

Development of an IoT Based Irrigation Control System using Convolutional Neural Network

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ABSTRACT

The automation of irrigation activities has the potential to revolutionize traditional manual and static irrigation practices, leading to increased productivity with reduced human intervention. Manual irrigation practices often result in water wastage or inadequate water supply to specific crops, as different crops have varying water requirements (crop water need). Moreover, manual irrigation methods consume significant time and effort, especially when the farmland is located at a distance. This paper presents an IoT-based irrigation system that utilizes computer vision technology to capture and recognize crops in the irrigation field using a Convolutional Neural Network (CNN) model. The developed system continuously monitors and maintains the optimal soil moisture content for each specific crop, employing soil moisture and temperature sensors. The control unit of the system is implemented using the Raspberry Pi 3b+ platform. The performance of the developed system was evaluated using two key metrics: Accuracy and Response time. The CNN model achieved high accuracy, with a stabilized accuracy of 95 percent after 50 epochs of training and validation, using a dataset of 800 pictures. This indicates the system's capability to accurately identify crops in the field. The response time of the system was assessed through ten trials, resulting in an average response time of 14.3 seconds, which is considered satisfactory. The findings of this study demonstrate the effectiveness of the proposed IoT-based irrigation system in automating irrigation processes and optimizing water usage. By integrating crop recognition, soil moisture monitoring, and temperature sensing, the system ensures efficient irrigation practices, reducing water wastage and minimizing human effort. The successful implementation of the developed system paves the way for intelligent and dynamic irrigation systems, fostering higher agricultural productivity and sustainable water resource management.

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INTRODUCTION

Agriculture performs a vital role in almost every country's economy. Generally the usage of fresh water in Agriculture is over 85%, Because of the country's population growth, this percentage has dominated in water usage, and therefore it is very important to develop a system that is based on science and technology for efficient use of water. (Balaji, 2019). In agriculture,

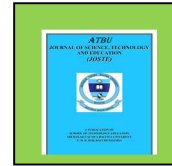
irrigation of crops is a very important process that increases crop production by supplying adequate water to the needed land, but Farmers have to visit their farm lands to check the quantity of water that is required for their farm. This irrigation method often takes a lot of time and work, especially when a farmer needs to water a wide area of farmland. Farmers have to be present in their fields to perform irrigation, but nowadays, people must

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manage their farm tasks alongside other jobs. As a result, the Internet of Things (IoT) and irrigation system automation have made the farmer's job considerably easier.(Chinedu et al., 2020; Dokhande et al., 2019)

Smart agriculture, environmental monitoring and forecasting, logistics and asset management, vehicular automation and smart transportation, healthcare and wellness, building and home automation, automation of industry, smart metering and smart grid infrastructures, and so on are just a few of the application scenarios. Every phase of the agricultural ecosystem may be monitored, analyzed, and controlled with IOT. (Sen et al., 2020). Automation is a major concept in most facet of life. In Agriculture there are many automation processes but it faces different problems like water scarcity, lack of human resource and so on. Due to these problems proper crop yield can be reduced and this can cause increase cost of most agricultural products(Singh et al., 2019).

There are a variety of devices available to save water and make farmer job easier, ranging from the most basic to the most technologically complex approaches. (Balaji, 2019). An IOT irrigation control system with the help of image processing is considered in this project to minimize the work load on the farmers. This particular technique of smart irrigation works based on a predefined process of irrigating crops depending on the level of moisture needed by the crops. It also keeps a track of moisture level and temperature of the soil throughout the crop life span (Abubakre et al., 2021). Due to the monitoring technique of this projects, the work load of the framers of visiting the farm land will be reduced. By the use of a camera the system will recognize the crop and then discharge amount water required by the plant.

REVIEW OF FUNDAMENTAL CONCEPT

Various crops require diverse amounts of water, frequency, rate, and time for irrigation, as well as different soil types and seasons. Summer crops, for example, require far more water than winter ones. The review of some fundamental

concept for the system under consideration is next preceding sections.

Irrigation Control System

An irrigation control system is a device that is used for the operation of automatic watering systems for example drip irrigation systems, lawn sprinklers and so on. Control systems for irrigations are used to ensure a desired quantity of moisture of the soil is maintained for the crops with the presence or absence of a user. Some of these control systems are capable to regulate the rate of irrigation, the starting time and the duration. An irrigation control system is also known as an irrigation controller(Momoh, 2018). These systems have evolved over the past decades. Modern irrigation systems are capable of scheduling irrigation according to the weather through temperature and weather sensors. Some irrigation control systems can also connect to the internet so that the data values collected by the systems can be transferred to the owner's database. (Sen et al., 2020)

There are two main types of irrigation control systems: domestic which is for home gardening, and the professional used in agricultural businesses which requires a more flexible operation in water volume, calculation of flow rate, and provision of feedback (Wang et al., 2015).

Internet of Things

The Internet of Things (IoT) is a new type of internet that connects (IoT), this is a network of interconnected computing devices, mechanical and digital equipment, objects, animals, or people with Unique Identifiers (UIDs) and the ability to automatically transfer data over the internet (Daniel & Momoh, 2021).

Any natural or man-made object that can be assigned an Internet Protocol (IP) address and can transfer data over a network, such as a person with a heart monitor implanted, an animal with a biochip transponder, a car with built-in sensors that alert the driver when a tire is low on pressure, or any other natural or man-made object that can be assigned an IP address and can

transmit signals, are all examples of things in the Internet of Things.(Sen et al., 2020).

Convolutional Neural Network.

A Convolutional Neural Network (ConvNet/CNN) is a Deep Learning algorithm that takes in input photos and assigns learn-able weights and biases to different aspects/objects in the images that may be distinguished from one another. When compared to other classification algorithms, a ConvNet requires very little pre-processing. With enough training, ConvNets can learn these filters/characteristics, whereas filters in traditional systems are hand-engineered. (Sumit, 2018)

Key Components for Irrigation Systems

Irrigation systems consist of different components like soil moisture sensor, temperature and humidity sensor, raspberry pi, relay, water pump and so on. A sensor is a device, module, or subsystem that detects events or changes in its surrounding and transmits the data to other electronics; it translates physical quantities into electrical impulses. The sensitivity of a sensor refers to when the measured amount varies, how much does the sensor's output change.

Soil Moisture Sensor

The sensor is a device used in measuring the moisture level of the soil. Current is passed to the electrodes in order to know the soil condition. It's used to figure out how much water is in a certain amount of soil. Soil moisture sensors indirectly measure the volumetric water content by using another property of the soil as a proxy for the moisture content, such as electric resistance, dielectric constant, or neutron interaction, because direct gravimetric measurement of free soil moisture necessitates the removal, drying, and weighting of a sample.(Dokhande et al., 2019). Figure 1 shows the representation of a soil moisture sensor used in this research paper.

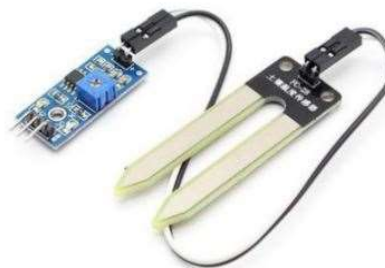


Figure 1: Soil Moisture Sensor. (Dokhande et al., 2019)

Temperature Sensor

Temperature sensors are electronic devices that measure the temperature of their surroundings and convert the input data into electronic data in order to record, monitor, or signal temperature changes. Temperature sensors come in different types, for example LM35, DHT11, DHT22 and so on. (Dokhande et al., 2019).

Raspberry pi

The Raspberry Pi is a small single-board computer that can perform all of the tasks that a typical desktop computer can, such as spreadsheets, word processing, surfing the internet, programming, and playing games. The Raspberry Pi 3 B+ in figure 2 with these outstanding features; a 4.2 Bluetooth, can provide a much faster and greater Ethernet connection. It Has a Dual-Band Wi-Fi feature with a more improved processor and it uses a 2.5A Power which makes it suitable for this project. (Raspberry Pi /Opensource.Com, n.d.)



Figure 2: A Raspberry Pi 3 Model B+. (Raspberry Pi /Opensource.Com, n.d.)

Relay

A relay is a switch that is controlled by electricity. Relays are employed in circumstances when a separate low-power signal is required to regulate an electrical circuit. To protect electrical lines from short circuits, a relay with calibrated operating characteristics and multiple operational coils is occasionally employed. It is the link between the pump and the control unit. The relay can be utilized as a switch to turn on or off the pump in this scenario. (Pawar et al., 2018).

Pumping Machine

The pumping machine is a Direct Current (DC) powered pump that moves fluid in a variety of ways by using direct current from a motor, battery, or solar power. Motorized pumps are typically powered by 5, 12, 24, or 32 volts of DC. In solar energy, photo-voltaic (PV) panels with solar cells that produce direct current when exposed to direct sunlight are used to power DC pumps. It is used for pumping water stored in a reservoir to the crops. The pumping machine operates on the principles of electromagnetic induction in which a temporary magnetic field is created whenever the flow of electric current is detected within the coil. For the purpose of the developed system, the 5 volt pump is used to minimize power consumption by the pump (DC Powered Pumps/Engineering360, n.d.)

Raspberry Pi Camera v2

The Raspberry Pi Camera Module v2 represents the camera board. On the board is a Raspberry Pi with an 8 megapixel Sony IMX219 camera sensor and a fixed focus lens. Static pictures with dimensions up to 3280x2464 pixels are supported, as well as video with resolutions of 1080p30, 720p60, and 640x480p90. It uses the CSI interface and connects to the pi via one of the small ports on the board's upper surface (Amazon.com: Raspberry Pi Camera).

REVIEW OF RELATED WORKS

After exhaustive research about the irrigation system in agriculture, many researchers found that the productivity in agriculture is decreasing. However, with the help of various agricultural technologies, production can be increased while manual labor is reduced.

This research shows an image recognition technique using the Convolutional Neural Network (CNN), which is used to recognize a particular crop and initiate the threshold level of the recognized crop. The operation of the system is according to the threshold value of the crop recognized.

According to (Rouse, 2019), The Raspberry Pi was utilized to develop an IoT-based smart watering system. Using a camera, the device was able to autonomously manage the water motor and monitor the plant's growth. They could view live streaming of the farm on their mobile phone via a Wi-Fi network, thanks to the system's architecture. The system uses a wireless network to transfer data from the soil-moisture sensor and temperature sensor, which are both placed in the root zone of the plants. The webcam was connected to the Raspberry Pi through Wi-Fi Module, which served as the system's control unit. Tasks were automated using the Python programming language. Their technology consisted of a wireless sensor network and a wirelessly based station that use data from the sensor to automate watering. The raspberry pi model was designed to turn on or off the water pump if either the soil moisture or temperature measurements reach a predetermined threshold value.

The model according to (Cost, 2020), the system was created to keep the soil at the proper moisture level and communicate the data to an Arduino. The Arduino serves as the control unit. Water was then supplied to the plant based on the sensed values, thereby avoiding over- and under-irrigation. A water sensor was used to determine how much water was still available in the tank using the WIFI module. The web page was updated on a regular basis with data from the two soil moisture sensors, and a message alert was delivered to the user. Sensor readings were posted to the Thingspeak channel to generate graphs for study; the same was also viewed in-app, and the motor was operated, as well as real-time data in the Thingspeak cloud.

Pawar et al., 2018 made use of three sensors (ultrasonic sensors, soil moisture sensors, temperature sensors) which were interfaced with a Raspberry pi. The system was used to draw data from the plants using the concept of image processing. This information will be compared with LCC chart and further process of providing the fertilizers will be done. The project aim was achieved by developing an IoT based Efficient Irrigation system using sensors and Image Processing which increased irrigation efficiency and also kept track of Humidity, moisture and Temperature level of the soil throughout the season.

Sahu & Verma, 2017 created an automated sprinkle system to assist farmers in irrigating farmland in an efficient manner depending on soil, humidity, and weather. This sprinkler system provides soil temperature control, moisture sensing to help ensure that plants are watered when needed, live streaming of the farm, and humidity and temperature sensing, as well as forecast lookup from similar weather services. When the sensors detect a change in humidity, temperature, or the present status of rain in the vicinity, an interrupt command is sent to the Raspberry Pi.

Yasin et al., 2019 worked on a moisture-sensing automatic irrigating system in a contained setting. The system was set up to use a soil moisture sensor to read the moisture of the soil and turn on the water pump when the moisture fell

below the threshold value for the soil under consideration. Whenever the moisture value in the soil exceeds the preset limit, the system shuts down the pump. A 162 LCD display shows the pump's status as well as the moisture level. This system is cost effective, and there is minimal time delay due to the lack of internet communication; however, farmers can only manually turn on or off the system based on the weather by visiting the land.

Rahman et al., 2019 design an integration of an Internet of Things (IoT) with a fibrous capillary irrigation system based on climatic demand determined by weather conditions, which was an improvement of a smart fibrous capillary irrigation management solution with an Internet of Things integration. Their system was designed to manage irrigation by adjusting the depth of a water supply based on potential evapotranspiration (ETO). A soil moisture sensor was utilized to track the development of root water uptake and input. The crop medium's water requirements were determined using a fuzzy logic algorithm. The ETO data was utilized to approximate crop water requirements in near real time.

METHODOLOGY

System Overview

The developed system is made up of both software and hardware components. The hardware consists of an embedded system that includes a soil moisture sensor, a temperature sensor, and a humidity sensor, Raspberry pi 3b+, Pumping machine. The software is used for accessing data sent to the website through internet connection.

The Input Unit

The input unit include: the soil moisture sensor, temperature sensor, and pi camera. The soil moisture sensor keeps track of the moisture content of the soil. It is inserted in the soil and the water level present in the soil is measured in percentage. This sensor monitors by utilizing capacitance to determine the amount of water in the soil (dielectric permittivity). By detecting the

electrical resistance between two electrodes, the temperature (DHT11) estimates relative humidity. The DHT11's humidity sensor consists of a moisture-holding substrate with electrodes placed to the surface. When the substrate absorbs water vapour, it releases ions, increasing the conductivity between both electrodes. The change in resistance between the two electrodes is affected by relative humidity. The resistance between the electrodes decreases as relative humidity increases, while it increases as relative humidity decreases. On a chip mounted on the back of the unit, the DHT11 converts the resistance measurement to relative humidity and transmits the humidity and temperature readings directly to the raspberry pi via Arduino Nano, which serves as the ADC.

The Image sensor is a Raspberry Pi Camera v2 of 8 megapixels with a fixed focus lens fixed on the Raspberry Pi for capturing high quality images.

The Control Unit

The Control unit consist of the Raspberry pi 3b+ model where the whole processing and function execution of the system is done. This is where the CNN trained model is run to carry out the recognition, here the particular crop on the field is identified and the required amount of water for the crop is supplied through the pump. The sensors readings, crop identified and pump status are sent to the webpage which is the output unit to be viewed and controlled even at remote location.

The CNN is implemented using the sections that follows, this explains the working principle of the constructed CNN trained model as well as its overall architecture. A succession of layers, including Convolutional Layers, Max-Pooling Layers, activation layers, and drop out layers, are stacked to create this effect. The next sections go over these procedures in further depth:

1. Layer of convolution: The basic process for extracting characteristics from input photographs is convolution. A 2-D picture can be mapped onto a convolution window that glides continuously to produce the

associated convolution value in two - dimensional convolution calculation. The operation of convolution on an input x_i of the i th convolution layer is represented by Equation 1.

$$x_{i+1} = f(W_i + 1 x_i) \quad 1$$

Where * stands for convolution operation, W_i stands for linear operator, and f stands for nonlinear activation function. The activation function creates a non-linear mapping between the networks layer, allowing the network to learn and perform increasingly complex tasks. With the exception of the output layer, which utilizes the soft max activation function, we employed Rectified Linear Unit (RELU) in each layer.

2. Max Pooling Layer: Convolution layers extract image features, to combine the statistics of the feature map, after the convolution layer, the pooling layer is used. The basic pooling procedure necessitates feature map down sampling, resulting in fewer trainable parameters. Stride and filter size are two pooling hyper-parameters that dictate pooling features. We employed max pooling, which means that throughout the pooling procedure, the maximum value of a given feature over a region of the image is computed and kept.
3. Drop out Layer: The main goal of using dropout layers is to boost the generalization ability of the trained model. During the training stage, a drop out layer with hyper parameter- p ignores activation with probability p at random. By minimizing correlation between neurons, this gives regularization and actually nullifies over-fitting. All activations are used throughout the testing phase, but they are scaled by factor p .
4. Flatten Layer: Flattening the pooled feature map reduces the spatial dimensions while keeping the channel dimension. Flattening the layer adds another dimension even if the inputs aren't structured with a channel dimension. Following the flattening

- procedure, the feature matrix is transformed into a vector that is inputted into Keras, a fully - connected networks.
5. Dense Layer: The purpose of these layers is to conduct linear operations on input. These completely linked layers multiply the input by a weight matrix, then add a bias vector to produce the output.

The Output Unit

The output unit comprises of web page and water pump;

The web page is a platform that allows the user to log in using user email and password after which allows the user to have remote access and control of switching on/off of the pump in the system.

The water pump in this system is used for pumping water stored in a reservoir to the crop after being triggered by the relay to dispense the required amount of water.

The design and development of website. Hypertext Markup Language (HTML), Cascaded Style Sheet (CSS), JavaScript, and Python were used to create the developed web page interface. The HTML was used to design the elements and content of the page, while CSS was used to give the whole web page a defined structure which include position of contents, font and others. JavaScript was used to solve and implement the regular update of moisture and temperature sensor values on the web page and how other data change with time on the web page. For the hosting, the web page was hosted on python server which happens to be a sub domain used in place of an originally registered domain. Flask was the firmware used for the hosting and functions were written for API on the python server, so that it can be possible for data to be shared from the hardware down to the website.

Figure 3 shows the circuit diagram of the developed system which depicts how all the components are connected

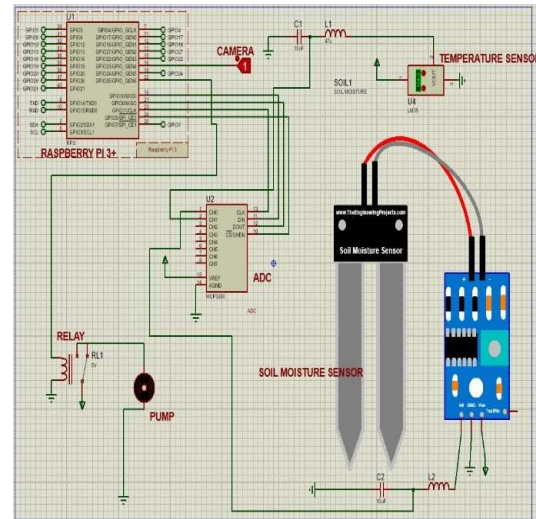


Figure 3: The circuit diagram of an IOT based irrigation control system using CNN

The Developed System Process

The developed system at its initial stage of operation will capture the crop on the field, pass the captured image through a trained convolutional neural network model in the raspberry pi and recognized crop is send to a webpage. The control unit which is the raspberry pi will also receive the soil moisture and temperature of the environment from the input unit and also send to the webpage.

On recognition of the crop and measurement of soil moisture and temperature levels. The system will automatically select the threshold level programmed for the recognized crop, and switch on or off the pump based on the condition met. The pump status is sent to the webpage and it can also be controlled through the webpage.

The Algorithm of the developed IoT based Image recognition irrigation control system using CNN

Step 1: Start.

Step 2: The system will be initialized on Raspberry pi.

Step 3: The camera will capture the crop on the farm land.

Step 4: The system will process the image and selects the threshold level.

Step 5: The sensors will constantly sense the soil moisture, humidity and temperature of the field and update the system and the website.

Step 6: If the required level of water in the soil is reduce, the pump connected to the Raspberry pi will turn ON the pump.

Step 7: Similarly, when, the soil is too wet, the pump will turn off.

Performance Evaluation

The accuracy of the trained CNN recognition model and the sensors used as assessment criteria for the IoT based irrigation control system utilizing CNN. The performance of the classifier in a CNN model is measured using a variety of assessment metrics. The accuracy measure is the CNN evaluation metric utilized in this study. A confusion matrix is used to quantitatively describe classification accuracy. The confusion matrix is a machine learning method that holds information about a classification system's actual and predicted classes. Actual and predicted classes make up the two dimensions of the confusion matrix. Each row is an actual class example, whereas each column is the anticipated state of the class. In the confusion matrix, TP denotes the number of true positives, TN denotes the number of true negatives, FP denotes the number of false positives, and FN denotes the number of false negatives. Divide the amount of correctly classified data by the total number of data as shown in equation 2 to calculate accuracy. (Image Classification Using CNN, n.d.)

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \quad (2)$$

The response time is another parameter used to assess the created system's performance. The amount of time it takes one system node to react to the request of another is measured by response time. It is the time it takes for a system to reach a given input and complete the process. For this project response time is evaluated based on the time taken to send data from the developed

system to the developed website using equation given in equation 3 and equation 4.

$$\text{Response Time} = T_0 - T_1 \quad (3)$$

$$\text{Average Response Time} = \frac{\sum T_0 - T_1}{N} \quad (4)$$

Where T_0 represent the start time, T_1 represent the stop time and N is the number of trials.

TESTING AND DISCUSSION OF RESULT

A total of 10 trials were used to test the response time of the developed system. Figure 4 and figure 5 depicts a graph plotted for soil moisture and temperature reading against response time from table 1 respectively.

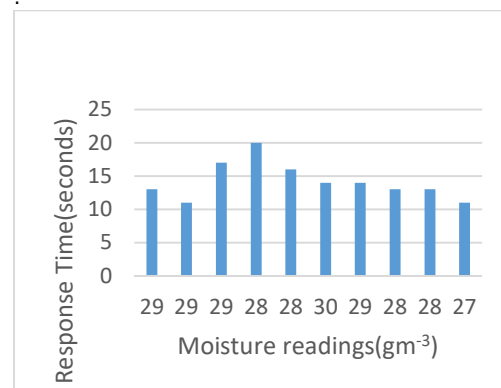


Figure 4: Graph showing Response time with respect to moisture reading.

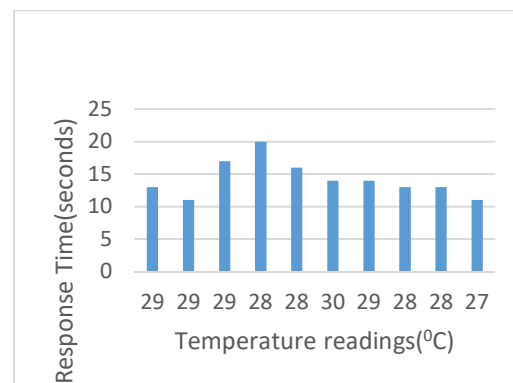


Figure 5: Graph showing Response time with respect to temperature reading.

The response time recorded for the 10 trials as indicated in table 4.1 indicates a little change in obtained data. The recorded values are in the range of 11 to 20 seconds whereas the average response time recorded was 14.3 seconds before sensor values were updated on the website. The Table 1 represent the Response Process of the developed system.

Accuracy of the Result

The trained CNN model accuracy and loss curve were obtained after the training and the validation process using the datasets was completed. The Tensor Flow board generated. The graphs in figure 6 and figure 7 which give the analysis of the training at 50 epochs.

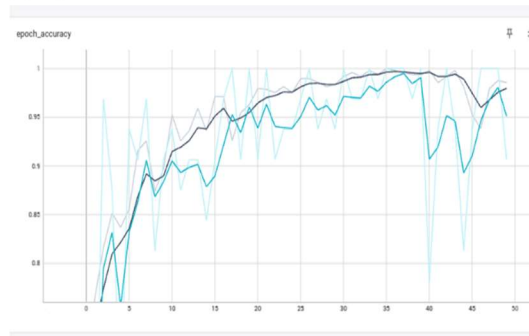


Figure 6: Accuracy of the trained model

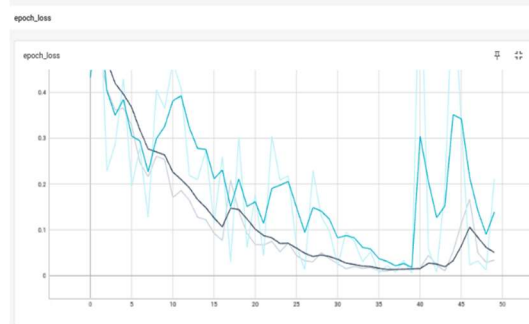


Figure 7: Loss Curve the trained model

After 50 epochs, the model accuracy stabilizes at 95%, as shown in Figure 6. This pattern is consistent with the loss curve seen in Figure 7, which begins to settle around 40 repetitions. On test data, the trained model was evaluated and found to be 97 percent accurate. The developed system uses the image of the crop

under observation as the convolutional neural network's input to identify the crop.

Figure 8 and 9 shows webpage user interface and a prototype of the developed systems respectively.

	Crop Type	Moisture readings(gm-3)	Temperature readings(OC)	Response time (seconds)
1	Maize	1023	29	13
2	Maize	976	29	11
3	Maize	865	29	17
4	Maize	789	28	20
5	Maize	700	28	16
6	Rice	921	30	14
7	Rice	870	29	15
8	Rice	692	28	13
9	Rice	500	28	13
10	Rice	447	27	11

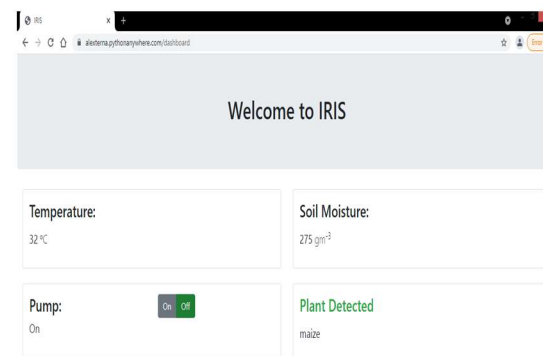


Figure 8: webpage interface



Figure 9: The Developed IoT Based Irrigation Control System.

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CONCLUSION

An IoT-based irrigation control system using CNN was developed that involved utilizing a raspberry pi as the control unit, integrating input units such as soil moisture sensor, temperature sensor, and pi camera, as well as output units like the water pump. The system was monitor a web page that was developed through HTML, CSS, JavaScript, and Python. The website design was implemented using HTML, CSS provided structure, and JavaScript handled real-time updates of sensor values. The implemented system successfully monitored and controlled irrigation, reducing labor costs and human intervention and was able to achieve a 97 percent accuracy base on the training model. Finally, the overall system can also provide an effective solution for modern irrigation needs, particularly suitable for the Nigerian agricultural context.

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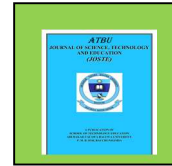
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