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Smart Irrigation System Prototype for Chili Plants with Voice Control Using Wit.ai Based on NodeMCU ESP8266

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Abstract – *Inefficient manual irrigation in chili cultivation contributes to significant water waste and inconsistent crop management. This study presents a dual-mode smart irrigation system prototype using the NodeMCU ESP8266 microcontroller, integrating soil moisture, raindrop, and ultrasonic water level sensors for automatic control, alongside voice command input via the Wit.ai Natural Language Processing (NLP) platform and an offline KY-037 sound sensor fallback for manual operation. The system was evaluated through 40 controlled voice command trials and repeated sensor testing across calibrated threshold conditions. The results demonstrate a voice command accuracy of 95%, with a precision value of 0.95 and a recall value of 0.94. Furthermore, the sensors exhibited consistent response performance within the predefined calibration thresholds. The proposed dual-control architecture enables continuous system operability under intermittent network conditions, thereby providing a practical, reliable, and scalable Internet of Things (IoT) solution for precision irrigation in small- to medium-scale chili farming.*

Keywords – *Internet of Things (IoT); NodeMCU ESP8266; Wit.ai; Voice Control; Soil Moisture Sensor.*

I. Introduction

AGRICULTURAL productivity in Indonesia, particularly in horticultural commodities such as chili (*Capsicum annuum* L.), remains highly dependent on effective irrigation management. Chili cultivation requires precise and timely watering to support optimal plant growth and maximize crop yield. According to agricultural statistics published by the Indonesian Ministry of Agriculture, water-related inefficiencies contribute significantly to yield losses in smallholder farming systems, with chili being one of the most vulnerable crops due to its sensitivity to both water deficit and excessive irrigation [1]. Furthermore, irrigation practices in many rural areas continue to rely on manual operation, while limited broadband infrastructure and unstable internet connectivity present additional challenges for implementing fully cloud-dependent agricultural technologies.

In recent years, the adoption of Internet of Things (IoT)-based technologies has become increasingly important in modern agriculture. Smart irrigation systems utilize environmental sensing devices and automated control mechanisms to improve water-use efficiency, reduce labor requirements, and promote sustainable farming practices. Earlier studies have demonstrated the feasibility of automated irrigation systems using microcontroller-based platforms. For example, Fadhil *et al.* developed a timer-based irrigation system utilizing the RTC DS1307 module and an ATMega16 microcontroller for aeroponic cultivation applications [2]. Moreover, Mutyalamma *et al.* proposed an IoT-enabled agricultural monitoring system capable of measuring soil moisture, temperature, humidity, pH, and nutrient levels in real time [3, 4]. Despite these advancements, most existing systems rely either on fully automated sensor-based control or stable internet connectivity and rarely investigate hybrid control architectures that combine cloud services with embedded fallback mechanisms.

To address these limitations, this study proposes a dual-mode smart irrigation system that integrates automatic environmental monitoring with voice-controlled operation. The proposed system is developed using the NodeMCU ESP8266 microcontroller and incorporates a soil moisture sensor, a raindrop sensor, and an ultrasonic water-level sensor to support autonomous

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irrigation decisions [5–7]. In addition, the system provides manual operation through voice commands processed using the Wit.ai Natural Language Processing (NLP) platform [8–11]. Wit.ai was selected because of its lightweight HTTP-based integration and efficient intent-classification capabilities. To ensure continued operability during network interruptions, the system also incorporates a KY-037 sound sensor as a local hardware-based fallback mechanism [12–14]. Unlike embedded NLP frameworks that require greater computational resources, the KY-037 enables a simpler and more resource-efficient offline control strategy suitable for low-cost IoT devices [15–17].

The primary objective of this research is to design, develop, and evaluate a smart irrigation prototype capable of improving water management efficiency for chili cultivation through the integration of real-time environmental sensing and voice-command interfaces [18, 19]. The novelty of this work lies in the systematic integration of cloud-based NLP services with a local fail-safe acoustic triggering mechanism within a modular IoT architecture. The proposed approach is experimentally validated to demonstrate its feasibility and effectiveness for small-scale agricultural applications operating under infrastructure and connectivity constraints.

II. Research Methods

This study employed a systematic engineering approach consisting of literature review, system development, calibration, testing, and performance evaluation. Previous studies on smart irrigation systems, sensor technologies, and IoT-based agricultural applications were reviewed to establish the theoretical foundation of the proposed system [2–5, 9].

The proposed irrigation system was developed using the NodeMCU ESP8266 microcontroller as the central processing unit. The hardware architecture integrates a soil moisture sensor, raindrop sensor, ultrasonic water-level sensor, and KY-037 sound sensor. The system operates in two modes, namely automatic irrigation based on environmental sensing and manual irrigation using voice commands processed through the Wit.ai platform or offline acoustic input. The research methodology was organized into five major phases, including hardware design and component selection, software development, sensor calibration, testing scenario definition, and performance evaluation.

i. Hardware Design

The hardware design involved selecting and integrating all electronic components required for irrigation control. The NodeMCU ESP8266 served as the central controller and was connected to a soil moisture sensor (analog output, 10-bit ADC), a raindrop sensor (digital output), an HC-SR04 ultrasonic sensor (digital I/O), a KY-037 sound sensor (analog/digital output), and a two-channel relay module controlling two 5V water pumps. The components were assembled on a breadboard prototype and enclosed within a weather-resistant casing for experimental deployment.

ii. Software Design

The software was developed using the Arduino IDE environment. The firmware continuously reads sensor values, applies threshold-based decision logic, and activates relay outputs according to predefined operating conditions. HTTP GET requests are employed for communication with the Wit.ai Application Programming Interface (API), allowing cloud-based voice command processing. The received JSON response is parsed to extract the classified intent, which is subsequently translated into relay control actions.

iii. Calibration Procedure

Prior to system integration, each sensor was individually calibrated to ensure measurement reliability. The soil moisture sensor threshold was established by averaging analog readings obtained from thirty repeated measurements under both dry and moist soil conditions. The ultrasonic sensor refill threshold was determined through direct distance measurements against known water levels. Furthermore, the KY-037 sound sensor threshold was calibrated by measuring ambient noise levels across thirty independent trials and selecting a trigger value above the average background noise level.

iv. Testing Scenarios

The developed prototype was evaluated through four testing scenarios:

1. Automatic irrigation under controlled soil moisture and rainfall conditions.
2. Voice-command irrigation control using Wit.ai under quiet and moderate-noise environments.
3. Offline manual control using the KY-037 sound sensor during simulated network failure.
4. Connectivity interruption testing to verify fallback control mechanisms.

v. Evaluation Metrics

System performance was evaluated using several quantitative metrics. Voice-command recognition performance was assessed through accuracy, precision, and recall. Sensor reliability was evaluated using mean deviation and percentage agreement across repeated measurements. In addition, average response latency was measured to determine end-to-end system responsiveness. Each sensor was tested through at least twenty repeated trials per operating condition, whereas voice-command testing involved forty independent trials.

The following subsections describe each hardware component integrated into the proposed smart irrigation system.

vi. NodeMCU ESP8266

The NodeMCU ESP8266 is a low-cost microcontroller developed for IoT applications requiring wireless communication and real-time data transmission. It provides multiple digital input/output pins, one analog input channel, and native Wi-Fi connectivity. Within the proposed system, the ESP8266 functions as the primary processing unit responsible for sensor acquisition, decision-making, relay control, and communication with the Wit.ai cloud platform.

As illustrated in Figure 1 (a), the NodeMCU ESP8266 serves as the central controller coordinating all sensing and actuation processes.

The soil moisture sensor measures the volumetric water content of soil and provides analog output values ranging from 0 to 1023. The measured values are classified into dry and moist conditions based on experimentally determined thresholds. Irrigation is automatically activated whenever the measured value falls below the calibrated dryness threshold.

Figure 1 (b) presents the soil moisture sensor employed in this study.

The raindrop sensor detects rainfall through conductivity variation across its sensing surface. During operation, irrigation is permitted only when dry soil conditions are detected and rainfall is absent. This sensor therefore acts as a secondary verification layer within the irrigation decision process.

The raindrop sensor utilized in the prototype is shown in Figure 1 (c).

(a) **(b)** **(c)**

Figure 1: (a) NodeMCU ESP8266 Microcontroller (b) Soil Moisture Sensor v1.2 (c) Raindrop Sensor

vii. Ultrasonic Sensor (HC-SR04)

The HC-SR04 ultrasonic sensor measures the distance between the sensor and the water surface inside the storage tank. Distance measurements are calculated based on pulse transmission and echo return time. A refill threshold of 5 cm was established through calibration measurements. The refill pump is activated whenever the measured distance exceeds the specified threshold.

Figure 2 (a) illustrates the HC-SR04 ultrasonic sensor used for tank-level monitoring.

(a) **(b)** **(c)**

Figure 2: (a) HC-SR04 Ultrasonic Sensor (b) KY-037 Sound Sensor (c) Two-Channel Relay Module

The KY-037 is a high-sensitivity acoustic sensor utilized as a local manual override mechanism. The trigger threshold was experimentally determined through ambient-noise measurements and clap-based activation tests. The selected threshold minimizes false triggering while maintaining reliable user interaction under moderate environmental noise conditions.

Figure 2 (b) shows the KY-037 sound sensor employed as the offline control interface.

The relay module serves as the actuator interface between the ESP8266 and the water pumps. Relay channel 1 controls irrigation operations, whereas relay channel 2 controls water-tank refilling. Reliability testing was performed through repeated switching cycles to verify stable electrical operation.

The relay module configuration is presented in Figure 2 (c).

viii. Integration with Wit.ai

Voice-command functionality is implemented using the Wit.ai cloud-based NLP platform. Spoken commands are converted into text, transmitted to the Wit.ai server, and classified into predefined intents. The ESP8266 receives the resulting JSON response, extracts the identified intent, and executes the corresponding irrigation action.

The overall voice-command processing workflow through Wit.ai is illustrated in Figure 3.

III. Results and Discussion

This section presents the implementation results, hardware validation, sensor performance evaluation, and

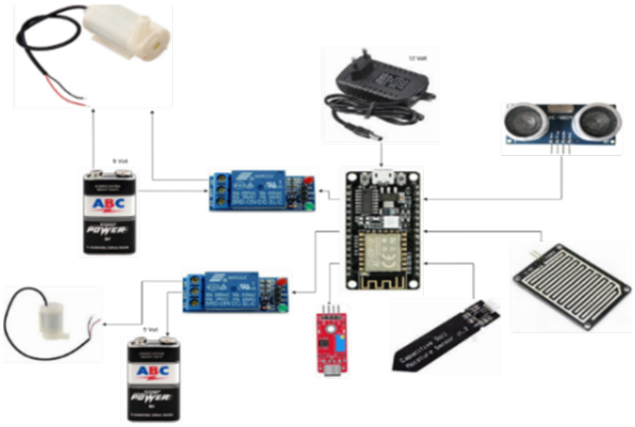

Figure 3: Voice Command Integration Using Wit.ai

voice-command testing of the proposed smart irrigation system. Experimental observations are discussed to assess the effectiveness of the developed prototype under various operating conditions.

i. Hardware Design

The smart irrigation system developed in this study was designed to automate and optimize water distribution for chili cultivation based on real-time environmental conditions. The hardware architecture integrates several key components, including soil moisture sensors, a raindrop sensor, an ultrasonic water-level sensor, a KY-037 sound sensor, two water pumps, and a two-channel relay module.

An overview of the developed irrigation prototype is presented in Figure 4.

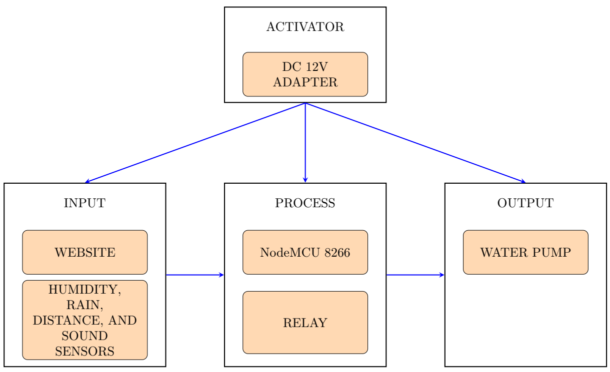

Figure 4: Overview of the Smart Irrigation System

ii. Block Diagram

To facilitate system understanding, the overall architecture was divided into input, processing, and output layers. Input devices include environmental sensors and a sound sensor for local manual control. The processing layer consists of the NodeMCU ESP8266, which executes control logic and communicates with the Wit.ai cloud service. The output layer consists of water pumps controlled through relay modules.

The overall block diagram of the proposed system is illustrated in Figure 5.

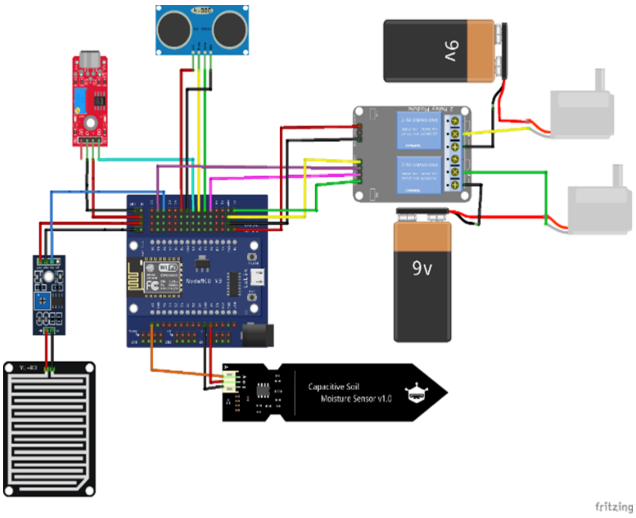

Figure 5: Block Diagram of the Proposed System

iii. Overall System Design

The complete circuit integrates all sensors, actuators, and communication modules on a single embedded platform. Input components are connected directly to the analog and digital pins of the NodeMCU ESP8266, while output devices are powered through an external power supply and controlled via relay modules. The entire system is enclosed in a weather-resistant housing to support agricultural deployment.

The complete system schematic is shown in Figure 6.

iv. Software Design

The software was developed using the Arduino IDE environment. During operation, the microcontroller continuously reads sensor values, evaluates predefined thresholds, and executes corresponding control actions. Voice commands received through Wit.ai are processed through HTTP communication and interpreted as irrigation control instructions.

The software workflow implemented in the system is illustrated in Figure 7.

The integration process between the NodeMCU ESP8266 and the Wit.ai platform is shown in Figure **??**.

In automatic mode, the microcontroller continuously evaluates environmental conditions to determine whether irrigation or reservoir refilling is required. When soil moisture falls below the predefined threshold and no rainfall is detected, Pump 1 is activated to irrigate the crops. Similarly, when the ultrasonic sensor

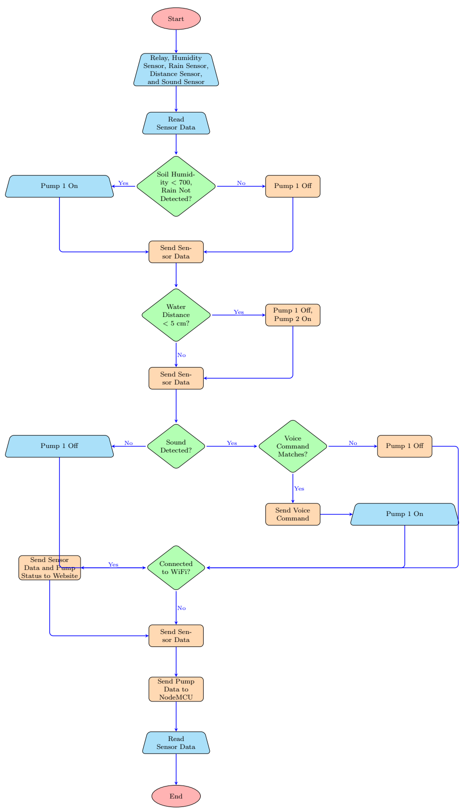

Figure 6: Schematic of the Entire Smart Irrigation System

indicates a low water level in the reservoir, Pump 2 is activated to refill the tank.

The system also supports manual operation through voice commands. Spoken commands are converted into text through a speech-recognition interface and transmitted to the Wit.ai platform for intent classification. The resulting JSON response is interpreted and translated into relay control signals. For example, the command "Turn on irrigation" activates Pump 1 regardless of current sensor readings. In the event of network disruption, the KY-037 sound sensor provides an offline fallback mechanism, ensuring uninterrupted system operation.

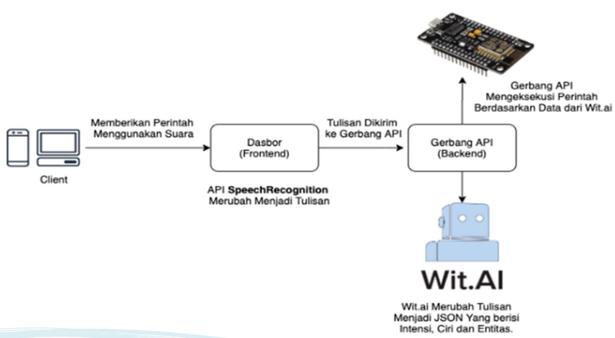

Figure 7: Flowchart of the Smart Irrigation System

v. KY-037 Sound Sensor Testing

The KY-037 sound sensor was evaluated as a local manual-control mechanism for situations where internet access is unavailable.

The testing results are summarized in Table 1.

Table 1: KY-037 Sound Sensor Testing Results

Environment	Number of Trials	Successful Detections	Accuracy (%)
Indoor Quiet Environment	15	15	100.0
Semi-open Environment	15	14	93.3
Total	30	29	96.7

The experimental results demonstrate that the KY-037 sensor successfully distinguished ambient silence from intentional sound triggers. Across thirty trials, the sensor correctly detected activation events in twenty-nine cases, corresponding to an accuracy of 96.67%.

vi. Soil Moisture Sensor Testing

The soil moisture sensor was evaluated to determine its ability to identify irrigation requirements based on soil water content.

The experimental results are presented in Table 2.

Table 2: Soil Moisture Sensor Calibration and Testing Results

Soil Condition	ADC Range	Average ADC	Pump Status	Trials
Dry Soil	750–900	825	ON	20
Moist Soil	200–400	300	OFF	20

Across twenty repeated trials, dry-soil measurements ranged between 750 and 900 ADC units, whereas moist-soil measurements ranged between 200 and 400 ADC units. The average deviation remained within ± 15 ADC units, indicating good measurement repeatability.

vii. Raindrop Sensor Testing

The raindrop sensor was evaluated to verify rainfall detection performance and irrigation inhibition capability.

The results are summarized in Table 3.

Table 3: Raindrop Sensor Testing Results

Condition	Trials	Correct Detection	False Detection	Accuracy (%)
Dry Surface	20	20	0	100.0
Wet Surface	20	20	0	100.0
Total	40	40	0	100.0

The sensor achieved 100% classification accuracy across forty controlled wet and dry trials, demonstrating reliable rainfall detection and over-irrigation prevention.

viii. Ultrasonic Sensor Testing

The HC-SR04 ultrasonic sensor was tested to evaluate reservoir-level monitoring performance.

The measurement results are shown in Table 4.

Table 4: Ultrasonic Sensor (HC-SR04) Testing Results

Actual Distance (cm)	Measured Distance (cm)	Error (cm)	Pump Status
3	3.2	0.2	OFF
4	4.1	0.1	OFF
5	5.3	0.3	ON
6	6.4	0.4	ON
8	8.2	0.2	ON
Average	–	0.3	–

The sensor achieved an average measurement error of only ± 0.3 cm compared with manual measurements, demonstrating sufficient precision for reservoir management.

ix. Wit.ai Voice Control Testing

Voice-command functionality was evaluated using the Wit.ai NLP platform integrated with the NodeMCU ESP8266.

The corresponding results are presented in Table 5.

Table 5: Wit.ai Voice Command Recognition Results

Command Type	Trials	Correct	Incorrect	Precision	Recall
Turn On Irrigation	20	19	1	0.95	0.95
Turn Off Irrigation	20	19	1	0.95	0.93
Total	40	38	2	0.95	0.94

A total of forty predefined command trials were conducted under controlled and moderate-noise environments. The system achieved an overall recognition accuracy of 95%, with precision and recall values of 0.95 and 0.94, respectively. The average end-to-end latency ranged from 1.2 to 1.8 seconds, which is suitable for real-time irrigation control applications.

IV. Limitations

Despite the promising results obtained from the prototype evaluation, several limitations remain.

First, the KY-037 sound sensor and Wit.ai voice-recognition platform were only evaluated under moderate environmental noise levels. Their performance under extreme agricultural noise conditions exceeding 80 dB remains unverified.

Second, the current implementation was designed as a single-zone irrigation system intended for small-scale cultivation. Future multi-zone deployments would require additional sensor nodes, relay channels, and distributed control mechanisms.

Third, long-term durability testing was not conducted. Although short-term outdoor operation demonstrated stable performance, prolonged exposure to environmental conditions may introduce sensor degradation, calibration drift, and electrode corrosion.

V. Conclusion

This study successfully designed, implemented, and evaluated a dual-mode smart irrigation system for chili cultivation using the NodeMCU ESP8266 platform.

The experimental results demonstrated that voice-command control through the Wit.ai platform achieved an accuracy of 95%, with precision and recall values of 0.95 and 0.94, respectively. Furthermore, the soil moisture sensor, raindrop sensor, and ultrasonic sensor exhibited stable and repeatable performance within their calibrated operating ranges. The KY-037 sound sensor also proved effective as an offline fallback mechanism during simulated connectivity interruptions.

The proposed dual-control architecture provides operational flexibility and enhances reliability for agricultural environments with intermittent internet connectivity. Moreover, the modular system architecture enables future expansion through the integration of additional sensor nodes and irrigation zones.

Future research should focus on long-term field validation, multi-zone deployment strategies, and advanced acoustic preprocessing techniques to improve voice-recognition robustness under high-noise agricultural environments.

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