Materials Research Proceedings 64 (2026) 299-305 https://doi.org/10.21741/9781644904091-37

Smart Sprinkler and Irrigation System for Ifrane Region: A Simulation-Based Approach Using AVR Microcontrollers

Ahlam MOUSSA[1,a], Kacem CHAWQI[1,b *], Ilham NAIT HIM[1,c], Jamal BAHRI[1,d] and Moulay El Hassan El AZHARI[1,e]

[1]P.O Box 104, Hassan II Avenue, 53000 Ifrane, Morocco

[a]ah.moussa@aui.ma, [b]k.chawqi@aui.ma, [c]i.naithim@aui.ma, [d]j.bahri@aui.ma, [e]m.elazhari@aui.ma

Keywords: Smart Irrigation, AVR Microcontroller, PWM Control, Soil Moisture Sensing, PID Control, Weather-Aware Irrigation, Proteus

Abstract. A method to minimize and monitor water and energy consumption in agriculture and landscaping lies in using smart automated sprinkler irrigation systems. This paper presents a complete simulation of a smart irrigation design for efficient water use and optimal soil quality. The proposed system utilizes an ATmega32 AVR microcontroller, along with soil moisture, temperature, gas, and humidity sensors, a Pulse Width Modulation (PWM) control of water pumps and valves. It is automated to regulate irrigation intensity with a closed-loop control enhanced by a PID controller and a lightweight artificial intelligence-inspired decision layer using rainfall data of the region of Fes-Meknes-Ifrane for threshold adjustments. The results highlight the improvement of soil moisture stability in the range of 4%, as well as a respective mean absolute error and a root mean square error of 3.5% and 5% compared to a threshold sensing method only.

Introduction



Fig. 1 Water Stress Analysis Map: Fez-Meknes-Ifrane Region

Water scarcity is a growing issue worldwide, particularly in arid and semi-arid regions like Morocco [1]. Traditional irrigation practices often rely on fixed schedules and manual control, resulting in increasing water consumption and uneven soil hydration, directly affecting energy costs, and, since often water sources are underground, accelerating aquifer depletion [2]. This emphasizes the importance of developing systems capable of adapting water delivery to real-time environmental conditions [3].

With the rising water demand in agriculture and urban landscapes, smart irrigation techniques emerged. This work proposes a new and fully simulated design for a smart sprinkler and irrigation system based on an AVR ATmega32 microcontroller and AI integration with a focus on the Fez-Meknes-Ifrane region, Fig. 1. The system combines a low-cost and modular AVR-based architecture with adaptive PWM actuation, closed-loop PID control strategy, multi-zone irrigation, safety awareness, as well as Artificial Intelligence (AI)-inspired weather-informed logic that inputs

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 license. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under license by Materials Research Forum LLC.

Materials Research Proceedings 64 (2026) 299-305 https://doi.org/10.21741/9781644904091-37

rainfall probability into irrigation decisions. This allows the system to avoid watering in case of a rain forecast then the system conserves water depending on the weather patterns and requirements in the area.

Although this work is a fully functional Proteus simulation, it offers vital information on the behavior and robustness of the system, which can be used for prototyping.

Materials and Methods

System Architecture. The overall architecture of the system consists of four main blocks, illustrated in Fig. 2. An ATmega32 AVR microcontroller serves as the central component, due to its efficient cost and low energy consumption. Hence, it could be power with solar energy.

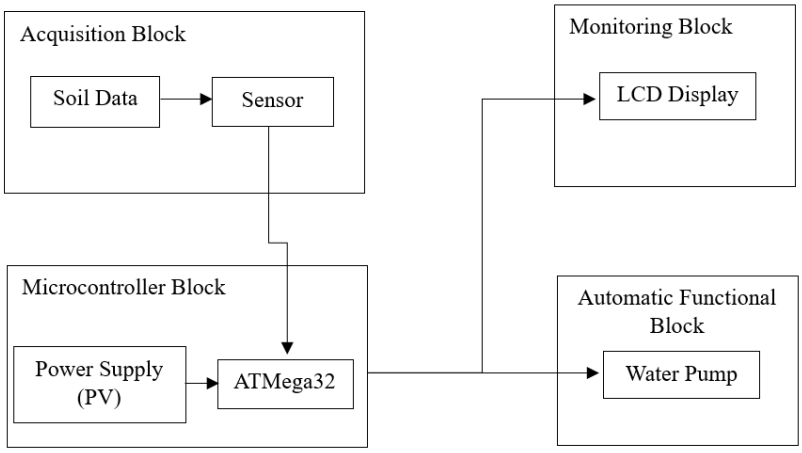


Fig. 2 Overall System Architecture Block Diagram.

Sensors Parameters and Threshold Selection. The soil is considered dry when moisture levels are less than 40% and optimal when between 40% and 70% [4]. The temperatures have a cutoff threshold of 50 °C to avoid overheating. For safety, a gas/smoke sensor is implemented too, and uses a predefined broad range between 10 and 1000 ppm.

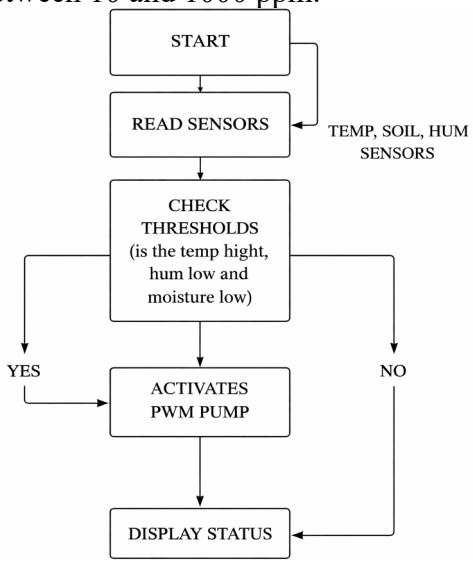


Fig. 3 Flowchart of Embedded Control Logic

Functional Overview. The microcontroller ADC samples sensor data periodically, and the integrated control algorithm compares measured values with predefined thresholds. Then, the appropriate PWM duty cycle is computed. Actuators are then driven accordingly to regulate water flow. An LCD and Universal Asynchronous Receiver/Transmitter (UART) interface continuously

Materials Research Proceedings 64 (2026) 299-305 https://doi.org/10.21741/9781644904091-37

provide feedback to the user and allows the user to configure the pump if needed too. We used Atmel Studio for the embedded C code. The algorithm is summarized in Fig. 3.

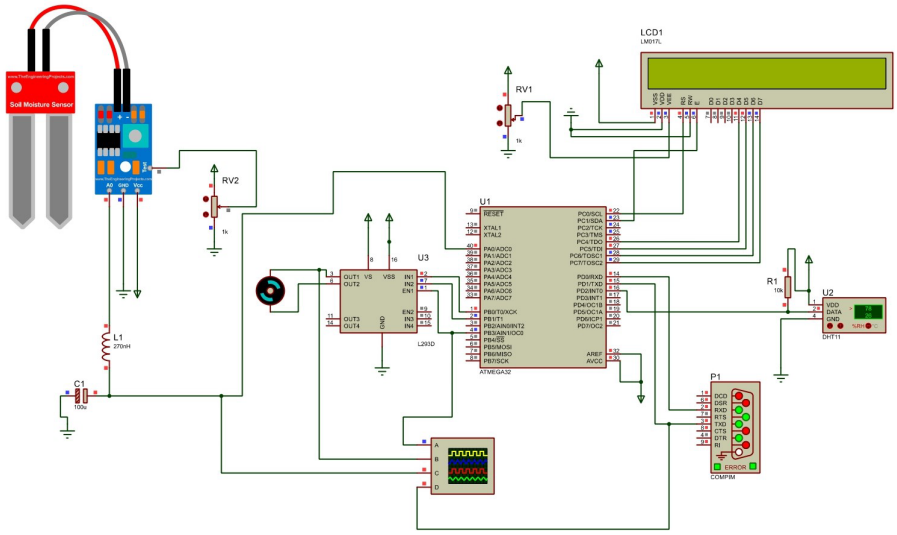


Fig. 4 Proteus Circuit

Proteus Simulated Circuit Design. Fig. 4 represents the Proteus circuit with a single sprinkler configuration. The AVR operates at a frequency of 8MHz for a 9600 baud serial data.

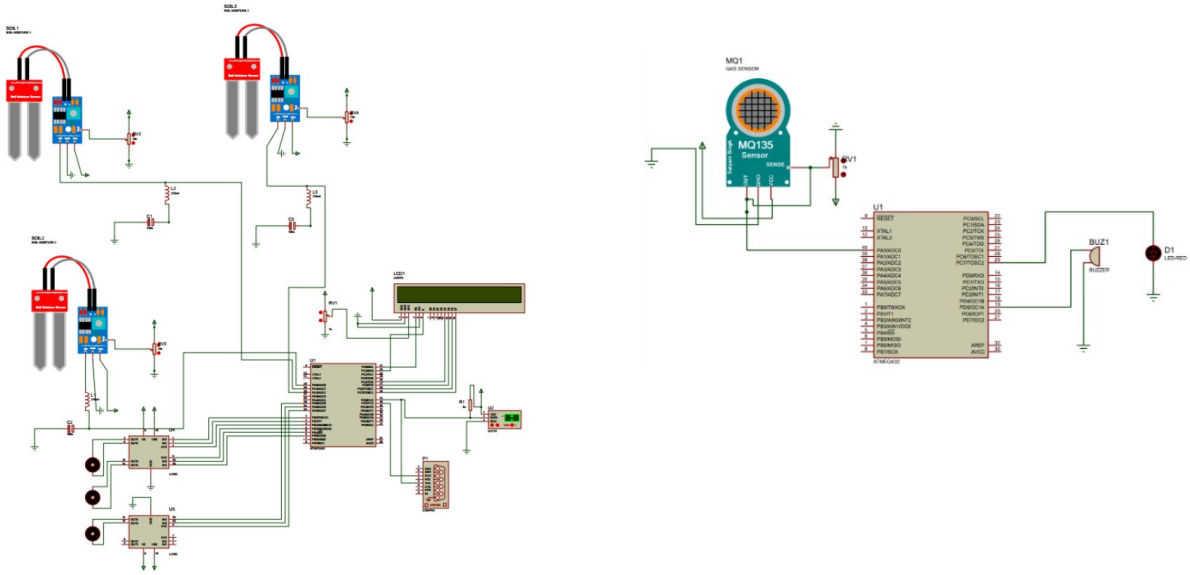


Fig. 5 Overview of the Proteus Zone Control and Safety Circuit

transmission and correct readings for sensitive components. It is connected to the moisture sensors controlled with a potentiometer, and a temperature sensor, DHT11, also capable of measuring relative humidity. The water pump or valve controlled by the PWM is represented by the PWM-controlled DC motor. The 16x2 LCD represents the user interface to display sensed data, the state of the pump and energy consumed. Periodic updates and threshold configuration are provided through a UART virtual terminal.

Using three virtual soil moisture sensors connected to separate ADC channels of the ATmega32, the zone control feature divides the irrigation area into three manageable zones. Each zone is associated with its own PWM-controlled DC motor actuator (e.g., a pump) and respective

Materials Research Proceedings 64 (2026) 299-305 https://doi.org/10.21741/9781644904091-37

sensors, as shown in Fig. 5. At every sampling period, the microcontroller reads the moisture levels from the sensors and compares the values to reference moisture levels. The resulting error drives the appropriate PWM duty cycle to precisely feed the motor driving the valve or pump of the specific zone, rather than a simple ON/OFF operation.

As for environmental safety, a gas sensor MQ-135 was used to detect general air pollutants (e.g., CO_2 and NH_3) and smoke. This analog sensor sends signals to the AVR once a threshold level is exceeded, immediately indicating a buzzer, turning on an LED, and shutting down the pumps.

PID Controller. To adjust the motors' speed in response to fluctuations in soil moisture and temperature and continuously minimize the sensor error, we used a PID controller [5]. The error is translated from the duty cycle of the PWM, and is defined as

$$e(t) = r(t) - y(t), \quad (1)$$

where $r(t)$is the reference soil moisture (or temperature limit) and $y(t)$is the measured value. Since data was sampled discreetly, the control output was computed in discrete form with a sampling period of 1s using the Backward differentiation:

$$u[k] = K_p e[k] + K_i \sum_{i=0}^{k} e\,[i]T_s + K_d \frac{e[k]- e[k-1]}{T_s}. \quad (2)$$

The output $u[k]$ modulates the pump and defines the operation of the PWM. The coefficients K_p, K_i and K_d represent the gains, tuned iteratively based on the step response. The time sample used is T_s=1s. The results of approaches using thresholds only were compared to those of this PID control approach, to scrutinize the stability and convergence of the system.

Results and Discussion

Oscilloscope readings in Fig. 7 present the PID and PWM-driven behavior (Yellow and Blue traces). The y-axis represents logic-level voltage (0-5 V), while the x-axis represents time. A "widening" of the rectangular pulses is observed in this scope-view, corresponding to an increase in PID control effort, following a detection of a deficit in moisture given by the soil moisture sensor (red trace). The proportional term K_p particularly triggers the expansion of the duty cycle, maximizing actuator power.

Simulation Limitations. Some limitations must be regarded, despite Proteus providing a reliable platform to conduct the functional validation of the proposed system. First, since they do not consider noise, the sensor models are abstract with calibration error or drift over time. Secondly, instead of physical hydraulic models, the soil moisture logic was modeled with threshold values, rendering them not always aligned with real field behavior. Real-world implementation would require calibration and robustness testing under varying operating conditions, even though the simulation was stable in control and logically correct.

Materials Research Proceedings 64 (2026) 299-305 https://doi.org/10.21741/9781644904091-37

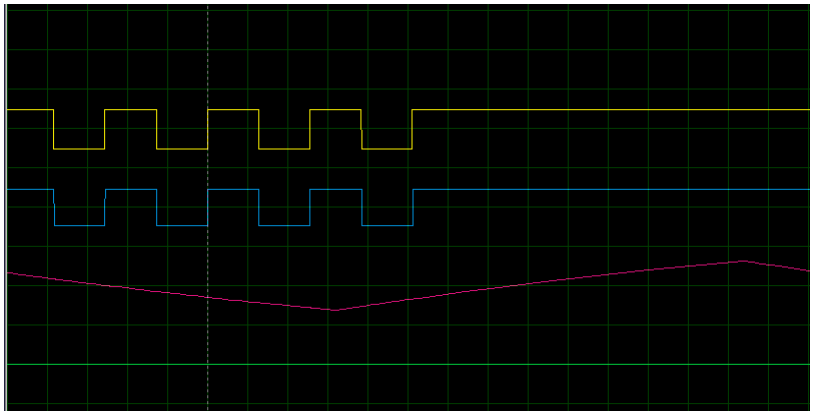


Fig. 7 PWM output under PID control

Error Metrics. Over a sampling interval of 1 second, a time domain metrics evaluation was discreetly computed. The signal error for each zone was defined as the difference between the soil moisture level defined as 55%, and the average of optimal moisture levels used in the literature.

Table 1: Error metrics values

Control	***MAE***	***RMSE***	***Max Error***
Threshold only	*8.5%*	*10%*	*15%*
Threshold + PID	*3.5%*	*5%*	*4.5%*

Additionally, ADC values to percentage scales were mapped. The error metrics were computed over 600 samples for an activation period of 10 minutes. Absolute error and root mean square error were calculated in order to calculate the mean. The soil moisture behavior is illustrated in Figure 8. As compared to the threshold-only approach, it is noticeable that the PID system stabilizes with respect to the reference with fewer oscillations, better convergence, and a tighter tracking band that remains within about 4% of the reference. This explains the decreased error measurements in Table 1. The MAE and RMSE values are rounded averages.

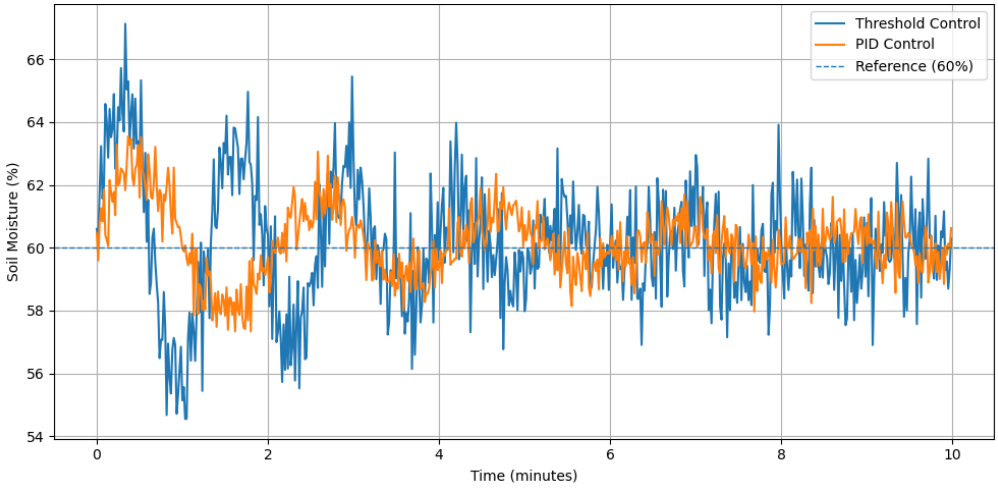


Fig. 8 Soil Moisture Regulation During Irrigation Cycle

Real Time Weather Integration. To take larger and updated environmental inputs, the weather station and local infrastructure in Ifrane were used [6]. By integrating an AI-inspired decision layer to simulate intelligent irrigation behavior in response to forecasted environmental conditions, the system becomes weather-aware. The system dynamically adjusts its behavior

based on rain probability data specific to the Ifrane region, rather than relying on static thresholds alone.

Regional precipitation trends were integrated with data from the Moroccan National Meteorological Service and publicly available historical weather databases, such as MeteoBlue and OpenWeatherMap, which provide hourly and daily rain probability forecasts for Ifrane [7, 8]. For other broader regions, data would be accessed with an API and parsed through an external script or onboard IoT [9].

In comparison, traditional irrigation controllers without environmental awareness might activate regardless of incoming rainfall, leading to inefficient water use. Real-time integration with weather APIs and adaptive machine learning models could automate this logic entirely in future versions of this system, requiring no human intervention to optimize decisions based on historical and forecasted data.

Technically, the integration of AI can be achieved through UART communication protocols or by incorporating wireless modules, such as ESP8266/ESP32, for API-based access to weather station data over Wi-Fi [10]. JSON-formatted weather data from online APIs or local campus networks can be retrieved by these modules. This information can then be parsed by the microcontroller to decide autonomously. This system could also participate in a distributed environmental sensing network managed centrally by university facilities, if expanded into a microgrid of sensors. The limitations of such a setup can be found in the asynchronous nature of the UART; that is why the baud rate between the connected devices must be matched. UART is also typically used for short-range communication, which must be considered in the setup [10].

Implementation of the System for Universities. Linking the integration of smart sprinklers with a university Smart Campus Dashboard can be done to create a centralized platform for managing water and energy resources and generate long-term analytics on vegetation health and resource efficiency. This approach, which is infrastructure-aware, aligns with global trends in smart agriculture and urban planning, where more resilient and adaptive ecosystems are reached thanks to the fusion of embedded systems, real-time data analytics, and Internet of Things (IoT) technologies [11]. For Al Akhawayn University in Ifrane, implementing such a system offers an interdisciplinary educational platform that engineering students can use for experimentation and innovation support, while sustaining its sustainability mission.

Comparative evaluation. By assessing existing smart irrigation solutions, the novelty of the proposed system is emphasized. The ATmega32-based Proteus prototype combines multi-zone sensing, PWM control, and PID correction, on top of environmental responsiveness. Such a holistic approach distinguishes itself from existing single-zone solutions [12, 13]. Furthermore, the extension of the suggested model with a safety circuit focused on smoke detection for fire prevention renders it more relevant to agricultural applications. The design also sets itself apart from conventional systems by supplementing its approach with UART-based weather adaptation, thus enhancing its precision and scalability into a larger network for minimized water waste.

Conclusion and Future Work

This work simulated a cost-efficient, scalable, and environmentally adaptive microcontroller-based sprinkler and irrigation system with temperature, humidity, and soil moisture sensors with a PWM actuator and PID regulation. The simulation demonstrated strong stability and precise sensing measurements reaching mean absolute errors of 3.5%. In a world driven by AI, it makes use of it to calibrate irrigation intensities and water monitoring. By taking multizone irrigation and safety measurements into account, the system is user-friendly and highly adaptable to different applications. Although the simulation is complete, a real-world application may require minor calibrations. Finally, suggested enhancements can be added to expand the system's scalability and application through IoT integration, Wi-Fi, and GSM connectivity, mainly for remote control, cloud-based analytics, and mobile notifications. The development of a user-friendly mobile

application to visualize sensor data, receive alerts, and configure thresholds remotely can be worked on as a separate project.

References

[1] F. Taheripour, et al., Water Scarcity in Morocco, World Bank Group, 2020, p. 10. https://documents1.worldbank.org/curated/en/642681580455542456/pdf/Water-Scarcity-in-Morocco-Analysis-of-Key-Water-Challenges.pdf

[2] R.M. Cruse, D.L. Devlin, D. Parker, R.M. Waskom, Irrigation aquifer depletion: the nexus linchpin, J. Environ. Stud. Sci. 6 (2016) 149-160. https://doi.org/10.1007/s13412-016-0370-y

[3] G. Rajagopal, V.M. Lodd, A. Vignesh, R. Rajesh, V. Vijayaraghavan, Low cost cloud based intelligent farm automation system using Bluetooth Low Energy, in: 2014 IEEE Region 10 Humanitarian Technology Conference (R10 HTC), Chennai, India, 2014, pp. 127-132. https://doi.org/10.1109/R10-HTC.2014.7026324

[4] E.F. Camacho, C. Bordons, Constrained model predictive control, in: Model Predictive Control, Springer London, London, 2007, pp. 177-216.

[5] M.A. Johnson, M.H. Moradi, PID Control, Springer-Verlag London Limited, London, 2005.

[6] M. Lagasio, S. Barindelli, Z. Chitu, S. Contreras, A. Fernández-Rodríguez, M. de Klerk, A. Fumagalli, A. Gatti, L. Hammerschmidt, D. Haskovic, M. Milelli, Integrating Advanced Sensor Technologies for Enhanced Agricultural Weather Forecasts and Irrigation Advisories: The MAGDA Project Approach, Remote Sens. 17 (2025) 1855. https://doi.org/10.3390/rs17111855

[7] Information on www.meteoblue.com/en/weather/week/blue_united-states_5286039

[8] Information on https://openweathermap.org

[9] A.R. Al-Ali, I. Zualkernan, M. Rashid, A Smart Home Energy Management System Using IoT and Big Data Analytics Approach, IEEE Trans. Consum. Electron. 63 (2017) 426-434. https://doi.org/10.1109/TCE.2017.015014

[10] P. Megantoro, S.A. Aldhama, G.S. Prihandana, P. Vigneshwaran, IoT-based weather station with air quality measurement using ESP32 for environmental aerial condition study, TELKOMNIKA (Telecommun. Comput. Electron. Control) 19 (2021) 1316-1325. https://doi.org/10.12928/telkomnika.v19i4.18567

[11] A.D. Dharmavaram, T.S. Savithri, S.L. Sai, Design and implementation of real time data acquisition system using reconfigurable SoC, Int. J. Adv. Comput. Sci. Appl. 11 (2020) 9. https://doi.org/10.14569/IJACSA.2020.0110953

[12] S.P. Shaik, N.V. Sarath, P.N. Ramarao, Smart Irrigation System for Sweet Corn, in: 2025 International Conference on Electronics and Renewable Systems (ICEARS), 2025, pp. 1498-1504. https://doi.org/10.1109/ICEARS61622.2025.10474640

[13] R.K. Jain, Design and Modeling of Control System for Automation of Irrigation System Using PID and ANN Methods, Available at SSRN 4197630 (2022). https://doi.org/10.2139/ssrn.4197630