Irrigation control and image acquisition for rice cultivation in UAE desert soil

M Ali¹, M Chowdhury¹,², M N Islam¹,², S Islam², S Kiraga², J H Jeong³ and S O Chung¹,²

¹ Department of Agricultural Machinery Engineering, Graduate School, Chungnam National University, Daejeon 34134, Republic of Korea
² Department of Smart Agricultural Systems, Graduate School, Chungnam National University, Daejeon 34134, Republic of Korea
³ National Institute of Crop Science, Rural Development Administration, Wanju 55365, Republic of Korea

E-mail: sochung@cnu.ac.kr

Abstract. Precision water management and crop growth monitoring are essential where water is a scarce, especially in desert soils. The purpose of the study was to control the irrigation and real-time image acquisition for monitoring the rice cultivation inside the net house under the UAE desert soil. An automated data acquisition system was constructed, installed, and tested in the experimental site at Al-Foah, Al-Ain. Soil water content sensors were placed in the different depths of desert soils, and an automatic irrigation logic was implemented to maintain the average of 30% desired water content level in desert soils. The irrigation rate was controlled based on the sensor data and the on/off of the pump and valves. When the average soil water content percentage level exceeds 30%, the pump and solenoid valve automatically turned off and vice versa. A Raspberry Pi operating system was used to control the irrigation, and a Raspberry Pi camera system was used to capture the real-time images for monitoring the rice growth and development. A web server was developed to upload and display the sensor values and images using python programming language through the embedded Wi-Fi network service. The web-based monitoring system was allowed to monitor the rice field situation from anywhere and download data from the site. The existing irrigation technique would help to grow the rice in UAE desert soil environments.

1. Introduction
Rice (Oryza sativa L.) is the prevalent irrigated crop in agriculture and one of the popular arable crops in the world. It is cultivated in more than 100 countries, and the covered area is approximately 158 million hectares globally, which produces 700 million tons of rice annually [1]. It is predicted that more rice production is required to meet the hunger of the increasing population in the world. This goal may be achieved by improving the rice production system and extending the available agricultural land for rice cultivation, even under significant climate threats. The arid desert soil, contemplated economically unimportant [2], can provide more space for rice production. Even though the environmental and socioeconomic factors are the most considerable parameters for growing rice in barren desert soil, coupled with the water scarcity and low productivity. The UAE is considered as a top rice importer globally due to the extensive demand throughout the country. Recently, the government is determined
to grow rice in the UAE desert land with special varieties and characteristics such as the ability to tolerate heat, salinity, and poor soil conditions [3]. In this region, the most important limitation is to provide the available irrigation water for growing the water-intensive rice crops, because more than 70% of water is used in UAE for irrigation purposes, where only 6.5% of suitable farming purposes [4]. Hence, the challenge is to grow rice in UAE desert soil by practicing the smart irrigation system for minimizing water loss and increasing rice productivity.

Several irrigation techniques were developed for increasing water use efficiency and reduce water losses. In general, most of the farmers use flood irrigation for growing the rice crops, which increases the water loss due to percolation, seepage, and evapotranspiration. The flood-irrigated rice consumed more than 45% of 90% of total freshwater used for agricultural activities [5, 6]. The drip irrigation technique is developed to decrease the water outflow during the rice cultivations, and it may save up to 25% volume of irrigated water [7]. The automatic sprinkler system was developed based on the real-time water contents of soils [8]. The IoT system was applied to minimize the excessive water loss and controlled the system remotely. In this situation, irrigation scheduling is important for observing the rice growth and necessary parameters in desert soils. Otherwise, it would be difficult to manage the rice water requirements manually due to the poor water holding capacity of the desert soils. Moreover, the automatic image acquisition and irrigation monitoring and control system would help to overcome these difficulties. The wireless monitoring system ensured long-range communication and allowed access from anywhere in the world [9, 10].

Internet of Things (IoT) is widely used in agriculture fields, especially for monitoring and control cultivation systems remotely. The various wireless communication technologies are being applied in IoT-based agriculture [11]. The network layer carried out the activities through the microprocessor or microcontroller, which collects the real-time data, processes, and transfers those using the various transporting media, such as ZigBee, near field communication (NFC), general packet radio service (GPRS), and global system for mobile communications (GSM), IEEE-802.11, Wi-Fi, 3G/4G/5G, and Bluetooth [12]. Nowadays, several types of research were conducted using low-cost microcontrollers, e.g., Raspberry Pi, Arduino including IoT platforms for automatic, on-site, and remotely monitoring purposes via web-based applications to enhance agricultural production [13-17]. These systems can also be installed easily in the rice field for monitoring and control the irrigation water according to crop water requirements. Therefore, the objective of this study was to develop an automated data acquisition (DAQ) system for irrigation control and image acquisition under the UAE desert soil condition using Raspberry Pi along with the real-time monitor of the water content levels, pump status, and captured images using a web server.

2. Materials and methods

2.1. System description

The ICT-based drip irrigation controlling and monitoring concepts were designed in the view of cultivating rice in the UAE desert soil. The system consisted of a water pump, sand filter, water flow meter, Raspberry Pi camera, drip irrigation set up, and a DAQ-box. The conceptual design of the proposed irrigation system is shown in figure 1. The components were selected and used in the experiment by considering the desert environmental conditions.

The programmable Raspberry Pi (RPI) device was deployed to control the necessary modules and actuators to investigate the indicated parameters: soil water content characteristics, irrigation pump status, and real-time images. Figure 2 represented the overall system architecture for rice cultivation in UAE desert soil. Five water content sensors, camera modules, and actuators were interfaced with the RPI through the microcontroller. The serial peripheral interface communication protocol was used to connect the water content sensors with the RPI operating system. The soil water content sensors were used to identify the soil water content behavior at different depths of sandy soil. The irrigation pump operation was controlled based on the sensor responses to fulfill the water demand for growing rice crops in the desert soil. An RPI camera module was used to capture the real-time images. A DAQ-box
was installed to collect the sensor and camera output and upload them to the developed web server using RPI. The system was able to store and display the outcomes in the database server to monitor them remotely by the authorized user through the web-based applications.

Figure 1. Schematic diagram of ICT-based drip irrigation control and image acquisition system for rice production in UAE desert soil. Water source (1), direction of water flow (2), water pump (3), solenoid valve (4), manual control valve (5), sand filter (6), water flow controller (7), bypass line (8), soil water content sensors (9), and experimental plot (10).

Figure 2. Overall system architecture for irrigation management and rice growth monitoring.

2.2. Components used in the experiment

2.2.1. MCU platform. A small-sized single-board RPI (Raspberry Pi 3 B+, Raspberry Pi Foundation, Cambridge, England, UK) was used to develop the overall system equipped with micro USB ports, display connector, micro SD card slot, micro USB, HDMI port, audio/video jack, CPU, camera serial interface (CSI) connector, and 40 numbers of general-purpose input and output (GPIO) header. A portable micro SD card was inserted to store the necessary libraries to run the programs and save the outputs. The GPIO pins were used to interface the sensors and actuators, and the CSI camera connector allowed to attach the RPI-based camera for capturing the real-time images continually. A touch-
enabled RPI monitor (Raspberry Pi Foundation, Cambridge, England, UK) displayed the entire activities and program outcomes. The embedded Wi-Fi system helped to send the output values to the dedicated web server. A 5-V, 2.5-A power adapter was used to supply the necessary power to operate the Raspberry Pi. A circuit board, multi-wired ribbon cable, plastic channels were used for DAQ-box fabrication. A circuit breaker, voltage controller, and essential electronic components were used for fabricating the DAQ-boxes. In the study, the entire irrigation control and image acquisition system was operated by a code programmed using python language.

2.2.2. Sensors and camera module. The soil water content sensors (ECH2O EC-5, METER Group, Inc., Hopkins Ct. Pullman, USA) were used to measure the sandy soil water content levels in the desert environment. The RPI operating system (OS) was helped to obtain the water content values from the rice-growing field and control the watering application. The water content sensors used in the experiment provided the analog signals where the Raspberry Pi was unable to read the analog inputs directly. However, a microcontroller (MCP3008, Adafruit Microchip Technology Inc., Arizona, USA) equipped with 8 input channels and a 10-bit resolution analog to digital converter was used to preprocess the analog signals to digital signals. On the other hand, a 12.3 MP RPI camera (Raspberry Pi Foundation, Cambridge, England, UK) was used to capture the images from the experimental rice field for real-time monitoring. A 2 m long RPI camera module ribbon cable was used to fix the camera with the embedded camera connecting port.

2.2.3. Actuators. A water pump (FL-43, Guanzhou White Whale Mechanical Co., Ltd., Guangdong, China) was used for irrigating water in the experimental plots. The two relay modules were used to operate a switch to control several circuits by one signal. It allowed the circuit to turn on or off supplying the low and the high-voltage power by controlling the loads. In the study, the relay module acted as a switch. A solenoid valve (2W-320-32, Royal Supply Chain Management Ltd., Hongkong, China) was used to control the water flow through the water pipes. A 220V AC power supply was used to operate the 24V DC-powered solenoid valve with the help of relay modules. A sand filter (GLA100, Ningbo Irriplast Irrigation Systems Co., Ltd., Zhejiang, China) was used to remove the impurities by lowering the contamination of water using a fine physical barrier, a chemical process, or a biological process. In a sandy soil irrigation management system, the filters cleaned water from different extents of sand particles for agricultural irrigation. A digital water flow meter (DigiFlow 8800T, Savant Electronics Inc., Taiwan) was measured and displayed the irrigation flow rate in l/min.

2.3. Irrigation control and image acquisition process
The introduced irrigation logic worked depending on the real-time sensing values through the commercial soil water content sensors. It was developed and executed for controlling the ICT-based automatic irrigation system for the experimental rice plots. The RPI, a low-cost programmable single-board computer, was used as the main controlling device for regulating the sensor-based automatic irrigation regarding the preferable water application rates. The irrigation controlling flow chart was shown in figure 3. In the experiment, the proposed algorithm controlled the pump and valves based on the soil water content percentages. The RPI device was started with successful connections and communicates with multiple water content sensors through the developed program. The program was executed according to the output response of the five water content sensors at different depths, displayed in the RPI monitor, and calculated the average values following the input command.

In the study, the desired water level was assumed and fixed at 30% for growing the rice in the desert environment. The developed system monitored the ICT-based irrigation status according to the fixed water level percentages, when the average water level became lower than the fixed water level the pump and valve automatically started and extended up to target irrigation. On the other hand, when the average water level exceeded the limit, the actuators automatically stopped irrigating the rice plot. After initializing the program, the RPI camera captured the images according to the function loop. The RPI camera captured the images at every 30 minutes interval and sent the images to the server for storage.
and further processing. The overall process was continued effectively up to any problem that occurred during the experiment.

**Figure 3.** Irrigation control and image acquisition flow chart.

### 2.4. System installation and experimental procedure

The DAQ-system along with the RPI camera was installed inside the Al-Foah experimental net house (24° 21' 38" N, and 55° 48' 05" E) under the United Arab Emirates University, Al-Ain, UAE, to monitor the real-time system workability easily and conveniently (Fig. 4a–b). The experimental net house covered by 315 m² area was selected and prepared for cultivating the rice in the desert soil environment. The total area of the net house was split into four separated plots, where one plot was used for conducting the experimental test. The performance of the system was evaluated from October 2019 to February 2020 during the rice cultivation period in the winter season with the desert-friendly rice variety. The drip irrigation method was applied for growing the rice in the desert soil. The dripper lines were arranged laterally with a 0.3-m spacing, and the space between water emitters was 0.2 m. The selected irrigation method was designed for ensuring water coverage, and it showed successful performances throughout the experimental period. The experimental plot was prepared manually and visited by the assigned assistant regularly to investigate the overall systems. Figure 4c shows the installed DAQ box in the net house along with its components. Soil water content sensors were placed into five different depths of 10, 20, 30, 40, and 50 cm, respectively, to investigate the water percentages in the particular depths in
the desert soil. Besides, the RPI-based camera was used to check the rice growth thoroughly and monitor the irrigation mismanagement inside the experimental net house.

![Image](image_url)

**Figure 4.** The experimental site (a), DAQ-box installation with RPI camera inside the net house (b), and assembly of DAQ-box (c): Raspberry Pi display screen (1), fabrication channel (2), ribbon cable (3), circuit board (4), sensor connectors (5), power supply (6), cooling fan (7), analog to digital converter (8), relays (9), voltage controller (10), and circuit breaker (11).

3. Results and discussion

3.1. Evaluation of irrigation monitoring system and control

The output values (\%) of the soil water content sensors were sent on a Linux-based VPS (Virtual Private Server) web server through an embedded Wi-Fi network system using python programming language. Figure 5a shows the developed sensors dashboard for monitoring the soil water contents at five different depths of sandy soil. It displayed in the server site and indicated columns of sv1, sv2, sv3, sv4, and sv5 for marking the soil water content values at 10, 20, 30, 40, and 50 cm depths, respectively.

![Image](image_url)

**Figure 5.** Outcomes snapshot of sensor dashboard in the website (a), and the pump status execution based on the soil water content requirement (b).

3.2. Real-time monitoring of the rice plot using Raspberry Pi camera

The RPI-based real-time monitoring system was developed using the RPI camera module for observing the rice cultivation inside the net house. The modified RPI camera coding was able to operate the camera application. The assigned camera captured the field images at every 30 minutes interval and sent them to the dedicated web server. The mentioned webserver stored the captured images and saved them as a stream history folder shown in figure 6a on the website dashboard. The RPI camera module, indicated as Cam-1, was assigned for monitoring the experimental rice field irrigation situation continuously.
Figure 6 shows the developed dashboard for monitoring and storage the captured images through the RPI camera. The stored images were used to monitor the abnormality of irrigation and rice-growing activities visually. Although, a single RPI camera was able to monitor the irrigation inconveniences and rice plots with low coverage, a multi-camera interface with the RPI device can improve the monitoring performance of a large area and be used for security purposes as well. For getting the better performance of the picture, different types of Pi cameras were used for evaluating the image quality. A night vision Pi camera was also experimented but it showed poor picture quality at night time. The good quality of the pictures was depended on some factors including camera position, lens, camera resolutions, and size of sensors. In the study, a 12.3 MP RPI camera showed better performances with clear site viewing in the daytime to monitor the rice-growing plot according to the irrigation requirement.

Figure 6. Developed dashboard for image monitoring and storage (a), and a sample of storage images (b).

4. Conclusions
The developed DAQ system was able to control the irrigation, captured the images, and monitored the soil and rice growth remotely. This system was designed with a small-sized RPI, which can be readily configured. It allowed the different open-source packages integrated with the wireless sensor network and database web server. The system can be deployed to provide the long-term monitoring of rice growth in desert soil conditions. The ICT-based operating system controlled the sensors, camera module, and actuator activities and was responsible for timely irrigation by controlling the solenoid valves through the relay (on/off) activities. A farmer can easily operate the overall techniques with less skill and costs. Though the existing system was performed well for the small-sized experimental rice-growing field in the desert soil environment, further improvement would help to make the system more reliable and adapt for commercial applications.

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