users must complete this first step. Once the installation is finished, **the ESP32 microcontroller** and the control device (such as a smartphone) are paired. **The ESP32's integrated Wi-Fi module** facilitates this pairing, and the Blynk app is used to create the connection. Cloud infrastructure from Blynk enables users to keep an eye on data and manage the system. Following a successful pairing, the Blynk app may show the sensor data, including temperature, humidity, rainfall, and soil moisture. Users are able to keep an eye on the condition of their plants in this way.

When soil moisture falls below a predetermined threshold, the system initiates a sequence of activities automatically. First, the irrigation pump is activated. The user is then alerted by a buzzer that sounds. Updates are also sent to the user via the Blynk app and email. These automated reactions allow the user to intervene swiftly and efficiently to water their plants. The Blynk program allows the user to continuously monitor their plants, ensuring that the system is functioning properly and allowing them to do so at any time. The mobile interface that shows sensor reading values, such as soil moisture, ambient temperature, and humidity, is shown in Figure 22.

Figure 22. Mobile Interface [41]

2.4. Preliminary Results

According to the project's preliminary results of the study, the materials needed to put the suggested IoT and AI-based smart autonomous irrigation system into practice have been determined and acquired. The components utilized, together with their corresponding quantities and costs, are summarized in Table 4 below:

Table 4. Materials for Smart Autonomous Irrigation System

Component Name	**Quantity**	**Unit Price (TL, VAT Included)**	**Total Cost (TL)**
ESP32-WROOM-32U Wi-Fi Bluetooth Development Module	1	209.90	209.90
DHT11 Temperature and Humidity Sensor	2	42.84	85.68
Arduino Soil Moisture Sensor (Hygrometer)	8	21.42	171.36
Water Flow Sensor (YF-S201)	4	128.51	514.04
12V Plastic Solenoid Water Valve (1.27 cm)	3	364.11	1092.33
5V 4-Channel Relay Module	1	81.39	81.39
Arduino Rain Sensor	2	25.7	51.40
40 pcs Male-to-Male Jumper Cable (20 cm)	1	23.99	23.99
40 pcs Female-to-Male Jumper Cable (20 cm)	1	22.7	22.70
40 pcs Female-to-Female Jumper Cable (20 cm)	1	21.42	21.42
20x30 Perforated Prototype Board	1	107.09	107.09
			2.381,30 TL

The fundamental hardware elements needed to construct a smart autonomous irrigation system prototype are compiled in this table. The selection of each component was based on cost-effectiveness, compatibility, and dependability. For instance, the ESP32 module was selected due to its low power consumption and built-in Wi-Fi functionality, both of which are necessary for real-time cloud communication. The machine learning model for irrigation forecasts is fed vital environmental data from sensors including the DHT11, soil moisture sensors, and rain sensors. Relay modules and solenoid valves optimize resource use by precisely and automatically controlling water flow.

The project is to contribute to sustainable farming practices and show the viability and effectiveness of smart irrigation systems by incorporating these elements into the system.

3. Results and Discussion

This thesis aims to culminate in a functional prototype. As outlined in previous chapters, the prototype will integrate various approaches, including IoT and AI-based mechanisms. Although there are several studies in the field, none have achieved a stable AI-driven prediction system.

For instance, Ramanamma Parepalli and Sreejith S (2024) designed a similar process to address the same problem. However, their AI model employs a ‘Linear Regression’ approach, with no explanation provided for this choice. Additionally, their study indicates that the AI component has not yet been fully designed [25].

Another relevant study in the field by Samira Akter and Akiful Islam (2023) also claims to propose an IoT and AI-based system. However, their thesis does not specify the machine learning techniques used in their model [42].

Our research in the field indicates that the Linear Regression approach cannot be effectively utilized in such systems. This is because sensor data is typically in a time series format and heavily reliant on historical patterns rather than simple linear relationships. Therefore, the planned approach must utilize an LSTM model, which is well-suited for adapting to and learning from historical data effectively.

This study has been submitted as a candidate for the TUBITAK 2209-A University Students Research Projects Support Programme.

4. Future Work

In the planned project, all aspects have been designed in detail so far, and the necessary orders have been placed. Work will continue at full speed to complete the software and hardware installations. Around mid-January, efforts will focus on LSTM model development and ESP32 programming. At the beginning of the second term, the designed circuit will be assembled, and its integration with the mobile application will be ensured. The project is expected to be largely completed by the end of April. The process flow is illustrated in Figure 23 below.

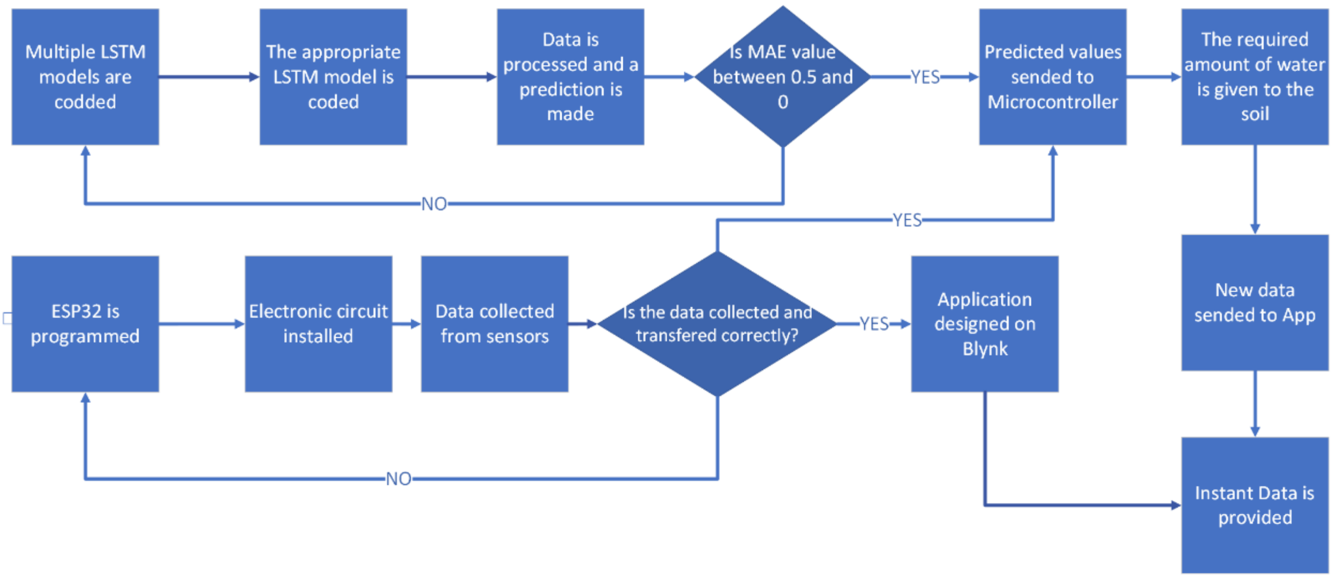


Figure 23. Future Workflow Diagram

5. CONCLUSION

At the end of this process, the output product will be a prototype that demonstrates how water savings in agriculture can be achieved efficiently by effectively controlling the entire process and predicting future conditions. Additionally, it will save time for users and allow them to control the system remotely, even when they are far from the field. The system's controllability enables users to manage all processes manually or automatically in case of any issues. However, as producers, we recommend using the AI mode for general purposes.

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Appendix A

Thesis Information

Does your thesis have impacts on health, environment, and safety? Please explain.

Yes, the thesis project has significant environmental and health-related impacts. The project significantly contributes to **environmental sustainability** by addressing water scarcity issues in agriculture. By using sensors and AI, the system ensures water is used only where and when needed, reducing wastage. Overall, the system supports eco-friendly farming and enhances agricultural productivity without compromising safety.

What are the problems of your thesis topic reflected in the engineering field of the era? Please explain.

Modern engineering faces challenges in integrating advanced technologies like IoT and AI into practical fields such as agriculture.

- **Adaptability**: Many current irrigation systems lack the flexibility to adjust dynamically to changing environmental conditions, such as sudden rainfall or drought.
- **Affordability**: High costs of implementing IoT systems can limit their adoption by small-scale farmers.
- **Data Dependence**: The effectiveness of AI models like LSTM relies heavily on accurate and sufficient data collection. Any inconsistency in sensor data could reduce prediction accuracy.

This project addresses these issues by designing a **cost-effective, data-driven system** that adapts to varying conditions, providing a scalable solution for farmers.

Appendix A

Thesis Information

What are the realistic constraints and conditions applied to your Graduation Project? Please explain.

Economic Constraints: The system uses **budget-friendly components** like ESP32 and open-source platforms (e.g., Blynk) to minimize costs while maintaining functionality.

Resource Availability: The project relies on the availability of accurate sensors and electronic components, requiring careful procurement to avoid delays.

Time Constraints: A strict project timeline required tasks such as circuit design and coding to be completed efficiently, ensuring that testing and improvements could be made within the planned schedule.

Climatic Limitations: The system is designed for variable weather conditions; however, extreme environments (e.g., very high rainfall or prolonged drought) may require adjustments to the sensor placements and system thresholds.

What are the Engineering Standards that are aplied to your Graduation Project? (For example, IEC 61131, IEEE1100, ISO 17025) Please explain.

To make sure the project complies with engineering and safety regulations, the following criteria were used:

- **ISO/IEC 27001 (Information Security)**: Prevents data breaches by guaranteeing the safe transfer of sensor data to the cloud.
- **IEEE 802.11 (Wireless Communication)**: For dependable Wi-Fi-based data transfer, the ESP32 microcontroller makes use of this standard.
- **IEC 61131 (Automation)**: Provides guidelines for the system's construction and functionality to provide effective and secure irrigation automation.
- **ISO 14001 (Environmental Management)**: By promoting sustainable farming methods and maximizing water use, the project complies with environmental regulations.

By following these guidelines, the initiative promotes ecologically friendly solutions while guaranteeing quality, dependability, and safety.

Appendix B

Thesis Check List / Contact Information

Thesis Check List	Yes (Y) / No (N)
Engineering Design or Graduation Project report has the same template given in the department web page?	Y
Report includes whole sections given in the thesis template. (Özet, abstract, introduction etc.)?	Y
Introduction part covers state of the art studies in literature? Also, short and clear explanation about the main study of the thesis given at the end of the introduction part?	Y
Thesis has at least 10 citation and 6 of them are from state of art articles, conference papers and thesis?	Y
Equations, tables and figures are created by the student?	Y
Tables, figures etc. are used in the result section to show outcomes of the study. Results of the study is discussed in conclusion section.	Y

Appendix B

Thesis Check List / Contact Information

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