바이오시스템공학(*J. of Biosystems Engr.*)
Vol. 29. No. 3, pp. 243~250 (2004)

미곡 도정공장의 인터넷 기반 감시시스템 개발

Development of an Internet-based Monitoring System of a Rice Processing Complex

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적 요

본 연구에서는 국내 미곡도정공장의 도정기계 작동상태와 가공된 쌀 품질의 원격감시를 위해서 인터넷기반 감시시스템을 개발하고자 하였다. 인터넷 감시시스템은 Laboratory Virtual Instrument Engineering Workbench(LabVIEW)를 이용하여 개발되었으며 Hypertext Transfer Protocol(HTTP)을 제공할 수 있는 중앙서버, 현장제어용 Programmable logic controller (PLC) 및 각종 센서 등으로 구성되었다. 비상상태를 대비하기 위하여 도정기계를 원격으로 제어(ON/OFF)할 수 있도록 제어알고리즘을 설계하였다. 개발된 인터넷기반 감시시스템은 미곡 도정공장에 설치한 모든 도정기계의 작동상태, 백미 탱크내의 백미 무게와 백미의 온도 및 평형상대습도를 실시간으로 감시할 수 있었으며, 원격으로 측정한 백미탱크내의 평형온도 및 평형상대습도를 이용하여 백미의 함수율도 예측할 수 있었다. 거리 및 인터넷속도에 의해 발생된 시간지연의 측정과 원격으로 수집된 자료의 검증을 통해 인터넷 감시시스템의 성능을 평가하였다. 인터넷상의 시간지연(서울-광주간)은 약 1.2 ± 0.2 s이었다.

Keywords : Internet-based monitoring system, Equilibrium temperature and moisture content, Rice processing complex.

1. INTRODUCTION

Korean agriculture is confronting the challenges from foreign agricultural products since Korea joined in World Trade Organization. As rice is a major staple crop in Korea, it is very important to make native rice products more competitive. One of the most effective ways is to improve the automation of rice processing complexes (RPC).

Currently, about 90 percent of the RPCs are mainly controlled by local monitoring and control systems. The Internet is the world's largest powerful computer network connecting personal computers, sophisticated mainframes, and supercomputers around the globe(Tan and Soh, 2001). Korea has the highest per capita broadband penetration in the world, and more than half of her households have high-bandwidth Internet connections. Therefore, the advanced network infrastructure makes it possible to develop an Internet-based monitoring system to modernize the Korean agricultural industry.

In fact, operators usually have to watch in front of the central or local control panel to control each machine and to monitor the status of these machines. Such an operating method makes the management of the overall operation in a RPC limited and inconvenient. Moreover, paddy is processed into milled rice by various machinery causing noisy working conditions that make operators very stressful. An Internet-based system can monitor the status of machinery, quality of rice in the bin and can also be used under an emergency condition of a RPC.

In order to reduce labor costs and to improve the automation and management level of a RPC, the rice quality has to be measured remotely and accurately on line. Moisture content is one of the most important

This study was conducted by the research fund supported by Agricultural R&D Promotion Center. The authors are Jong Hoon Chung, Professor, T. Y. Yan, Graduate Student, Dept. of Biosystems and Agricultural Engineering, Inst. of Ag. Sci. and Tech. Chonnam National University, Gwangju, Korea. The article was submitted for publication in May 2004; reviewed and approved for publication by the editorial board of KSAM in June 2004.
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factors related to the quality and shelf life of rice products. Equilibrium air temperature and equilibrium relative humidity in a silo containing milled rice are usually measured to predict the moisture content of milled rice, however, currently the factors are manually collected in most RPCs. These parameters can be monitored by an Internet-based monitoring system to provide the information on rice quality to managers out of the RPC on line.

In 1997, the first Internet-based monitoring system was demonstrated by Kevin Brady at the International Conference on Robotics and Automation, who successfully controlled the motions of a Puma robot in his laboratory more than 1,500 kilometers away(Fitzpatrick, 1999). The contribution opened new horizons of the Internet applications. Since then, some researches have been aimed at developing systematic design methods for the design of an Internet-based monitoring system. So far, some Internet-based monitoring systems have been found in agricultural industry. Chung et al.(2000) developed an automatic environment control system for a low temperature warehouse to preserve the quality of stored agricultural products. According to their report, this system could automatically control storage conditions such as air temperature, relative humidity, and carbon dioxide gas concentration. The farmers could monitor the conditions inside the warehouse at home via the Internet. When an abnormal condition occurred, the system alarmed the user via telephone or beeper. Park et al. (2000) developed a remote monitoring and control system based on the mobile Internet through Transmission Control Protocol/Internet Protocol(TCP/IP). It was reported that the system could monitor and control the machines as well as the crucial variables such as air temperature, moisture content, etc. in a greenhouse through a Personal Digital Assistant(PDA). When there were problems in the greenhouse, warning messages could be sent to a manager's PDA, and environmental conditions could be monitored and controlled by the greenhouse manager via the Internet.

The main objective of this study was to develop and evaluate an Internet-based monitoring system for a RPC. The specific objectives were to: 1) develop an Internet-based system for monitoring and controlling(ON/OFF control) all the machinery in a RPC; 2) monitor the weight of white rice in silo and equilibrium air temperature, equilibrium air relative humidity surrounding the white rice; 3) predict the moisture content of the white rice in a storage silo and to validate it.

2. MATERIALS AND METHOD

A. Brief description of RPC

This study was conducted at the RPC of Chonnam National University. The main processes of the RPC are cleaning, hulling, polishing, and packing processes as shown in Fig. 1. A paddy cleaner, a general de-stoner, and a paddy bin were used for the cleaning process of paddy, and a huller, a screen sorter, a brown rice separator, a thickness grader, and a brown rice de-stoner for the hulling process. The polishing process was

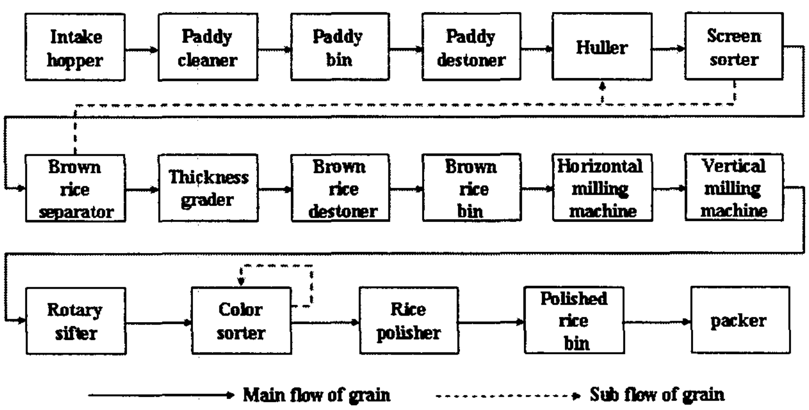


Fig. 1 The block diagram of the RPC of Chonnam National University.

performed using a horizontal milling machine, a vertical milling machine, a rotary sifter, a color sorter, and a polisher. And the packing process was done using an automatic vinyl packer. Originally, the processes were locally controlled by a programmable logic controller (PLC) system, which consisted of a PLC, relay switches, level sensors, electrical contactors, etc.

B. System software

The schematic diagram of the Internet-based monitoring system is shown in Fig. 2. The important components used in this system were 1) a PLC(Model: Master-K200, LG Industrial Systems, Korea) served as a front-end-control unit; 2) a 1.2 GHz central computer, which provided a Hypertext Transfer Protocol(HTTP) service for the remote monitoring and control via the Internet; 3) a data acquisition card(Model: Lab-PC-1200, National Instrument Co., USA) utilized for monitoring the air temperature, relative humidity, and weight of milled rice in the bin.

Laboratory Virtual Instrument Engineering Workbench (LabVIEW 6.1, National Instrument Co., USA) language was used to design the main algorithm of the proposed Internet-based monitoring system(National Instrument Co., 1998). The essential subroutines of the system consisted of: 1) subroutines for monitoring the machine status(Fig. 3); 2) subroutines for controlling each machine remotely (Fig. 4); 3) a subroutine for sensing weight, air temperature, and air relative humidity; 4) a calibration subroutine for improving the accuracy of the predicted moisture content. Table 1 briefly summarizes the main functions used in the algorithm. To monitor the machine status and to control all the machines connected to the front-end-control unit, the read and write protocols for the PLC communication module were applied in the algorithm to exchange data and control signals between the central computer and the PLC. Furthermore, to monitor and control the mill via the Internet, the above subroutines of the Internet-based monitoring system were converted using a 'web publishing' function so that they could be executed through a web browser. A graphical user interface of the control system was developed and embedded in a standard web browser. The detailed configurations of the HTTP server, upon which the Internet-based monitoring system were based, were: 1) IP address of the HTTP server was 168.131.70.54; 2) access type: monitor or control; 3) HTTP port was 80.

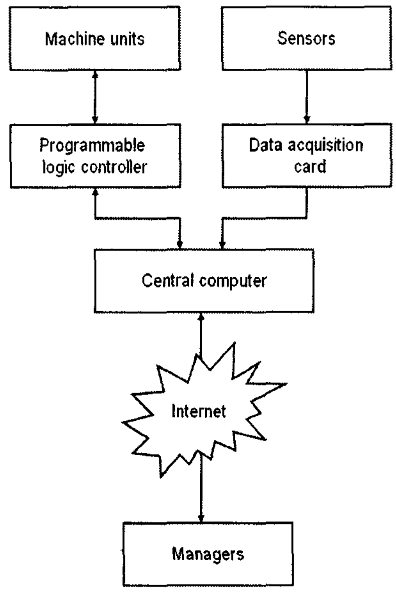
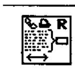
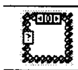
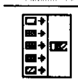


Fig. 2 Schematic diagram of the Internet-based monitoring system of a RPC.

Table 1 Some functions used in the main algorithm of the Internet-based monitoring system

Icons	Function
	Initializes the selected serial port to specified settings
	The serial read with timeout will read requested bytes unless a timeout conditions is met first
	Reads the number of specified characters from the serial port
	Writes the specified data to the serial port
	Indicates whether an error occurred
	Case structure
	Concatenates input strings
	Computes the logical AND of the inputs
	Computes the logical negation of the input

C. System security

In a RPC, there are many machines for handling,

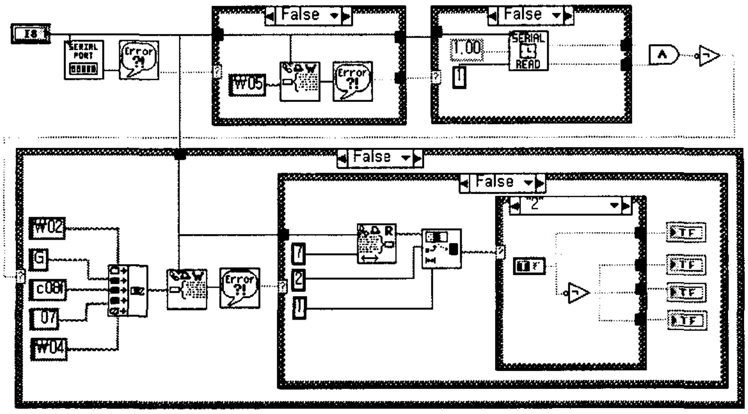


Fig. 3 A subroutine designed to monitor the status of a typical machine unit.

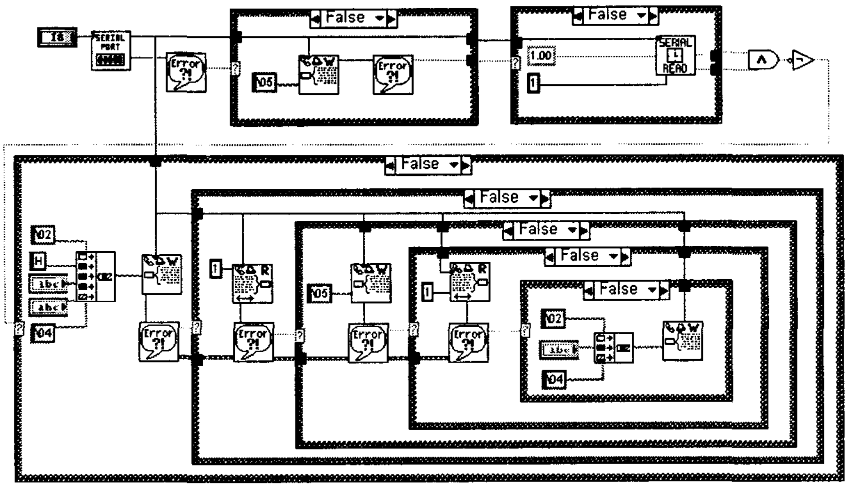


Fig. 4 A subroutine designed to control a typical machine unit.

cleaning, hulling, and polishing processes. As unidentified on-line users or hackers from all over the world make access to the Internet simultaneously, safe monitoring and reliable control are two important issues when designing Internet-based monitoring systems. In this study, The HTTP server of the proposed Internet-based control system could control the clients of the developed Internet-based monitoring system using a web access list. The clients, whose IP address was added into the access list, would have the permission to access the HTTP server via the Internet. Meanwhile, all other clients excluded in the list would not be permitted to remotely monitor and control the machinery in the RPC. Even the clients allowed by the HTTP server had different type of access rights such as monitor type, monitor and control type. Moreover, the information such as connection start time, connection status, control time remaining, last status change, etc. of each client would be stored into a log file to enhance the system security.

Beyond the above safety measures, another access security was also incorporated into the proposed system via the basic access authentication scheme specified in HTTP/1.0[10]. If a user intends to remotely control the machinery in the experimental RPC, the authentication mechanism implemented in the developed Internet-based monitoring system always require a user ID and a password for user identification in order to protect the system from possible outside attacks.

D. On-line weight measurement

To facilitate the automation of a RPC, all the respective processing stages should be efficiently organized. Especially, it is necessary to provide the weight of milled rice in a bin to the manager on the graphical user interface. Four 5-ton load cells(CAS Co., Korea) were installed on the legs of the bin. The load cells were calibrated as shown in Fig. 5. Using the regression analysis, an empirical equation($p < 0.01$) relating the rice weight to the output voltage of the load cells with an R^2 of 0.96 was derived as follows:

$$W_R = 1274.20V_W - 1164.96 \quad (1)$$

where: W_R is the weight of milled rice (kg); V_W is the output signal(V).

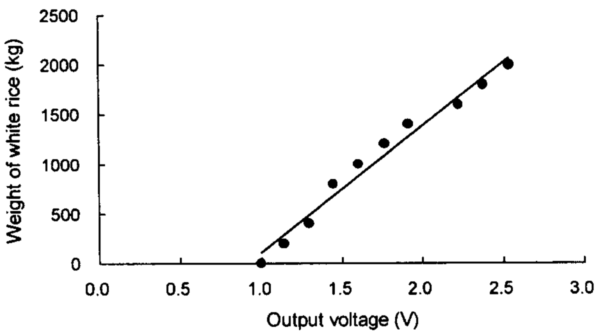


Fig. 5 Relationship between rice weight and the output voltage of load cell.

E. On-line measurement of equilibrium air temperature and relative humidity

The air temperature and relative humidity surrounding milled rice in a bin should be continuously monitored to prevent possible deterioration in rice quality because chemical components such as fat and carbohydrate of milled rice are easily dissolved and oxidized. The fatty acid and various organic acids are generated during the storage periods due to high temperature and high relative humidity of air in summer(Hosokawa *et al.* 1995). Moreover, when the air temperature and relative humidity in the bin reached the equilibrium values, they were utilized to predict the moisture content of the milled rice automatically. The air temperature and relative humidity sensor used in this study was a hygrometer(Rotronic Co., Switzerland). The sensor probe was composed of an air temperature element and a relative humidity one. It was vertically installed in the silo to sense the above two parameters for predicting the moisture content of milled rice.

To calibrate the relative humidity element, twelve kinds of saturated salt solutions were used as standard relative humidity samples. The relative humidity sensor was calibrated over the entire range by placing the sensor in a closed chamber containing a saturated salt solution. When the air within the chamber reached equilibrium after 24 hours, the output voltage of the humidity sensor was recorded for calibration. The regression equation($P < 0.01$) relating the output signal of the equilibrium relative humidity sensor to equilibrium relative humidity was derived with an R^2 of 0.98(Fig. 6).

$$R_H = 27.26V_{RH} - 28.95 \quad (2)$$

where: V_{RH} is the output of the relative humidity sensor (V); R_H is the equilibrium air relative humidity(%).

The air temperature element was also calibrated in the same chamber with an accuracy of 0.1℃ by adjusting the temperature in the chamber at 10, 20, 30, 40, and 50℃, respectively. A linear regression analysis($p < 0.05$) resulted in Eq. 3(R^2=0.99) where the air temperature can be calculated at the output voltage of the air temperature element of the sensor.

$$V_T = 0.0432T_A + 2.034 \quad (3)$$

where: V_T is the output voltage of air temperature sensor (V), T_A is the equilibrium air temperature(℃).

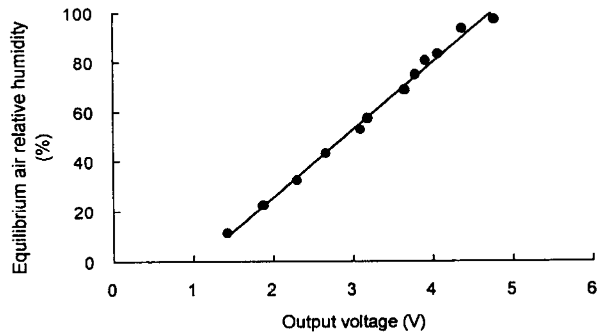


Fig. 6 Relationship between equilibrium air relative humidity and output voltage of a humidity sensor.

F. Prediction of the moisture content of white rice in a silo

Moisture content is one of the important factors related to milled rice quality because it much affects the taste of cooked rice. Chen(2001) evaluated the accuracy of the measurement of grain moisture content using the equilibrium relative humidity and temperature of the air surrounding the grain. It was reported that Modified-Henderson equation, Eq. 4, was much reliable than other models (Brooker et al. 1992; Keum et al. 1995) in predicting the moisture content of milled rice. Therefore, the Modified-Henderson model was chosen in this study.

$$H_R = 1 - \exp[-K\ (T+C)(100\ M_E)^N] \tag{4}$$

$$M_E = 0.01 \left[\frac{\ln(1-H_R)}{K(T+C)} \right]^{\frac{1}{N}} \tag{5}$$

where: H_R is equilibrium relative humidity(decimal); M_E is equilibrium moisture content(decimal, d.b.); T is equilibrium air temperature surrounding polished rice (℃); and K, C, and N are regression coefficients: K=0.000418, C=12.0640, N=2.0909.

G. Validation of air temperature, relative humidity, and predicted moisture content

The air temperature and relative humidity in the milled rice bin measured by the Internet-based monitoring system were validated using a hygrometer(Hygrometer 6010, Germany). Five milled rice samples at different moisture content were randomly chosen to validate the air temperature and relative humidity sensed by the developed monitoring system. Each sample was stored in the bin for 24 hours. After two parameters reached equilibrium values, the equilibrium air temperature and relative humidity surrounding milled rice sensed by the Internet-based monitoring system were compared with those measured by the hygrometer at the RPC for validation.

The predicted moisture content of the milled rice in the bin was validated using a moisture meter(Model: Riceter K305, Kett Co., Japan) with an accuracy of ±0.1%. Six samples of milled rice at different moisture content(12.3, 13.2, 14.6, 15.3, 16.2, and 16.6%) were chosen to validate the predicted moisture content by the Internet-based monitoring system.

3. RESULTS AND DISCUSSION

A. Internet-based monitoring system

The developed system had a user-friendly graphic interface as shown in Fig. 7. The status of each machine in the experimental RPC could be observed in real time via the Internet. The air temperature, relative humidity, and predicted moisture content of rice were reported in the waveform graphs. The weight of milled rice in the silo was monitored by the developed Internet-based monitoring system. The weight sensed by the Internet-based monitoring system was validated through comparing with the respective data shown on the local weight indicator. Generally, the weight error was less than 0.48%.

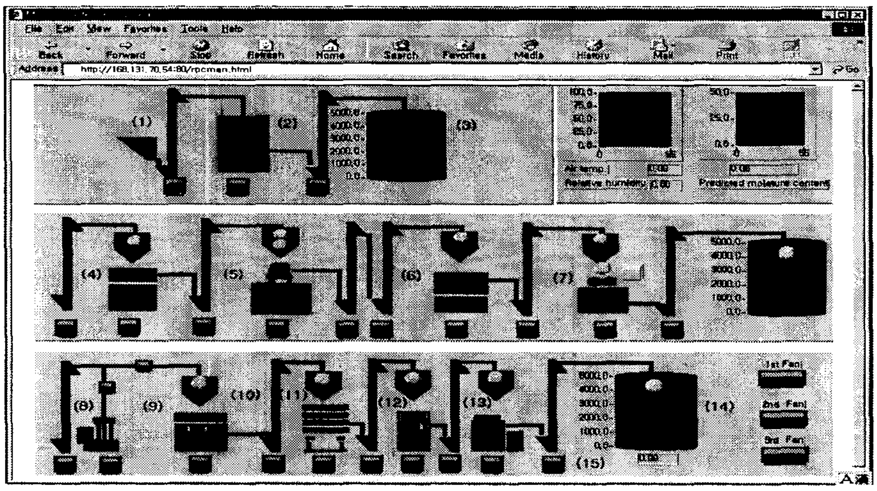


Fig. 7 The developed user interface of an Internet-based monitoring system of a RPC:
(1) Intake hopper; (2) Paddy cleaner; (3) Storage silo for paddy; (4) Paddy de-stoner; (5) Huller; (6) Brown rice separator; (7) Thickness grader; (8) Vertical rice milling machine; (9) Horizontal rice milling machine; (10) Bucket elevator; (11) Rotary sifter; (12) Color sorter; (13) Rice polisher; (14) Storage silo for milled rice; (15) Control button.

B. Time delay for Internet-Based control

Luo and Chung (2002) extensively discussed the stabilization problem for a class of linear, uncertain, remote control systems with time latency and provided a delay-dependent criterion to guarantee asymptotic stabilizability for time-latency systems. Compared with general feedback control systems, the developed Internet-based monitoring system was a different monitoring and control(ON/OFF control) system whose performance mainly relied on the speed of the Internet. The performance of the developed remote control system was evaluated in terms of Internet-based time delay. Due to the limited speed of the Internet, there existed a short time delay when the Internet-based monitoring system was applied in the experimental RPC. The time delay also depended on the distance between a workstation and the central computer. In this work, the time delay was measured by a 'time_delay.vi' subroutine, which was designed for calculating the time interval between the instant of a request sent to the central computer and the corresponding response instant. An operator turned on all the machine units of the experimental mill one by one via the Internet in Seoul city about 350 km from the site where the mill is located. The time delay of each machine unit was recorded, and the mean time delay and its standard deviation were automatically obtained by the subroutine. It was found that the mean time delay was 1.2 s and the standard deviation was 0.2 s. During the control experiment, the developed system was evaluated successfully.

The network traffic load on the HTTP server was monitored using an analysis subroutine embedded into LabVIEW. Figure 8 shows the results of network traffic analysis before and after a client having a monitor and control access right logged on the HTTP server. In this case, the mean network traffic load after logging on was about 5k bytes. The delay time(1.2 s) of the Internet-based monitoring system was almost consistent with the rise time of the network traffic load in Fig. 8.

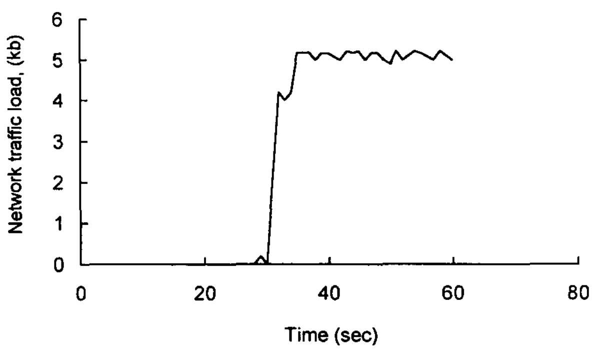


Fig. 8 The transient response of the network traffic load of the central computer when a client logs on.

C. Monitoring of air temperature, relative humidity and moisture content

The equilibrium air temperature and relative humidity monitored by the Internet-based monitoring system and those measured by the moisture meter were compared for validation, respectively(Table 2). It was found that the air temperature and relative humidity measured by the Internet-based monitoring system were accurate enough to predict the moisture content of milled rice in a silo.

Table 2 Comparison of equilibrium air temperature and relative humidity of milled rice in a silo between Internet measurement and local measurement

Samples	Remotely measured via the Internet		Locally measured using a hygrometer sensor	
	Air temperature (℃)	Relative humidity (%)	Air temperature (℃)	Relative humidity (%)
No. 1	23.9	77.2	23.8	76.9
No. 2	25.9	79.9	25.7	80.1
No. 3	26.3	80.5	26.4	80.8
No. 4	24.1	82.7	24.2	82.6
No. 5	22.8	79.1	23.0	79.4

The developed system could predict the moisture content of milled rice in the silo using the equilibrium air temperature and relative humidity via the Internet. For validating the predicted moisture content, each of the six samples at different moisture content was stored in the silo for 24 hours in order to reach equilibrium values. The moisture content of the each sample was predicted by the remote control system. The predicted moisture contents of the six samples were 12.5, 13.0, 14.5, 15.4, 16.3, and 16.8%(w.b.), and the moisture contents of the same samples manually measured using the moisture meter were 12.3, 13.2, 14.6, 15.3, 16.2, and 16.6%, respectively. It was found that predicted values were accurate enough compared with the measured moisture contents locally. To improve the accuracy of the predicted moisture content, the linear regression equation ($P < 0.05$) relating the predicted moisture content to the measured moisture content was obtained with an R^2 of 0.996(Fig. 9).

$$M_m = 1.012M_p \quad (6)$$

where: M_m is the measured moisture content(%, w.b.); M_p is the predicted moisture content(%, w.b.).

The above equation was implemented into the control algorithm of the Internet-based monitoring system for predicting the rice moisture content more accurately.

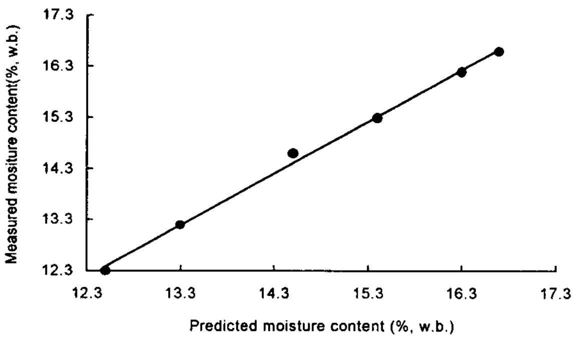


Fig. 9 Relationship between the predicted moisture content and the measured moisture content of milled rice in a silo.

4. CONCLUSIONS

The methodology for designing an ordinary control system is not appropriate for an Internet-based monitoring system, as the general control systems do not consider the Internet environment factors such as Internet-based interface, Internet-based safety, and Internet-based delay. This study was conducted to improve the automation level of a RPC.

(1) An Internet-based monitoring system with a graphic user interface was developed using LabVIEW software.

(2) The system enabled the remote monitoring and control of the various machines and processes in the mill under the security control of HTTP server. All the machines in the mill were controlled successfully via the Internet, but there existed some delay time due to the Internet speed limitation and the distance from a workstation to the central computer.

(3) The equilibrium relative humidity and air temperature in a silo were monitored and validated. The moisture content of milled rice in a silo was well predicted using the developed system.

The Internet-based monitoring system was developed as an innovative management system for RPCs. The developed Internet-based monitoring system increased flexibility, convenience, and efficiency in managing RPCs.

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