THE APPLICATION OF SMART IRRIGATION SYSTEMS ON PADDY CULTIVATION: A REVIEW

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Abstract

Water scarcity and inefficient water use in agriculture demand innovative solutions such as intelligent irrigation. This article evaluates the various facets of implementing these systems in paddy fields, focusing on advancements, benefits, and challenges. The study highlights sensor-based technologies, weather forecasting integration, and automated irrigation control as key components of smart irrigation systems. These technologies offer precise and demand-driven water delivery, optimising water usage, and increasing yield. In addition, the review discusses environmental sustainability, economic considerations, and farmer acceptance as important factors in system adoption. This review highlights the transformative potential of smart irrigation systems in enhancing paddy cultivation's productivity and resource efficiency, highlighting the need for continued research and practical application to ensure sustainable agricultural practises.

Keywords: smart irrigation system, Internet of Things (IoT), wireless personal network (WPN), smart sensor, paddy

Introduction

Paddy, scientifically known as *Oryza sativa*, is a staple crop in most of Asia, the Caribbean, and Latin America. Paddy crops' growth needs an adequate amount of water to produce high yields. It is crucial to maintain an adequate water level to maintain optimum growth for the paddy. Water stress due to a water shortage in paddy fields can lead to poor root development and decrease the number of panicles and grains, resulting in a decrease in yield (Chen et al., 2023).

Occasionally, Malaysia's tropical climate is humid throughout the year, with the mean annual rainfall being approximately 2540 mm and uniform high temperatures ranging from 23 to 32 ^{o}C, causing water levels to fluctuate. Water is a very important limiting factor for paddy growth and development. The depletion of water resources due to climate change is expected to have significant impacts on soil fertility and crop productivity. The shortage of water supply can cause a decrease in rice growth index, quality, and yield (Zhang et al., 2023). In order to improve the water efficiency of rice cultivation, several innovative irrigation technologies and management systems have been developed recently (Arouna et al., 2023). However, there are some knowledge gaps in adapting these technologies for rice farming, which include irrigation water use efficiency and water saving effectiveness. Moreover, different regions might have impacts on the adaptability of the technology due to the variations in climate and soil conditions. Therefore, it is essential to review the potential of smart irrigation systems to be adapted for rice cultivation. This article reviewed the performance and potential features of irrigation systems that relate to water use efficiency and rice yield to promote their suitability for the rice industry in Malaysia.

Overview of Irrigation System

Rice production requires a high amount of water for their irrigation system. Water is an important plant growth limiting factor that has an impact on rice quality and productivity (Yang et al., 2019). There are several natural water sources that can be utilised in irrigating the field area, which includes rivers and lakes. The depletion of water supplies due to water pollution, soil degradation, and the global warming crisis can lead to a shortage of rice production. Research on innovative irrigation systems to increase the water efficiency for rice cultivation is crucially required as a solution to water resource scarcity (Suwanmaneepong et al., 2023; Erejepovich et al., 2022). The smart irrigation system for rice cultivation also promotes sustainable rice production by reducing greenhouse gas emissions and fertiliser losses (Chen et al., 2022). In addition, the application of technology in irrigation systems will benefit farmers by increasing their work productivity. The adaptation of this technology can increase the amount of real-time data on the crop and the remote monitoring and control of farmers (Elsayed et al., 2021).

There are a variety of water-saving technologies for diverse crops, ranging from basic to complex systems. This smart agriculture technology requires the adaptation of artificial intelligence (AI) and Internet of Things (IoT) for efficient water management. It is able to address many issues related to crop production by monitoring possible factors, from climate changes to soil properties. The Internet of Things (IoT) technology has the capability to link a variety of sensors into a system by using the Internet to be operated automatically (Kumar & Periasamy, 2021). The data from different sensing devices will be collected using wireless sensor networks (WSNs). In order to use this technology, a complete system is required to include ground sensors, control systems, automated devices, information and communication technology (ICT), and cloud services. The availability of high-speed internet and advanced devices are additional benefits for smart agriculture management. Smart agriculture technology that is related to the irrigation system for paddy consists of four main components: moisture and water level monitoring systems, water valve systems, unmanned ground vehicles (UGV), and mobile and cloud-based solutions (Srivinas and Sangeetha, 2021). In adapting the technology, there are six basic pieces of software or hardware required to run the system, as described in **Table 1** for each item.

Table 1 Software or hardware for paddy smart system irrigation

Software/hardware	Description
Moisture sensor	It measures the moisture percentage of soil and transmit the data to the PIC Microcontroller via ZigBee for opening and closing of the solenoid valve.
Water level sensor	It measures the water level and transmits the data to the PIC Microcontroller via ZigBee for opening and closing of the solenoid valve.
Microcontroller	It receives and processes the data by comparing the values to control the valve opening and closing.
ZigBee	It transmits the data wirelessly to the microcontroller.
Solenoid Valve	It receives the electric pulse from the microcontroller to open the valve or remain closed.
GSM Modem	It is a wireless modem.

Moisture and Water Level Monitoring System

This method is developed to automate the control of water flow in paddy fields by using moisture and water level monitoring systems. Traditionally, the water flow from one area to another is directed manually by the farmers. This technique needs manpower, as the farmer must be present at the site. Otherwise, it can lead to water wastage if not managed properly. In addition, the water level for each stage of the paddy life cycle is different. Therefore, it is crucial to monitor the field water level based on the paddy stage. Both low or high-water tables have an impact on paddy growth and yield performance. In smart irrigation systems, soil moisture and water level are monitored using moisture and water level sensors, respectively. Note that soil moisture is placed at the root zone of the paddy plant. The data from the sensor's readings (moisture and water level) are delivered to the microcontroller by ZigBee. Then, the data is processed by the microcontroller by comparing the threshold value with the transmitted value.

Water Valve System

Valves are important in controlling the water flow into the paddy field area. The paddy fields are divided into several sections by constructing bunds. The irrigation water flows from one section to another through an opening at the bunds. This traditional practise requires the manual removal of the bund opening when the required water level has been reached. This involves considerable manpower and is a time-consuming process to operate. Hence, the valve system is a practical solution to reduce waste and improve the water management system. In considering the suitable type of valve for agriculture, the low-cost solenoid is used to control the water in the rice irrigation system. The data on soil moisture and water level is transmitted from the microcontroller to the solenoid valve for opening or closing the valve (Coates et al., 2013). In this way, the water level in the paddy area can be maintained effectively.

Unmanned Ground Vehicle (UGV)

As the paddy field area is undulating under muddy conditions, it is difficult to place the sensors at the right location. In addition, due to the presence of different standing water levels in the paddy fields and uncertain weather conditions in tropical regions, an unmanned ground vehicle (UGV) is required to measure the water level. An unmanned ground vehicle (UGV) is a robotic vehicle used in agriculture on the ground to carry selected sensors that are related to the irrigation system. In selecting a suitable design of UGV to carry the sensors, several factors should be considered, including the type of sensors that will be carried by the UGV, the motor's speed, and the weight of all the components attached to the UGV.

Mobile and Cloud Application-based Solution

The integration of technology with ICT develops end-to-end IoT solutions. The mobile application is a web-based application that helps in operating the UGV, controlling the valves, and receiving notifications regarding the water irrigation status. In the mobile application, farmers are able to control the UGV movement that carries the water level sensors to the field area. They can also control the opening and closing of the valve for water flow direction in the field from their mobile. Commands made by the farmers on mobile applications for UGV movement and valve control are transmitted to the local server through Wi-Fi. The local service then processes and stores the raw data. The data could be any possible factors related to agriculture that depends on the available sensors, such as water level, humidity, temperature, and rain. The local server then logged and stored the processed sensor data in the system. The data were also compared with the threshold data in the system for further action of the valve. The farmers will receive notifications regarding the irrigation status of the field, such as the duration of water flow for each section, through the mobile application with convenience. The stored data can be used for the purpose of recording and further evaluating crop performance.

Smart Irrigation System

The automated irrigation system integrated with IoT and the cloud for rice cultivation could benefit the farmers in terms of water savings, yield productivity, and economic perspective. By using this technology, water is supplied to the field when only needed by the crop. This can conserve the environment by reducing water waste and chemical leaching. The system can also monitor the status of paddy data from any location at any time with a mobile device. There are varieties of smart irrigation systems that can be applied to rice cultivation. **Table 2** shows the various smart irrigation systems developed using IoT and WSN.

Table 2 Smart irrigation system

Types of smart irrigation system	Description	References
Automatic drip irrigation	The drip irrigation or commonly known as micro irrigation, supplies the water from water resources or tank through pressured pipes valves and drippers to the root zone. The integration of drip system with the installation of appropriate sensors with IoT and WSN enhances the irrigation system. The irrigation schedule and crop status can be monitored through a mobile phone. Environmental and soil condition can be assessed with smart sensors.	Nicholas et al., 2012; Nilesh et al., 2013; Joaquin et al., 2016; Barkunan et al., 2019
Smart alternate wetting and drying (AWD)	Alternate wetting and drying are a water saving technology with the consumption of less irrigation water when compare against conventional method for lowland rice. It is also known as a controlled and intermittent irrigation method. The installation of smart AWD tube and IoT provides real-time data on the water level at the rice field. The farmers can remotely control the individual pump by using a mobile	Siopongo et al., 2013; Lampayan et al., 2015; Wang et al., 2020; Pham et al., 2021

	application to irrigate the plant.	
Automatic sprinkler irrigation	The sprinkle irrigation is an irrigation method that uses a pressurised system to supply water to the cultivated area. For the automatic sprinkler irrigation in rice cultivation, soil water tension is monitored through a sensor. The water is automatically supplied based on the data of water pressure and soil moisture received by the microcontroller.	Vories et al., 2013; Chlapecka et al., 2021; Wasaya et al., 2022;

Water and Yield Productivity with Smart Saving Water Irrigation System

The application of smart irrigation has an impact on water and yield productivity. There has been much research conducted to study the effectiveness of this technology for water usage efficiency and crop performance. **Table 3** shows the findings of the smart irrigation system's application on water usage and crop cultivation.

Table 3 Impact of smart water saving irrigation on water and rice yield productivity

Types of smart irrigation system	Impact on water and rice yield productivity	References
Drip irrigation	The experimental framework has been developed for irrigation systems with an IoT platform. This intelligent irrigation system with model prediction can reduce water and energy consumption.	Abioye et al., 2021
	The study in Punjab, India, found that the irrigation water for rice is reduced by 48 to 53% when compared to the flood irrigation method.	Sindhu et al., 2019
	The system increased water productivity to 1.03 kg/m^3 and reduced the irrigation water consumption by 42% when compared to surface flooding at Nueva Ecija, Philippines.	Samoy-Pascual et al., 2022
Alternate wetting and drying (AWD)	The comparison between conventional and AWD technology with sensors for rice in Vietnam's Mekong Delta for paddy cultivation. The application of AWD technology resulted in precise water level measurements and moderately enhance the rice yields. The technology enhances water saving by 13 to 20% and reduced the energy cost by 25% as compared to the manual	Pham et al., 2021

	method.	
Alternate wetting and drying (AWD)	The researchers found that AWD irrigation has the highest water saving rate up to 40% and the highest grain production.	Wang et al., 2020
	Study at Pingtun, Taiwan, found that AWD demonstrated water saving of 55 to 74% as compared to the continuous flooding.	Pascual and Wang, 2016
Sprinkler irrigation	Study in Edirne, Turkey, demonstrated that the water saving rates ranged from 12.3 to 43.1% in comparison to continuous flooding. However, lower yields were reported with this method.	Cakir et al., 1998
	The water usage was reduced to 28% less than conventional flooding.	Stevens et al., 2009
Modern irrigation system (MIS) using self-developed Maxii Station (IoT-based) weather monitoring station	The water use efficiency for three types of irrigation methods were compared: modern irrigation system with IoT, alternate wetting and drying, and basin irrigation. The application of MIS exhibits better water footprints as compared to the other methods with up to 40% of reduction. The rice productivity per area is also higher than other methods.	Laphatphakkhanut et al., 2021

Performance and Opportunity Cost of Smart Irrigation System

The automated irrigation system is a potential solution to improve irrigation water usage and labour burden. The cost was found to be effective with water-saving strategies and beneficial for the long term. In addition to the cost decrease with the reduction of water consumption, human capital and electrical costs are evaluated. The application of smart irrigation reduces water pumping expenses and fuel consumption by up to 38% (Lampayan et al., 2015). A study conducted by Lee (2022) found that labour power was reduced by 19.1% with the application of automatic irrigation systems compared to the conventional method. This is an alternative solution for the shortage of manpower due to ageing factors and man's interests in the agriculture sector. The direct cost of time and travel was also reduced with the mobility of smart irrigation through mobile applications to control the irrigation in the field.

Conclusion

The application of smart irrigation systems for rice cultivation has a high potential to increase water efficiency and improve crop productivity. The proposed systems offer an automated irrigation system that works well for aiding the farmers with better water management with minimal monitoring. However, in implementing the technology in agriculture, several factors should be considered, including cost and time. By using cutting-edge technologies, a high capital cost should be expected to incur when incorporating them into the agriculture system. The complex system also requires farmers to be skilled in operating the smart irrigation systems effectively. In the long run, these challenges can be converted into opportunities as the cost decreases with a high investment return and having skilled farmers operating the system in question.

Ethics Statement

The research does not require research ethics approval.

Authors Contribution

Writing, Review and editing, Norazlina, A.S; Review and editing, Zahari, M. K. Writing, Zaini, A. Z.

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Conflict of interests

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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