Soil Irrigation System Based on A Digital Camera and Graphic User Interface

Ali Al-Naji 1,2*, Ahmed Bashar Fakhri1, Mohammed Abdalmunaf Alnosh1 and Munir Oudah 3

1 Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq
2 School of Engineering, University of South Australia, Mawson Lakes, SA 5095, Australia
3 College of Engineering, Al-Nahrain University, Baghdad, Iraq
*Corresponding author: ali_al_naji@mtu.edu.iq

Abstract. Irrigation consumes 70% of the water quantity used worldwide. In a context of rising food demand and declining in water resources, the development of advanced irrigation technologies based on modern techniques in agriculture is a significant demand to keep this resource safe. To achieve this target, the management of water resources in agriculture needs to be specified and controlled. This study aims to propose an automatic, non-contact and cost-effective soil irrigation system based on analysing the changes in loam soil colour captured by a digital camera at different illumination levels. A graphic user interface (GUI) attached to the Arduino Uno microcontroller was used to drive the water pump and determine whether the loam soil requires irrigation or not. The experimental results illustrate the effectiveness of the proposed irrigation system to determine soil state and provide an accurate decision for soil irrigating, thus making this system a promising approach in future irrigation technologies.

Keywords— Non-contact soil irrigation system; Colour image analysis; Graphic User Interface (GUI); Arduino Uno Microcontroller.

1. Introduction

Annually, about more than 70% of the available water in Iraq is used for agriculture, especially in irrigation, where an estimated total area of arable agriculture is about 12 million hectares [1]. With the development of irrigation projects and the construction of dams in neighbouring countries (Turkey and Syria), it is expected that Iraq will face a significant decline in the waters of the Tigris and Euphrates rivers, which may reach a deficit of about 22-21 billion cubic meters in 2030 [1]. The decrease in the amount of water is also due to several internal factors, including ineffective water management, shortage of knowledge, unplanned water management practices and overtaking on water quotas by farmers [2, 3] and some external factors, including increased salinity, drought and depressed rainfall [4, 5]. Therefore, there is a fundamental need to renew and use cost-effective and advanced irrigation techniques for the effective utilisation of water resources in agriculture.

In the recent decade, many techniques based on attached sensors have been proposed for irrigation technologies in agriculture to characterise the water case of the crop [6-11]. Although these techniques used cost-effective components, their components may have exposed electronics elements that required to be waterproof and durable, and they are susceptible to salts in the substrate or soil [7]. Also, they require specialized hardware for wired and wireless connections to buried components, which somewhat leads to disconnection problem. Wireless sensor network has a major role in applications of intelligent monitoring and accurate agriculture in a larger area [12]. Moreover, near-
infrared and thermal sensing methods can measure the amount of water the plant requires [13]. The soft computing methods such as neural networks and fuzzy logic were also applied to agricultural yields for predicting the cornfield under difference irrigation types [14]. One of the most common methods used in row crop irrigation is furrow irrigation. A study by Long et al. [15] developed an automatic tool vision algorithm based on unmanned aerial vehicles thermal imagery for monitoring furrow irrigation advancement of large areas of a farm. The algorithm based on intensity partition from unmanned aerial vehicles thermal imagery to elicit the row angle preoperational to the camera. The experimental results showed proposed algorithm was more precise at a lower flying height. The system has successful detection of leading water edges with automatic monitoring the progress of large crop yields.

Remote sensing based on computer vision system can supply a number of data on water case and health of yield and could help in decision-making on irrigation. Recent developments on visible light cameras and infrared and satellites with high temporal repetitiveness, aerial light vectors extend new methods of a regular, environmental friend, monitoring of crops. Labbe et al. [16] viewed geometric and radiometric preprocessing of information from warm thermal cameras to able the integration of this information in spatial irrigation patterns. The development of thermal cameras can be treated as beneficial in airborne precision agriculture to monitor irrigation and thus better management and protection of water resources. The system has a high resolution and easy to use. However, it is affected by weather conditions. There is another method can be used to develop the irrigation systems which represented by the internet of things (IoT). The importance of IoT is mounting by the growth of cloud computing, the technology of mobile and data analytics [17, 18]. A study by Kabilan and Selvi [19] proposed an automatic system in the domain of agriculture based on IoT and web of things (WoT) techniques to distinguish and channelise the irrigation ways. These irrigation systems consist of the soil moisture sensor, DHT11 sensor, rainfall sensor, PH sensor, light derivative resistance, ZigBee transmitter, ZigBee receiver), power source, Arduino Uno, relay, solenoid valve, Wi-Fi module, WoT, and remote access. To avoid using buried sensors and components in the ground, automatic soil irrigation technologies based on a digital camera may offer a suitable alternative in such applications. In a recent study by Alnaji et al. [20], a pilot study based on analysing loam soil colour captured by a digital camera was proposed. This study used the colour information as input to an artificial neural network (ANN) system to decide as to whether to irrigate the soil or not. However, this study presents a complex soil analysis method with a lack of the hardware design. Each technique mentioned above, however, has its advantages and distavevtages and may perform well in some challenges while being inferior in others. This work aims to propose an efficient, low cost and precise approach for automatically irrigating the soil based on analysing of the colour changes during irrigation controlled by Arduino microcontroller to drive a water pump. The proposed irrigation system presents reliable results, and it is cheap to design, easy to implement and easy to program.

The remainder of this study is outlined as follows: Section 2 describes the methods and materials of the proposed irrigation system, including data collection, system design and hardware. Section 3 presents the experimental results based on data analysis and Matlab GUI and depicts some study limitations. Finally, section 5 presents the concluding remarks and suggestions for future work.

2. Methods and Materials

2.1. Data Collection

Soil data used in the experiment was collected during four weeks in an agricultural nursery located in the Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq. A digital camera (Model Nikon D5300) was installed on a tripod at a range of 1 metre from the loam soil placed in a planting bowl at an angle of 45°. The image data was captured by using a 18-50 mm lens with a resolution of 6000×4000 and saved in JPG format on a computer. The Nikon D5300 used 24MP DX format CMOS sensor with no optical low pass filter. The experiment was carried out under four illumination scenarios, where each scenario has 50 image samples. The image samples at the first scenario (S1) were when the soil was dry under sunny condition (without clouds). The images samples at the second scenario (S2) were when the soil was dry under cloudy condition (no direct sunlight
exists). The image samples at the third scenario (S3) were when the soil was wet under sunny condition. The last scenario (S4) was when the soil was wet and cloudy. The data collection at different four scenarios is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Data collection under four scenarios (a) S1: Dry-Sunny, (b) S2: Dry-Cloudy, (c) S3: Wet-Sunny, and (d) S4: Wet-Cloudy.

### 2.2. System Design

The schematic diagram of the proposed irrigation system that relies on analysing soil colour using Matlab GUI is presented in Figure 2. It has three main parts: soil colour analysis, including region of interest (ROI) selection and colour range selection, hardware design and Matlab GUI.

![Figure 2](image2.png)

**Figure 2.** The schematic diagram of the proposed irrigation system.

#### 2.2.1. Soil Colour Analysis

Colour is a fundamental aspect of human perception that the human eye can perceive any incident spectrum as a combination of red (R), green (G) and blue (B), which are called the three ‘primary colours’. The RGB colour space is a simple and robust colour definition that is composed by the primary colours: R, G and B channels. The colour of the loam soil changes during the irrigation process (dry and wet) and its colour also varies at different illumination levels resulting from weather conditions (sunny and cloudy). These changes in the colour directly cause changes in the reflected brightness values in the digital colour images. The colour representation of the brightness values changes can be found by using the following equations [21, 22]:

\[ R = \frac{I_R}{I_{R+G+B}}, \quad G = \frac{I_G}{I_{R+G+B}}, \quad B = \frac{I_B}{I_{R+G+B}} \]
\begin{align*}
R & = \int E_{\lambda} S_{r} \, d(\lambda), \\
G & = \int E_{\lambda} S_{g} \, d(\lambda), \\
B & = \int E_{\lambda} S_{b} \, d(\lambda),
\end{align*}

where \( E_{\lambda} \) is the light spectrum, \( S_{r}, S_{g}, S_{b} \) are the sensitivity functions for the R, G and B channels obtained from the colour image, respectively, and \( \lambda \) is the wavelength of the incident spectrum. After that, MATLAB built-in command ‘ginput’ with five inputs is used on the selected image to manually localise the ROI that is outlined by drawing a square form around ROI. The average value of the brightness pixel for each channel is extracted as follows [23, 24]:

\begin{align*}
\bar{i}_R(t) &= \frac{\sum_{x,y\in ROI} B(x,y)}{|ROI|} \\
\bar{i}_G(t) &= \frac{\sum_{x,y\in ROI} B(x,y)}{|ROI|} \\
\bar{i}_B(t) &= \frac{\sum_{x,y\in ROI} B(x,y)}{|ROI|}
\end{align*}

where \( B(x,y) \) is the brightness pixel value at image location \((x,y)\) from R, G and B channels, and \(|ROI|\) is the pixel region of the selected ROI, where each equation has a range from 0 to 255.

Next, the colour range selection was determined based on the average value of the brightness values obtained from 200 image samples (50 samples for each scenario). MATLAB built-in commands ‘if and elseif’ with the selected range were used to make a decision as to whether to irrigate the soil or not.

The selected brightness values of the first scenarios fall within a range of 200-226, 184-204 and 151-200 of the R, G and B channels, respectively. The selected brightness values of the second scenarios fall within a range of 93-120, 90-118 and 91-118 of the R, G and B channels, respectively. The selected brightness values of the third scenarios are 169-190, 141-167 and 128-155 of the R, G and B channels, respectively. The selected brightness values for the R, G and B channels of the fourth scenarios are 40-85, 38-81 and 37-80, respectively.

2.2.2. Hardware

The Arduino Nano microcontroller (ATmega328P) [25] is a powerful single-board computer that was used in this study to drive a DC water pump through a relay driving circuit with two indicating LEDs (green LED is to turn on the pump and Red LED is to turn off the pump). This microcontroller has 14 digital I/O pins and 8 analogue pins with the clock frequency of 16MHz. The Arduino Nano microcontroller is suitable for several digital applications [26-30] due to its availability, small size, low cost, efficient interrupt structure and ease to programming with an open-source software using an integrated development environment (IDE). Also, the Arduino Nano microcontroller can be easily linked with any computer and receive data from Matlab environment via Mini-B USB serial cable. The Matlab built-in command ‘A=arduino(COM3,’uno’)’ was used to identify the microcontroller in the computer and the Matlab built-in command ‘writeDigitalPin’ was used to drive a DC water pump.
3. Experimentation

3.1. Experimental Data Analysis

To evaluate how the proposed irrigation system could be used to determine whether the loam soil requires irrigation or not based on soil colour analysis, different averaged brightness ranges were obtained from 200 image samples at four scenarios. The selected ranges were then used by the Matlab 2019b program (MathWorks, NSW, Australia) and determine the soil state (dry or wet) and sending 0/1 to the microcontroller circuit that controls the water pump drive circuit. The data analysis of the selected ranges obtained from the R, G, B channels for four scenarios is shown in Figure 4.

![Figure 3. The hardware design of the proposed irrigation system.](image)

![Figure 4. The data analysis of the selected ranges obtained from the R, G, B channels for four scenarios.](image)

3.2. Experimental Results Based on GUI

The experimental proposed GUI model was carried out in the MATLAB program under the Microsoft Windows 10 operating system to allow the user to load soil image samples, manually select ROI and execute the algorithm to determine the soil state and whether it requires irrigation or not. The experimental proposed GUI provides an easy tool to see the RGB histogram and their brightness values, soil state (dry and wet under sunny or cloudy conditions) and water pump control. Figures 5, 6, 7 and 8 show the GUI main scenes of the proposed irrigation system at different scenarios.
Figure 5. The GUI main scene of the proposed irrigation system at S1 (Dry-Sunny).

Figure 6. The GUI main scene of the proposed irrigation system at S2 (Dry-Cloudy).
3.3. Limitations

Although the proposed irrigation system was efficient, inexpensive, easy to use and easy to program, it has some limitations that need to be considered in the future. The first limitation is that the ROI is manually selected, which limits such practical applications that need ROI to be selected automatically and only focused on the region of bare ground. The second limitation is that it sets up to work only for the loam soils and indicate the state of hydration of a particular soil type; therefore the proposed irrigation system would probably need an improvement to work with other types of soil. However, future improvement can be expanded to work with other types of soil and achieve better outcomes.

Figure 7. The GUI main scene of the proposed irrigation system at S3 (Wet-Sunny).

Figure 8. The GUI main scene of the proposed irrigation system at S4 (Wet-Cloudy).
4. Conclusion

In this paper, a design concept for a new soil irrigation system based on analysing the changes in loam soil colour captured by a digital camera at different illumination levels has been obtained. The hardware design of the proposed system was carried out by using the Arduino Uno Microcontroller as central controller linked with Matlab GUI to verify the reliability of the irrigation system. The implemented system was simple, accurate, inexpensive and flexible. Therefore, this system may have a significant potential for use in many agricultural applications. An intriguing possibility might be to have the system commence operation with a low cost, possibly wireless, hygrometer. The system could then automatically learn about the appearance of the soil once installed using the hygrometer as training feedback. This might allow the system to adapt to any type of soil over time, prior to the hygrometer expiring due to environmental conditions or battery life.

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