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System for determining the job status of individual laborers in a large-scale greenhouse

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ABSTRACT

To obtain the work status of individual laborers by drawing the work progress map and determining the work speeds of individual laborers in a large-scale greenhouse, we developed a simple system comprising smartphone and web-based server applications, using smartphones, two-dimensional (2D) barcodes (called QR codes), a cloud server, and a personal computer. Using the smartphone applications, the laborers read the QR codes on their smartphones when they started or ended the designated work. The timestamps obtained when reading the QR codes were sent to the cloud server. The work progress map was drawn and the work speeds of individual laborers were estimated by the web-based server application in the cloud server based on the length of the gutter and the time difference between the start and end of the designated work. In the field trial, we placed QR codes at the end of the gutters (556 gutters) in a model greenhouse where bell pepper plants were grown in an area of 3 ha. The work progress map and work speeds of individual laborers were obtained rapidly and remotely in the greenhouse based on the collected data. Because the system has a simple structure, its installation is relatively easy, indicating lower cost than that of the commercially available systems.

1. Introduction

Recently, many large-scale greenhouses have been constructed worldwide that are under operation. Compared with conventional small greenhouses, in large-scale greenhouses, manager(s) need to pay attention to various matters, including the management of laborers, cultivation, and logistics. These management tasks consume extensive time and are cumbersome. Hence, assistant tools for managing large-scale greenhouses are required to increase productivity.

In a large-scale greenhouse, the cost of labor is a significant contributor to the overall crop production cost (Hanan, 1997; Vermeulen et al., 2017). For ensuring profit, appropriate management of laborers is essential in large-scale greenhouses. The current work status, including the work progress and work speeds of individual laborers, should be determinable rapidly and remotely. Thus, in this study, we have focused on developing an assistant tool for the management of laborers in large-scale greenhouses.

In previous literature, several types of systems for determining the work speeds of individual laborers and work progress have been reported (Ampatzidis et al., 2016, 2012; Ota et al., 2019; Otuka and Sugawara, 2003). The work speeds of individual laborers are affected by the climate (Riemer and Bechar, 2016), laborers' skills (Ampatzidis et al., 2013; Strik et al., 2003; van 't Ooster et al., 2015), crop architecture, crop age, and number of fruits (Ampatzidis et al., 2013; Ampatzidis and Whiting, 2013; Strik and Buller, 2002). Hence, monitoring the current work status is necessary for the greenhouse manager to ensure completion of the planned job and to evaluate the laborers appropriately.

Currently, several commercial systems are available for determining the work speeds of individual laborers and the work progress in greenhouses (Table 1; Fig. 1). Nonetheless, owing to the high price of the system, the greenhouse managers have not been able to introduce the available systems ubiquitously. Hence, in this study, to reduce the cost of labor management, a simple system is developed for obtaining the work progress map and the work speeds of individual laborers in a large-scale greenhouse.

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Table 1
An example of commercially available systems used for determining the work speeds of individual laborers and the work progress in greenhouses.

Product	Input device	Input method	Data aggregation
Priva FS performance	Exclusive device or smartphone	Automatic	On-site software
HortiMaX Productive	Exclusive device	Automatic	On-site software
Ide Tomato Farm AGRIOS	Smartphone	Manual	Web-based software

2. Material and methods

2.1. System

The system comprises a smartphone application and a server application (Fig. 2). The smartphone application consists of modules for capturing the image of two-dimensional (2D) barcodes (react-native-camera, ver. 3.40.0), reading the QR codes (react-native-qrcode-scanner, ver. 1.4.1), and recording the time (JavaScript, ECMAScript5), a database (realm, ver. 10.0.0) in React Native framework (ver. 0.60.0), and an operating system (Android, ver. 8.0). The server application consists of modules for determining the work speeds, drawing the work progress map, receiving data, and authorization, MySQL database (ver. 5.7.23) in Ruby on Rails framework (ver. 5.1.7), a webserver (Nginx, ver. 1.14.0), and an operating system (Ubuntu, ver. 20.04). The codes for the modules were written in Ruby (ver. 2.5.1p57), HTML, CSS, Javascript, Jquery (ver. 3.4.1), and Bootstrap (ver. 4.4.1). The applications and PC were connected to the internet.

Once logged in to the smartphone application, the laborers' jobs are retrieved from the planning system and displayed in the application. Hence, the registration of laborers' jobs can be simplified (Ohyama and Fujioka, 2019). When reading a QR code placed at the end of each gutter, the timestamp information is sent to the server application. After reading the consecutive QR code, the web-based server application records the timestamp. Subsequently, the web-based server application draws the work progress map based on the locations of the QR codes and timestamps. The web-based server application estimates the work speeds of the individual laborers based on the length of the gutter and the time difference between the two timestamps. Using the smartphone application, the number of containers filled with crops are recorded at the gutter where they are harvested.

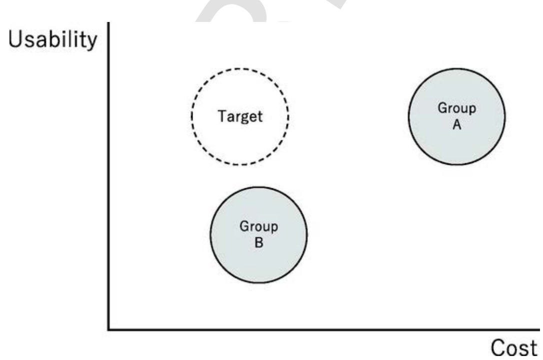

Fig. 1. A conceptual diagram of the relationship between usability and cost of the commercially available systems used for determining the work speeds of individual laborers and the work progress in greenhouses. The symbols of Group A included high-performance systems (e.g., Priva FS Performance, HortiMaX Productive), and Group B included low-cost systems (e.g., Ide Tomato Farm AGRIOS), respectively, described in Table 1. The dotted circle is the target of the current research.

2.2. Model greenhouse and plant material

In this study, a north–south-oriented Venlo-type glass greenhouse (floor area: 3 ha) was used as the model greenhouse. In the greenhouse, 556 gutters were installed to hold approximately 60,000 plants of bell pepper (*Capsicum annuum* L.) at a planting density of 2.5 plants m^{-2}. Slabs filled with coconut shell fiber or peat moss were placed on the gutter. Rockwool cubes were planted with paprika plants on the slabs. In each Rockwool cube, irrigation tubes were inserted to provide a nutrient solution (target drain EC of 3.0, and pH of 6.0).

2.3. Field trial

In the field trial, a unique QR code was attached to the aisle side of the slab on the gutter in the greenhouse. In the greenhouse, all laborers carried smartphones with applications installed for reading the QR codes and sending the timestamps to the web-based server application in the cloud server. The work progress map was drawn using the web-based server application based on the collected data. Simultaneously, the number of containers (containing approximately 8 kg of paprika fruit) and problems were recorded using the smartphone application in the greenhouse.

The data corresponding to the work speeds of harvesting and training were collected from the greenhouse where the bell pepper fruits were harvested. Data were collected from October 1, 2021 to March 31, 2021, and were selected from four skilled laborers involved in the same tasks during the period. From the data, the harvesting and training work speeds were determined for each laborer. The work speeds of harvesting and training for each laborer were compared based on the Wilcoxon rank sum test with continuity correction. *P* values were adjusted using Bonferroni correction. All statistical analyses were performed using R software (ver. 4.0.5). Approval for the use of the data was obtained from all laborers, and the data were anonymized.

3. Results and discussion

The data on the work status of individual laborers were successfully collected in the field trial. A work progress map was drawn from the data stored in the cloud server (Fig. 3). On the work progress map, the location of the gutter where the job started was blinked. When the job was finished, the corresponding location was filled. The number of containers where bell peppers were harvested was recorded. Conventionally, the greenhouse manager collects information on work progress using a paper-based map placed in a greenhouse. Using a paper-based map is time ineffective. Moreover, a significant amount of time is required to aggregate the data on the paper-based map. However, using our developed system, the work progress map in a greenhouse can be obtained rapidly and remotely. This significantly reduces the workload of the greenhouse managers. Simultaneously, since the simple structure of the system we developed, higher usability and lower cost can be achieved compared with the commercially available systems currently existed. In addition, the data acquisition method in this system is the same as using a stopwatch, so the system's accuracy is considered equivalent.

The work speed during harvesting was 5.4–10 times faster than that during training (Fig. 4; Table 2). The same trend was observed for all the laborers selected. During harvesting, laborers could pick the fruits easily because they were colored to enable recognition. However, axial shoots with similar colors were removed during training, and the stem was carefully twisted on a string. These differences can be attributed to the difference between the work speeds of harvesting and training for each laborer.

In the field trial, considerable differences in work speed were observed among the laborers (Table 2); this was mainly because of the laborers' skill. Laborers' skills reportedly affect the work speeds of indi-

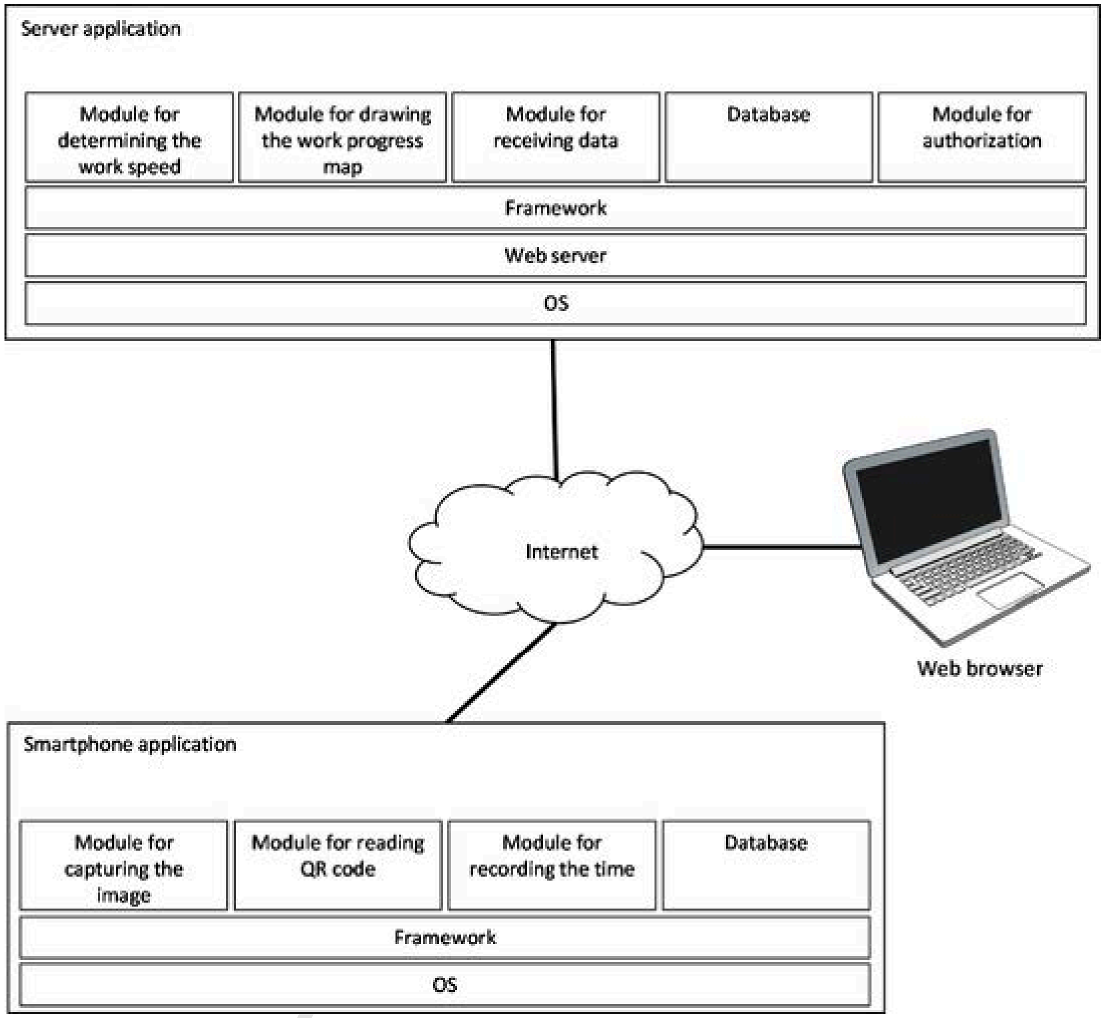

Fig. 2. Schematic of the system developed for determining the work progress map and work speeds of individual laborers in the large-scale greenhouse. The system consists of smartphone and web-based server applications, and is developed using smartphones, QR codes, and personal computer(s). The data corresponding to the time stamps and job status obtained by reading the QR codes using the smartphone application are sent to the cloud server. From the data stored in the cloud server, the work progress map is drawn and the work speeds of individual laborers are estimated by the web-based server application.

vidual laborers (Ampatzidis et al., 2013; Strik et al., 2003; van 't Ooster et al., 2015). It was expected that crop conditions such as architecture, crop age, and the number of fruits, would also affect the work speeds of individual laborers (Ampatzidis et al., 2013; Ampatzidis and Whiting, 2013; Strik and Buller, 2002). In a previous report, the work speeds of individual laborers were affected by the climate (Riemer and Bechar, 2016). Further data collection is required to clarify these effects.

CRediT authorship contribution statement

Katsumi Ohyama : Supervision, Conceptualization, Methodology, Writing – original draft. **Jun Fujioka :** Conceptualization, Software, Writing – review & editing. **Takahiko Sato :** Data curation, Writing – review & editing. **Takafumi Matsuo :** Data curation, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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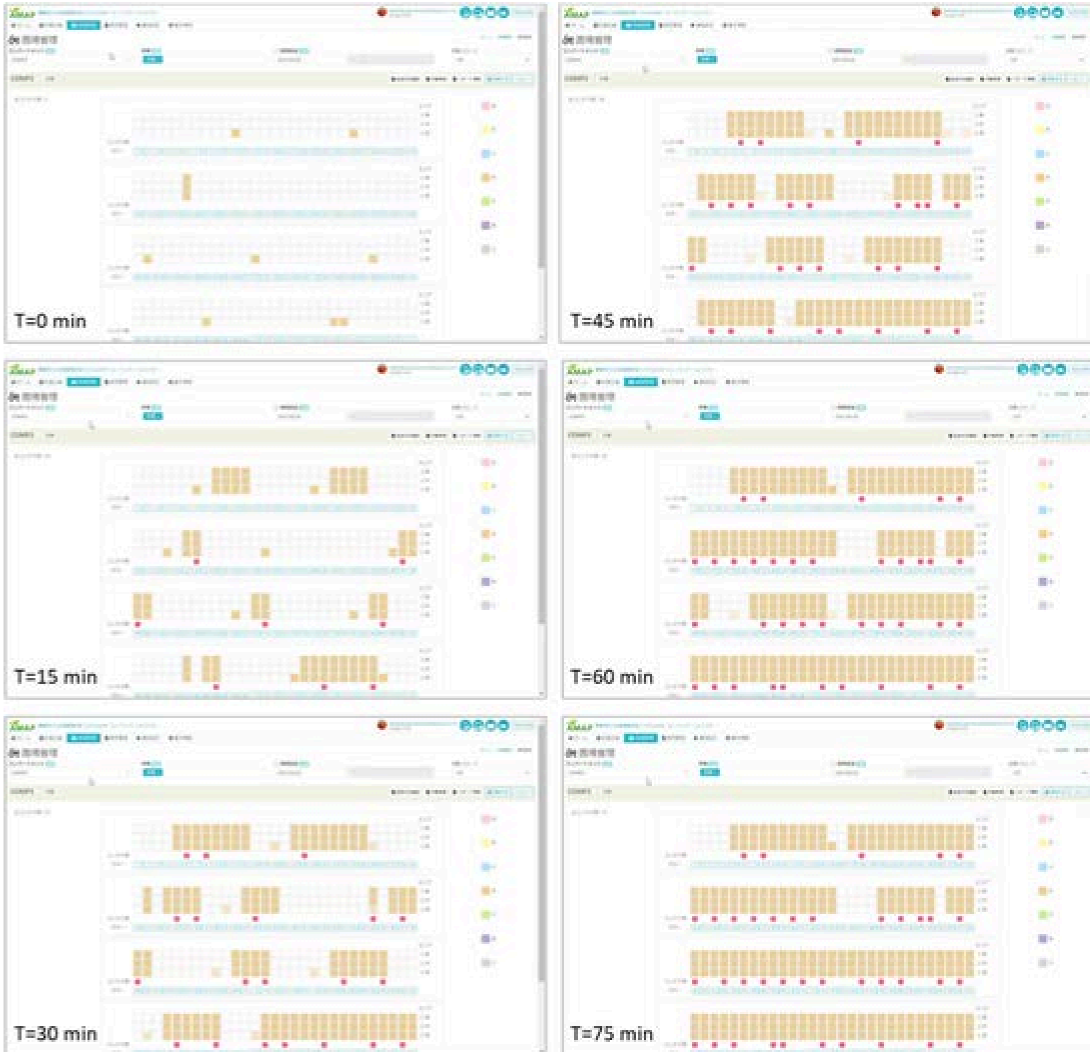

Fig. 3. Time course of the work progress map collected on 26 May 2021. When the job is finished, the column color indicating the gutter location is filled with another color.

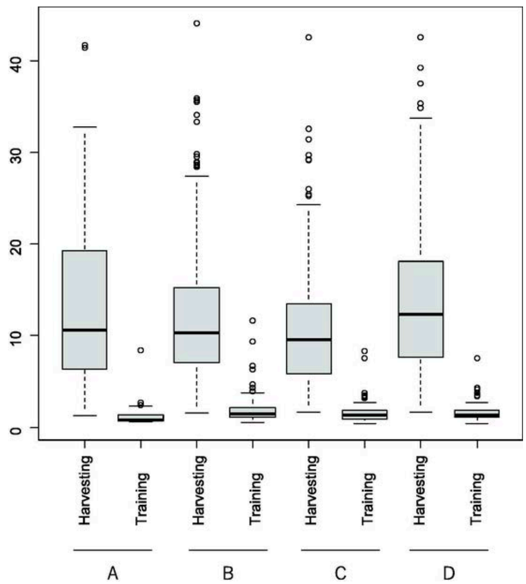

Fig. 4. Work speeds of harvesting and training, which were obtained from four laborers (A, B, C, and D) in the field trial.

Table 2
Pairwise comparisons of the work speeds in harvesting (H) and training (T) of laborers A, B, C, and D based on the Wilcoxon rank-sum test with the Bonferroni correction.

		A		B		C		D	
		H	T	H	T	H	T	H	T
A	H	–	–	–	–	–	–	–	–
	T	**	–	–	–	–	–	–	–
B	H	N.S	**	–	–	–	–	–	–
	T	**	**	**	–	–	–	–	–
C	H	**	**	N.S.	**	–	–	–	–
	T	**	*	**	N.S.	**	–	–	–
D	H	N.S	**	*	**	**	**	–	–
	T	**	**	**	N.S	**	N.S.	**	–

**, *, and N.S.: Significant difference at $P < 0.01$, 0.05, and no significant difference. The number of collected data (n) were 338, 554, 493, and 552 for harvesting, and 37, 112, 102, and 105 for training for laborers A, B, C, and D, respectively.

References

Ampatzidis, Y., Tan, L., Haley, R., Whiting, M.D., 2016. Cloud-based harvest management information system for hand-harvested specialty crops. Comput. Electron. Agric. 122, 161–167. https://doi.org/10.1016/j.compag.2016.01.032.

Ampatzidis, Y.G., Whiting, M.D., 2013. Training system affects sweet cherry harvest efficiency. HortScience 48, 547–555. https://doi.org/10.21273/HORTSCI.48.5.547.

Ampatzidis, Y.G., Whiting, M.D., Scharf, P.A., Zhang, Q., 2012. Development and evaluation of a novel system for monitoring harvest labor efficiency. Comput. Electron. Agric. 88, 85–94. https://doi.org/10.1016/j.compag.2012.06.009.

Ampatzidis, Y.G., Whiting, M.D., Liu, B., Scharf, P.A., Pierce, F.J., 2013. Portable weighing system for monitoring picker efficiency during manual harvest of sweet cherry. Precis. Agric. 14, 162–171. https://doi.org/10.1007/s11119-012-9284-3.

Hanan, J.J., 1997. Greenhouses: Advanced Technology for Protected Horticulture, 1st ed. CRC Press, Boca Raton.

Ohyama, K., Fujioka, J., 2019. Management system for crop production, server, information processing method, terminal, and program. Japanese Patent B6632104. (accepted on August 2, 2019).

Ota, T., Iwasaki, Y., Nakano, A., Kuribara, H., Higashide, T., 2019. Development of yield and harvesting time monitoring system for tomato greenhouse production. Eng. Agric. Environ. Food 12, 40–47. https://doi.org/10.1016/j.eaef.2018.09.003.

Otuka, A., Sugawara, K., 2003. A labor management application using handheld computers. Agric. Inf. Res. 12 (2), 95–103.

Riemer, R., Bechar, A., 2016. Investigation of productivity enhancement and biomechanical risks in greenhouse crops. Biosyst. Eng. 147, 39–50. https://doi.org/10.1016/j.biosystemseng.2016.03.009.

Strik, B., Buller, G., 2002. Improving yield and machine harvest efficiency of "bluecrop" through high density planting and trellising. Acta Hortic. 574, 227–231. https://doi.org/10.17660/ActaHortic.2002.574.34.

Strik, B., Buller, G., Hellman, E., 2003. Pruning severity affects yield, berry weight, and hand harvest efficiency of highbush blueberry. HortScience 38, 196–199. https://doi.org/10.21273/HORTSCI.38.2.196.

van 't Ooster, A., Bontsema, J., van Henten, E.J., Hemming, S., 2015. Model-based analysis of skill oriented labour management in a multi-operations and multi-worker static cut rose cultivation system. Biosyst. Eng. 135, 87–102.

Vermeulen, P.C.M., Raaphorst, M.G.M., Eveleens, B.A., 2017. Quantitative information on Dutch greenhouse horticulture 2016 2017. Plant Research, Wageningen UR, Wageningen.