Internet of Things based Smart Irrigation Control System for Paddy Field

Li-Wei Liu1,2), Mohd Hasmadi Ismail3), Yu-Min Wang4*) and Wen-Shin Lin5)

1) Department of Civil Engineering, National Pingtung University of Science and Technology, Taiwan
2) Department of Civil and Environmental Engineering, Texas A&M University, USA
3) Faculty of Forestry & Environment, Universiti Putra Malaysia, 43400 UPM, Serdang Selangor, Malaysia
4) General Research Service Center, National Pingtung University of Science and Technology, Taiwan
5) Department of Plant Industry, National Pingtung University of Science and Technology, Taiwan

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ABSTRACT

This study aimed to establish a water-saving irrigation technique-based Smart Field Cultivation Server (SFCS) for paddy field irrigation by employing information and communication technologies. The development of SFCS considered the requirement on rice growth, pest development, and fieldwork management. The proposed SFCS is equipped with a solar power supply system and consisted of sensors including illumination, air temperature, air humidity, water level, soil moisture content, soil electronic conductivity, and soil temperature. Narrowband Internet of Things (NB-IoT) is used for data transmission due to the data size and transmitting frequency. A smartphone-based application (APP) has been developed for users to monitor field environment by tabular, dashboard panel, and whisker chart box, provides multiple data display ways for different purposes. Moreover, a proposal for a water-saving irrigation technique named system of probiotics rice intensification (SPRI) has been integrated into the APP. With the developed APP, farmers will receive fieldwork reminders by calendar day that water-saving irrigation may be possibly implemented. The SFCS is not only shown ability on the field monitoring but also links the gap between the fieldwork application and modern technology.

INTRODUCTION

Due to the increment of crop demand under the growing population, it is estimated that by 2050, the world’s farmers should be producing by 70% from 2009 to satisfy the requirement (Bruinsma, 2009). To meet this situation, the water usage on crop production is assumed a dramatic rise to 4.5 trillion m3, or 45.1%, compared with the global irrigation water demand from 2005 (Addams, Boccaletti, Kerlin, & Stuchtey, 2009). Among the main crops worldwide, rice (Oryza sativa L.) is the second-highest produced crop in terms of harvested yield after maize for about 4 billion people globally (Awika, 2011). However, rice production has an enormous water requirement compared with other major crops (Chen, Xie, & Fu, 2015). The average water consumption during rice production is as high as 3419 l/kg, which is much higher than other crops such as wheat (1334 l/kg) and barley (1338 l/kg, Chapagain & Hoekstra, 2004), and utilized in about 30% of the World’s irrigated cropland (Dawe, 2005). Besides, under the water resources deficit threat of climate change, water consumption becomes a severe issue that causes rice production to be no longer cultivated in past empirical experience (Mohanty, 2009). Therefore, researchers focus on irrigation to cope with the agricultural water shortage and ensure food production (Pascual, 2016). Lowering water demand in paddy fields is a viable solution to conserve limited water resources. Radical changes and techniques were being adopted so far to increase water productivity in rice cultivation. Many impressive water-saving techniques have been established worldwide and reveal significant ability on water usage efficient enhancement.
compare with conventional continuous flooding irrigation (CF), e.g. alternate wetting and drying (AWD, Chlapecka, Hardke, Roberts, Mann, & Ablao, 2021; Pascual & Wang, 2017), semi-dry cultivation (SDC, Mao, 2001), a system of rice intensification (SRI, Uphoff, Kassam, & Harwood, 2011; Zoundou, Chen, & Wang, 2019), etc.

Although water-saving irrigation technology is more beneficial than CF, it is more complicated and difficult for farmers to adopt in their paddy fields due to the complete growth management (Moser & Barrett, 2003). Face to this situation, Battilani (2013) noticed that more reliable information systems and expert capabilities are needed to guide farmers to increase farmers’ willingness to use water-saving irrigation. Levidow et al. (2014) pointed out that a smart cultivation system provides farmers with a simple, instant, easy-to-use, free system to help farmers determine the daily irrigation amount and provide many crops possible to promote water-saving irrigation technologies and increase the utilization rate. Although there are many studies on developing and using Internet of Things (IoT) technology to help rice paddy field observation and automatic fieldwork operation, there only a few studies have been found integrating IoT and irrigation on an integer system (Bamurigire, Vodacek, Valko, & Rutabayiro Ngoga, 2020; Krishnan et al., 2020), especially in advanced Narrowband IoT (NB-IoT) technique and application guideline on water-saving irrigation. Due to the water-saving irrigation has considerable benefits to the environment and the income of farmers, this study is focusing on modern technology to develop paddy field observation equipment with smartphone-based real-time field data display system and cultivation calendar notification based on NB-IoT, to decrease the threshold for farmers to conduct water-saving irrigation technology. This study is focusing on the following objectives: (1) to develop a solar power-based continuous field environment observation server by low-cost NB-IoT data communication system for paddy field data collection; (2) to establish a smartphone-based application (APP) for displaying field real-time environment data; (3) to program a cultivation notification calendar APP for farmers easily conducting water-saving irrigation techniques.

**MATERIALS AND METHODS**

The NB-IoT-based paddy field environment monitoring system, called Smart Field Cultivation Server (SFCS), consisted of 3 major parts: water-saving irrigation technique, SFCS with NB-IoT based data storage and transmitting field server, and the APP, which could be described in the following sections. The operation concept of the SFCS is illustrated in Fig. 1. After the SFCS and the APP developed, they were applied in the experimental paddy field for operation testing. The experiment sites are located at Tainan and Taitung in Southern Taiwan (Fig. 2).

![Fig. 1. SFCS operation concept.](image)
Water-saving irrigation on paddy rice field system of probiotic and rice intensification (SPRI) water-saving irrigation technique was utilized in this study, which was established based on the system of rice intensification (SRI) and probiotics techniques. SRI used the same irrigation concept as AWD that possibly promotes yield potential based on efficient water and fertilizer absorption (Chapagain & Hoekstra, 2011; Glover, 2011). In SRI operation, very young seedlings were selected for transplanting. The distance between each transplanted seeding was 25 cm and irrigation management was by AWD method. Uphoff, Anas, Rupela, Thakur, & Thiagarajan (2009) point out that the most important difference between SRI to other conventional cultivations was increased soil aeration, which led to significant promotion in soil organic matter content. SRI applicants could use machine or manual-based weeders in an appropriate fieldwork timing to improve soil aeration. The SRI
practices provided a more healthy and productive rice growth condition including soil and plant because of the strong roots system, effective absorption, and enriched soil organisms (Kassam & Brammer, 2013; Thakur, Mohanty, Patil, & Kumar, 2014). The water usage efficiency of SRI had been found significantly lower than conventional cultivations accordingly intermittent irrigation by the saved-water percentage of 39 and 47% (Fonteh, Tabi, Wariba, & Zie, 2013). In Taiwan, Pascual (2016) found that intermittent SRI irrigation of 3 days intervals could save 55% irrigation water compared with CF irrigation, and the total yield does not change significantly. Zoundou (2018) noticed that the 3 cm irrigation water depth is suitable for SRI cultivation under Southern Taiwan. More detailed SRI practices and application guidelines can be found in Uphoff (2003).

In addition, probiotics were applied in specific rice growth stages to reduce chemical fertilizer usage and maintained soil health. Besides, probiotics were found to significantly enhanced soil microorganisms, promoted the nutrient usage efficiency of the plant by solubilization and mineralization of nutrient components, especially phosphorus, N-fixation, and synthesis phytohormones (Khan, Fariduddin, & Yusuf, 2017), and leaded yield increasing (Parmar, Bhanvadia, Ramani, & Rathod, 2017). Zoundou (2019) compared multiple treatments on probiotics and chemical fertilizer and found 50% of probiotics with 50% chemical fertilizer has the best combination to mitigate the huge use of chemical fertilizers for eco-friendly agriculture. Relative research on probiotics operation mechanism and application can be found in Maheshwari (2012). The field cultivation calendar concept of SPRI water-saving irrigation, including irrigation, fertilization, probiotics-adding guidelines with corresponding rice growth status, is illustrated in Fig. 3.

**NB-IoT based smart field cultivation server (SFCS)**

The development of NB-IoT was based on Internet of Things (IoT) technology. The main advantage of NB-IoT was a lower power consumption with a slower data transmitting rate (Park, Chang, & Lee, 2017). Due to the data size, transmitting frequency, and cost of use, this study utilized NB-IoT in SFCS for data transmitting. The core network of NB-IoT including the evolved packet system (EPS), the user plane cellular internet of things (CloT) EPS optimization, and the control plane for CloT EPS optimization. The optimal pathway for control. User data packets for both uplink and downlink data were chosen in both planes. On the control plane, the evolved Universal Mobile Telecommunications Service (UMTS, 3G) terrestrial radio access network (E-UTRAN) conducted the radio communications among User Equipment (UE) and Mobility Management Entity (MME) and consisted of the evolved base stations called eNodeB. Data transmitted to the Packet Data Network Gateway (PGW) through Serving Gateway (SGW). Data transmission in IP and non-IP by radio bearers through the SGW and PGW to the application of user plane. The Packet Data Convergence Protocol (PDCP) was from layer-2 (L2) with 1600 bytes. Non-radio signals transmission between UE and the core network were by non-access stratum (NAS) of the protocol stack. The NAS provided management of security, mobility, and bearer by encrypted L2 between UE and core network (Rastogi, Saxena, Roy, & Shin, 2020). The Random-Access Channel (RACH) procedure was started with a preamble transmission. The UE re-transmitted until maximum retransmissions number reached when the preamble transmission failed. If the eNodeB received the preamble, it sent the associated random-access response from UE and started the contention resolution message is transmitted to the UE (Sinha & Park, 2017). For detailed NB-IoT principle could be found in Rastogi, Saxena, Roy, & Shin (2020). The illustrated NB-IoT operation concept was illustrated in Fig. 4.
USA). The soil temperature, moisture content (volumetric water content, VWC), and bulk electronic conductivity (EC) were detected by 5TE (Decagon Devices, Inc., WA, USA). In water level measure, it did not necessarily measure a continuous water level variation. Therefore, two capacitive water detection sensors were conducted in 0 cm and 3 cm at the bottom of the SFCS. The operation concept of the SFCS was drawn in Fig. 5.

Fig. 4. Operation architecture of NB-IoT.

Fig. 5. The composition and operation concept of the SFCS.
Smartphone-based Application (APP)

The APP was developed on the iOS system, programmed in XCode 10, based on the Swift language. In writing, the user interface is completed by using copyrighted pictures or photos taken on-site. The APP is deployed in three parts: user login system, data display program, and SPRI-based field cultivation calendar. The concept of the APP development and operation was shown in Fig. 6.

The first part of the user login system was established by the Firebase database provided by Google. Firebase is a back-end service platform for APP development. The function was integrated by existed Google cloud services and new-released data analysis, message push, notification system, error report, remote configuration, and dynamic link. Cloud data, including user information and observed field data, can be acquired based on the Firebase application programming interface (API). An E-mail address was used for new registration with a custom 6-digit number or English letter as the password. The operating structure was shown in Fig. 7 (Albertengo, Debele, Hassan, & Stramandino, 2020). In data display, all observed data is converted into a light data exchange language, JavaScript object notation (JSON), to transmit data objects.

Fig. 6. The concept of the APP development and operation.

Fig. 7. Firebase operation concept.
composed of attribute values or sequential values format. It is relatively simple for data processing in the Cloud. When the user selects a function, the request will be sent to the Cloud to retrieve required data for the advanced calculation to display data. The observation data is shown in the dashboard and tabular format for the general user. Furthermore, calculated statistical data will be used for box plot establishment. The box plot elements, including the minimum, maximum, first quartile, third quartile, and daily average value, for the user, to quickly review the data changing.

The SPRI-based field cultivation calendar, established by long-term field cultivation, results in the cultivar KH147 (Fig. 2). The rice transplanting day is set as the 0th day in the calendar. The critical irrigation operation period is from 0th day to 10th day and 64th day to 74th day for continuous flooding in 3 cm water depth, and 15th day to the end of the effective tillering stage and 74th day to 10 days before harvest is using AWD irrigation with 3 cm water depth suggested by Pascual (2016) and Zoundou (2018). It should be noticed that the dry-land process has to be conducted from the end of the effective tillering stage to the beginning of the panicle initiation stage to reduce ineffective tiller. For fertilization, topdressing is conducted on the 15th and 25th day, and adopt spike fertilizer on the 64th day. A similar probiotics application was on the 12th day and the 54th day.

RESULTS AND DISCUSSION

The SFCS includes a bracket for stabilizing the whole equipment in the paddy field, a server including a datalogger and NB-IoT modules, and a solar panel (Fig. 8a). The consisted sensor is shown in Fig. 8b to 8e, including 5TE soil temperature, soil moisture, soil bulk EC sensor, ATMOS14 environment temperature, and relative humidity sensor, QSO-S PAR illumination, and water level sensor. The specifications of selected sensors are shown in Table 1.

The established iOS-based APP interfaces are shown in Fig. 8. The user login interface has a switch button to change the user identity. Two text boxes for the user to type account and password. If the user account is not existing, the system will automatically create a new user and log in directly (Fig. 9a). For the general user, a dashboard-based data display interface is generated for users to read their field environment data (Fig. 9b). A tabular data display button located on the top-right side allows users to review their latest data by tabular format (Fig. 9c).

![Fig. 8. Illustration of developed SFCS. (a): main server, including datalogger, battery, solar power panel and controller, NB-IoT module, and antenna; (b): ATMOS14 air temperature and relative humidity sensor; (c): QSO-S PAR illumination sensor; (d): waterlevel detection sensor; (e): 5TE soil temperature, moisture content, and bulk EC sensor.](image-url)
Table 1. The sensor specification of the SFCS.

| Sensors                  | Specification                        |
|--------------------------|--------------------------------------|
| Soil moisture content    | 0%~50%                               |
| Soil electronic conductivity | 0 ~ 23 dS/m                         |
| Soil temperature         | -40°C ~ 60°C                         |
| Air temperature          | -40°C ~ 80°C                         |
| Air humidity             | 0~100%                               |
| Illumination             | 0 ~ 5000 μmol/m²/s                   |
| Waterlevel               | 3 cm                                 |

Table 1. The sensor specification of the SFCS.

| Sensors                  | Specification                        | |
|--------------------------|--------------------------------------|
| Soil moisture content    | 1%~2%                                |
| Soil electronic conductivity | ±10%                                |
| Soil temperature         | ±1°C                                 |
| Air temperature          | minimum ±0.9°C                       |
| Air humidity             | Minimum ±12%                         |
| Illumination             | ±5%                                  |
| Waterlevel               | ±5% F.S.                             |

Fig. 9. Demonstration of SFCS-based APP. (a) user login interface; (b) dashboard data display; (c) tabular data display; (d) box plot data display; (e) SPRI cultivation calendar; (f) fieldwork notification reminder.
For the advanced user, a queryable box-plot is provided. The demonstration, Fig. 9d, shows the query result on 10/06/2019, which is conducted the SFCS and SPRI water-saving irrigation technique in Tainan experiment site. A similar application is in Taitung, Taiwan, the SPRI-based fieldwork day, and the reminder notification is shown in Fig. 9e and Fig. 9f. Two pictures were taken in Tainan (Fig.10a) and Taitung (Fig.10b) experiment sites in October 2019 and June 2019, respectively.

Due to climate change and population increment, limited water has to irrigate in a larger paddy field for rice production. Higher productivity and water usage efficiency are required in the future (Wallace, 2000). Therefore, the researcher developed many high-efficient water-saving irrigation techniques to achieve the goal. Although a significant irrigation water amount has been saved, these techniques are relatively complex and time-consuming (Moser & Barrett, 2003).

Farmers need to learn a different fieldwork knowledge compare with their long-term experience and have a higher fieldwork load. Fortunately, based on the technology’s development, several water-saving techniques based on rice production systems are established by advanced equipment and applications, e.g., Asnawi & Syukriasari (2019); Bamurigire, Vodacek, Valko, & Rutabayiro Ngoga (2020). However, these kinds of systems and related facilities typically come with a high price. Farmers who were farming in a small paddy field may not have the ability to afford the system and setup. Moreover, paddy rice cultivation is relatively complicated because of plant growth requirements. Inappropriate fieldwork has been found may reduce rice yield and quality.

Hence, this study used sensors to observe the field environment, conducted NB-IoT for data transmitting, and established a smartphone-based application for data displaying. Farmers are applying water-saving irrigation in their field and can adopt relative fieldwork according to field environment data. Furthermore, an SPRI-based fieldwork calendar in the APP has been developed for operation guiding. The fieldwork reminder notification will be sent automatically. This system provides farmers an easy way to adopt water-saving irrigation.

CONCLUSION

Rice production is the primary water usage in the world. A reliable water-saving irrigation technique can significantly reduce water consumption. The smart field cultivation system (SFCS) with probiotics and rice intensification (SPRI) based application (APP) possibly helps farmers acquire real-time field environment data without boundary limitation. Farmers can conduct the provided SPRI proposal on their paddy fields to save significant irrigation water and to promote rice yield. The gap between the fieldwork demand and modern technology has been linked by the SFCS.
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