DEVELOPMENT OF PADDY-FIELD WATER LEVEL GAGE CORRESPONDING TO A SENSOR-NETWORK
/
センサーネットワークに対応した水田水位計の開発

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ABSTRACT
This study proposes a measurement system that comprises an e-Tape water level sensor, Arduino and XBee. The system was considered a success because of the linear relation between measured voltage signals and water depths obtained by it. This linearity was essential because Arduino does not have non-linear calculation ability. As a result, the numerical order of RMSE in measuring water depth using this system was obtained as 3.52 mm. For measuring water consumption for 1 day at the standard scale of paddy fields in Japan, water consumption can be estimated using the system below non-flowing water surfaces. However, when there is water flow, it will be difficult to estimate water consumption because discharge errors may be cumulative.

摘要
この研究では，e-Tape 水位センサーと Arduino および XBee で構成される測定システムを提案している。 このシステムは，測定された電圧信号とそれによって得られた水深との間の線形関係のために妥当と見なされた。 Arduino には非線形計算機能がないため，この線形性は不可欠であった。結果的に，このシステムを使用して水深を測定した際の誤差 RMSE の数値の大きさは 3.52mm であった。日本の標準規模の水田で 1 日の減水深を測定する場合，それは流れのない水面下でシステムを使用して推定できることが示された。ただし，流れがある場合には，流量の誤差が累積する可能性があるため，減水深の推定が困難になると考察された。

INTRODUCTION
The importance of monitoring and predicting the impact of multiple factors in situ is often discussed. The charging of electric vehicles in smart grid cities can be monitored using predictive models, which can be used to manage energy distribution and lead to effective and efficient use of energy (*Park et al., 2011*). An energy distribution system (SMAS) will be beneficial to the industry and for home energy management. Sometimes, the prediction of solar-powered off-grid surface water quality is discussed for power management purposes (*Khalid et al., 2016*). In this regard, a wireless sensor grid is recommended for monitoring purposes. Wireless sensor network technology is used in water tank filling and management applications (*Mughal et al., 2014*). As one of the merits of predictive models, tidal movements can be accurately monitored.

Moreover, modeling in lowland paddy fields is proposed. For this discussion, sometimes, for the paddy, the development of the model is shown by a partially urbanized agricultural watershed. Presently, the use of water varies because of changes in cropping systems and the consolidation of farmworkers. Hence, these changes should be considered when constructing irrigation systems for paddy fields. From a water manager's viewpoint, the management of water resources is changing from the conventional supply-driven type to an end-user-based demand-driven type. Furthermore, farmers who are end users are increasingly cultivating their land in a centralized manner, thus making it difficult to achieve accurate water management and circulation was performed in the past. Moreover, in their rice fields, farmers may be uncertain whether there is water, thus increasing the requirement for the remote monitoring of farmlands. *Tanji et al, (2010),* proposed a smart grid for paddy field irrigation to prevent possible drought, reduce water costs, and ensure the availability of water at any time. The smart grid used information technology to efficiently operate and manage energy distribution. Paddy field meters were also used in the smart grid to monitor water distribution and drainage in the paddy field irrigation system and to select appropriate water contents for the paddy field. Furthermore, *Hirafuji et al.*

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(2013) developed an open source field server (Open-FS) using Arduino, which is an open-source hardware. The authors aimed to collect, visualize, and share measured data using the Open-FS at a low cost. The authors proposed a “sensor cloud system,” which comprises an existing cloud service (Twitter, etc.) and browser written in HTML5.

By installing JPEG cameras and XBee on an Arduino board, an inexpensive smart sensor was built that has a wireless communication function that can be practically used even in agriculture (*Ito and Kawakita, 2013*). “Arduino” is an open-source hardware and software company, project, and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices. Its products are licensed under the GNU Lesser General Public License or the GNU General Public License, thus permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are commercially available in a preassembled form or as do-it-yourself kits. Digi XBee is the brand name of a family of form factor compatible radio modules from Digi International. e-Tape is the name of a water level sensor made by Milone Technologies.

This study is a reprint of a previous study (*Ito, 2014*). Note that approximately six years have elapsed since this worked was examined. The demand and spread of information and communication technology (ICT) is on the rise. However, the practical use of ICT in actual fields is still extremely low (such as, *Kameoka et al., 2017, Madushanki et al., 2019, Ito and Yamaguchi, 2019, Tsukahara et al., 2020*). Particularly, the use of image processing in farmlands, as introduced in this study, is unpopular. One of the most important tasks for farmers is to monitor the growing condition of crops. Therefore, this study is a contribution to agriculture. However, certain researchers who are not directly involved in agriculture do not see the merits of using ICT in this regard. To that end, we introduce our research contents and hope to receive the opinions of multiple readers. In future, if a multi-node system is developed, it can be used for both water-saving irrigation and automatic gate operation associated with rotary irrigation. As a premise for the provision of a multi-node system, a single system must be constructed.

MATERIALS AND METHODS

OBJECTIVE

To perform water-saving irrigation, an Arduino board is installed at each node to monitor water depth. However, the conversion of water depth information to voltage information using complex equations is challenging (nonlinear calculation is impossible to handle). Therefore, the aim in this study is to construct a system in which a personal computer is used to remotely receive water depth information from the e-Tape-Arduino-XBee set. Furthermore, we require to measure the relationship between the output voltage from the A-D conversion system in Arduino (digitalized analog value) and water depth information to examine the linearity of this relationship.

This research aims to develop a water level gage for the management and monitoring of water level in paddy fields using the abovementioned technologies by developing and analysing the detail of the paddy field system, which is based on Arduino and XBee. The second aim of this study is to assess the potential of the system for measuring water consumption by discussing the methodology used by the system.

Although the system’s monitoring and management capabilities using input information and radio information can be expected, the implementation of the e-Tape water depth sensor for measuring water depth in paddy fields was not very clear. Therefore, the detail between water depth and analog voltage for this system is carefully measured and explained in the following experiment section.

EXPERIMENTS

During the design process, several interviews were conducted to understand the requirements of the study site managed by the legal entity of Mie Prefecture’s Land-Improvement-District (LID). This district has a beneficiary area of ~3,183 ha, which is classified as a medium-sized land improvement zone and has many small-scale farmers as inhabitants, and there are blocks with open channel sections to the end. Based on interviews with the staff of LID in Mie Prefecture, it was stated: "We cannot grasp the flow rate, especially, in the open channel section, so the number of patrols of the branch water channel will increase in a drought year like last year." Accordingly, "The needs for a function to automatically measure the water intake at the terminal paddy field transfer data to the management office is high." To develop a paddy water level gage, Arduino and XBee were adopted as before (Fig. 1). Moreover, this information is reported in the reference (*Ito and Kawakita, 2013*). e-Tape from Milone Technologies was used to measure water levels.

This water level sensor has a resistance value that varies by water level and is priced at ~5,000 yen (~$50), which can be characterized as inexpensive (Fig. 2).

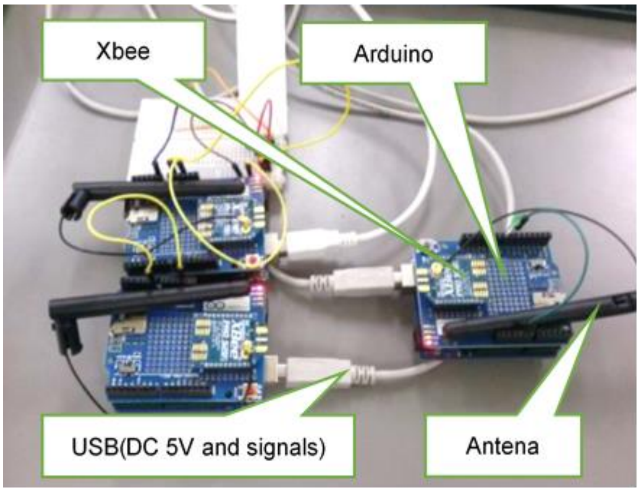

Fig. 1 - The example of multi-nodes the system prototype

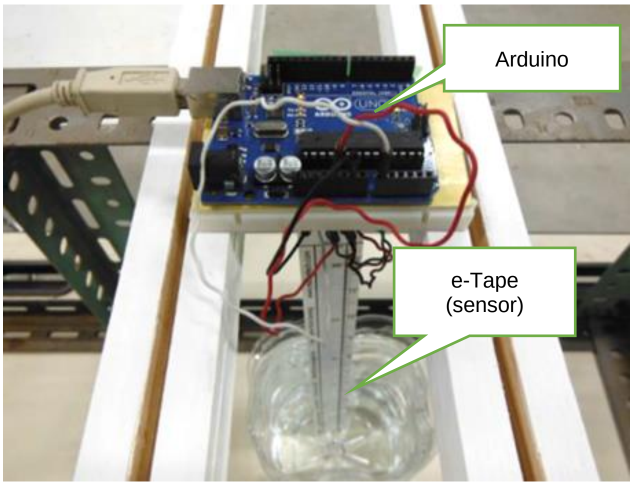

Fig. 2 - The water level sensor

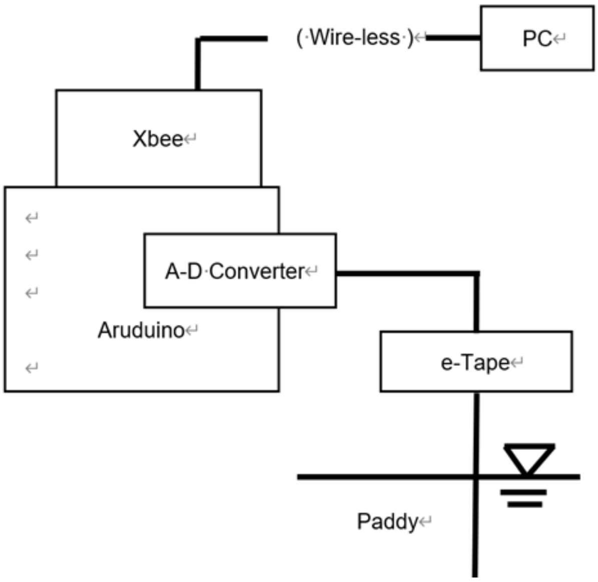

Fig. 3 - Conceptual illustration of the system for paddy

As shown in Fig. 3, the water level sensor and Arduino were connected; moreover, the water level sensor was attached to a polyethylene terephthalate bottle filled with water. The amount of water in the bottle was increased and the water level was read using a digital point gage.

Furthermore, the voltage value of the water in the bottle was measured 100 times at intervals of 1 s using Arduino. XBee, which is used to realize a one-to-one connection, can sufficiently register the individual identification (ID) number of each node and agree with the PAN ID. However, when multiple nodes are displayed as mesh networks, it is necessary to have a mechanism to identify individual nodes because this is required to broadcast packets.

RESULTS AND DISCUSSION

Using equation (1) of the A-D converter, input raw data i can be converted to an input voltage. At that time, water depth Y_{mes} will be measured, where i is the digitalized number of input voltage x (mV) obtained by the A-D converter.

$$x = 500 \times \frac{i}{i_{max}} \tag{1}$$

Fig. 4 shows the actual measurement result. The obtained ratio R^2 was 0.9951. Therefore, the liminality between water depths and voltage could be confirmed. Consequently, the following equation (3) is provided to ensure that water depth Y_{cal} is consistent with the water depth Y_{mes}.

$$Y_{mes} = the\ measured\ water\ depth\ by\ hand \tag{2}$$

$$Y_{cal} = -0.143x + 75.401 \tag{3}$$

Fig. 4 shows the relation between x and the measured water depth Y_{mes}. obtained by plots, where the obtained correlation coefficient is −0.997 (Table 1). Therefore, Fig. 4 shows a very strong negative relation between X and Y_{mes}. The *p*-value of n and R is 0.000, indicating that the relation is meaningful and significant.

By substituting measured raw data of x into equation (1), the simulated water depth Y_{cal}. (cm) can be obtained. In this manner, we can compare and discuss the difference between Y_{mes}. and Y_{cal}. Table 1 shows that the root mean square error (RSME) of Y_{mes}. and Y_{cal}. is 0.352 cm. The greatest absolute difference of Y_{mes}. and Y_{cal}. is 0.937 cm.

We connected e-Tape water level sensor to the core system using Arduino and XBee and developed a paddy level sensor corresponding to a sensor network for the management and monitoring of water levels in paddy fields. The standard order of the seepage at paddy fields seeps through at 2–3 cm/day. Therefore, in a case we obtain water depth Y_{cal}. daily, the order of the errors of 0.352 or 0.937 cm might be evaluated small.

In certain cases, it will be recommended to evaluate the obtained order of error of the calculated discharge. For this purpose, we use the following equations (4) and (5) for illustration. We can obtain the RSME or maximum error of Q_{mes}. and Q_{cal} using these equations.

$$Q_{mes} = 1.7 \times B \times (Y_{mes} - Y_{base})^{1.5} \tag{4}$$

$$Q_{cal} = 1.7 \times B \times (Y_{cal} - Y_{base})^{1.5} \tag{5}$$

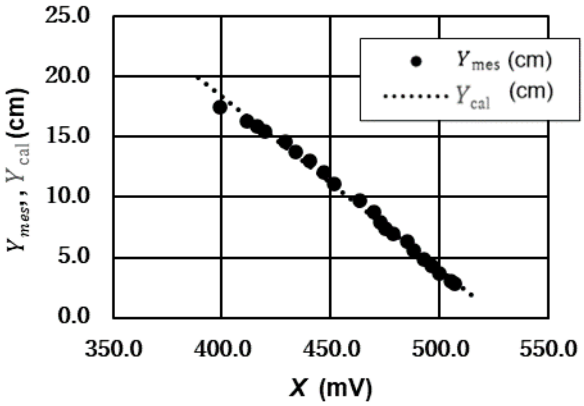

Fig. 4 - Test results

Note: black circles are the measured water depth Y_{mes} ; the dot-line is the approximate straight line of Y_{cal}

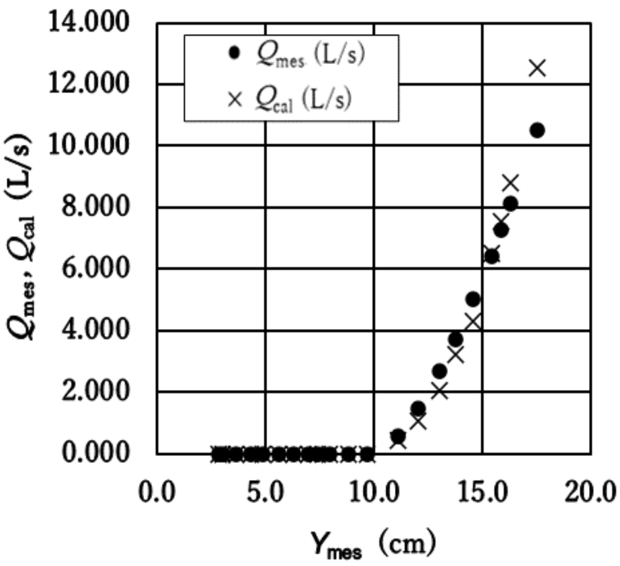

Fig. 5 - An example of the measured results

Note: Dots are Q_{mes} using equation (4), the cross marks are Q_{cal} using equation (5)

Table 1
Examples of obtained indexes in which width *B* of 0.3 (m) and Y_{base} of 0.1 m were used

Data number *n* of Y_{mes}	21	
R of *x* and Y_{mes}	−0.997	
p-value of *x* and Y_{mes}	0.000	
n of Y_{mes} or Y_{cal}	21	
RMSE of Y_{mes} and Y_{cal}	0.352	[cm]
Maximum value of | Y_{cal} - Y_{mes} |	0.937	[cm]
n of Q_{mes} or Q_{cal}	9	
RMSE of Q_{mes} and Q_{cal} (B =0.3 m, Y_{base}=0.1m)	0.812	[L/s]
Maximum value of | Q_{cal} - Q_{mes} | (*B*=0.3 m, Y_{base} =0.1m)	2.026	[L/s]

In Table 1, the RSME of Q_{mes}. and Q_{cal} is obtained as 0.812 L/s. The greatest absolute difference of Q_{mes}. and Q_{cal} is 2.026 (L/s). If we assume the area of the typical paddy field is 3000 m^2, these errors (0.812 and 2.026 L/s) will become 2.339 and 5.835 cm/day, respectively.

The order of the errors of 2.339 or 5.835 cm is almost the same compared to the standard order of the seepage at the paddy field, which is distributed from 2 to 3 cm/day.

CONCLUSIONS

We can convert input raw data to input voltage using the experimental equation of the A-D converter in Arduino. This could validate the linearity between water depth and voltage. The possibility of obtaining water depth needs to be confirmed because this system cannot perform non-linear calculations.

Consequently, the first aim of this study is to examine the potential of this system, and this was achieved with a high degree of feasibility. The numerical order of RMSE in measuring water depth using this system was obtained as 3.52 mm. To achieve the second aim of this study, we discussed the possibility of using this system to measure water consumption for 1 day based on the standard scale of paddy fields in Japan. Estimating water consumption will be possible if we can use the system below non-flowing water surfaces. Where there is water flow, it will be difficult because the error of discharge may be cumulative.

The equation shown in Fig. 3 can be used in a personal computer after a measured analog value has been inputted into the PC using Arduino and Xbee. Analysis can be conducted simply because the equation did not display the curving line. Moreover, a sensor network can be constructed by assigning and transmitting an identification (ID) number to each sensor node so that data from several sensor nodes can be identified. Therefore, high accuracy for practical use has been obtained. Moreover, a sensor network can be constructed by assigning and transmitting an ID number to each sensor node so that data from several sensor nodes can be identified. Moreover, the accuracy in measuring water levels was sufficiently high, and data communication between multiple nodes was possible. Furthermore, the model that was prototyped in this study achieved the initial target price.

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