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Farm Operation Monitoring System with Wearable Sensor Devices Including RFID

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1. Introduction

To increase agricultural productivity and promote efficient management in modern agriculture, it is important to monitor the field environment, crop conditions, and farming operations instead of simply relying on farmers' experiences and senses. However, it is difficult to realize such monitoring automatically and precisely, because agricultural fields are widely spaced and have few infrastructures, monitoring targets vary according to crop selection and other variables, and many operations are performed flexibly by manual labor. One approach to monitoring in open fields under harsh conditions is to use a sensor network (Akyildiz et al., 2002; Delin & Jackson, 2000; Kahn et al., 1999) of many sensor nodes comprised of small sensor units with radio data links. In our previous study, we developed a sensor network for agricultural use called a Field Server (Fukatsu & Hirafuji, 2005, Fukatsu et al., 2006, Fukatsu et al., 2009a) that enables effective crop and environment monitoring by equipped sensors and autonomous management. Monitoring with Field Servers facilitates growth diagnosis and risk aversion by cooperating with some agricultural applications such as crop growing simulations, maturity evaluations, and pest occurrence predictions (Duthie, 1997; Iwaya & Yamamoto, 2005; Sugiura & Honjo, 1997; Zhang, et al., 2002). However, it is insufficient for obtaining detailed information about farming operations, because these operations are performed flexibly in every nook and cranny depending on crop and environment conditions.

Several approaches have been used to monitor farming operations, including writing notes manually, using agricultural equipment with an automatic recording function, and monitoring operations with information technology (IT)-based tools. Keeping a farming diary is a common method, but it is troublesome to farmers and inefficient to share or use their hand-lettered information. Some facilities and machinery can be appended to have an automatic recording function, but it requires considerable effort and cost to make these improvements. Moreover, it is difficult to obtain information about manual tasks, which are important in small-scale farming to realize precision farming and to perform delicate operations such as fruit picking.

Several researchers have developed data-input systems that involve farmers using cell-phones or PDAs while working to reduce farmers' effort of recording their operations (Bange et al., 2004; Otuka & Sugawara, 2003; Szilagyi et al., 2005; Yokoyama, 2005; Zazueta

& Vergot 2003). By using these tools, farmers can record their operations easily according to the input procedures of the systems, and the inputted data can be managed by support software and then shared with other farmers via the Internet. However, these systems cannot be easily applied for practical purposes because it is difficult to train farmers to use these tools, especially the elderly, and the implementation of these methods requires farmers to interrupt their field operations to input data.

Other systems equipped with a global positioning system (GPS) or voice entry have been developed to solve the problems of data input (Guan et al., 2006; Matsumoto & Machda, 2002; Stafford et al., 1996). These hands-free methods help farmers by inputting operation places or contents. However, the system that uses a GPS requires detailed field maps including planting information, the development of which requires significant costs and efforts, and with the system that uses cell phones, it is sometimes difficult for the device to recognize a voice entry because of loud background noises such as tractor sounds. Furthermore, for easy handling, these data-input systems only accept simple and general farming operations such as just spraying and harvesting. To allow flexible use and detailed monitoring, such as what farmers observe, which pesticide they choose, in what area they are operating and how much they spray, a more useful and effective support system is desired.
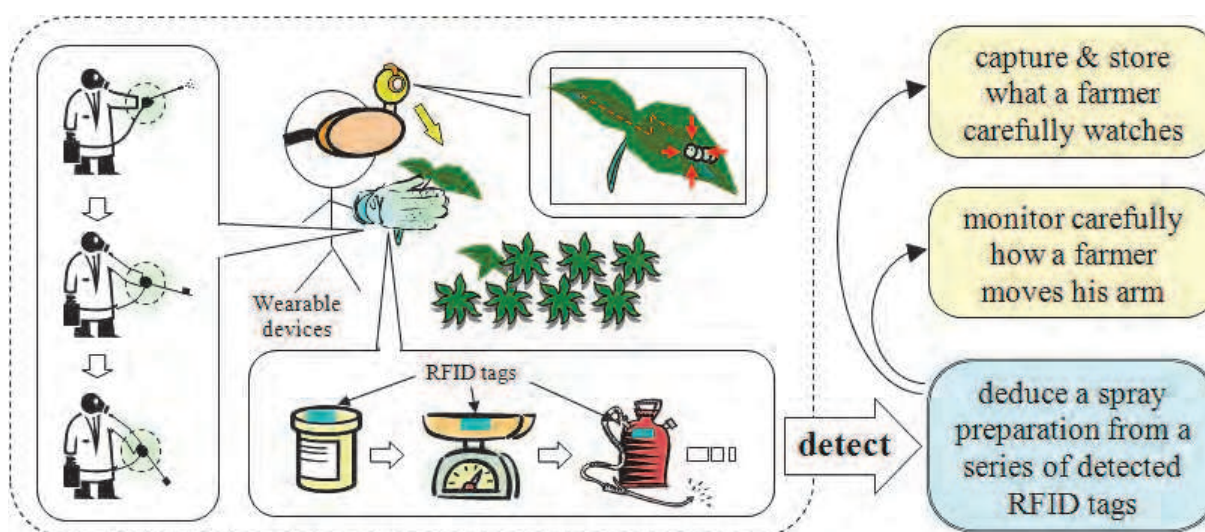

Fig. 1. Concept of farm operation monitoring system using wearable devices with RFID.

We propose a farm operation monitoring system using wearable sensor devices with radio frequency identification (RFID) readers and some sensing devices such as motion sensors, cameras, and a GPS (Fig. 1). This system recognizes detailed farming operations automatically under various situations by analyzing the data from sensors and detected RFID tags, which are attached to relevant objects such as farming materials, machinery, facilities, and so on. In this chapter, we describe the concept and features of the system, the results of several experiments using a prototype system, and the major applications and extensions of the current systems based on our research (Fukatsu & Nanseki 2009b; Nanseki et al., 2007; Nanseki 2010).

2. Farm operation monitoring system

Farmers want to record their farming operations in detail without interrupting their operations and without having to alter their farm equipment so that they can make effective

decisions about future operations by utilizing the collected information with support applications. To meet such needs, we propose an innovative farm operation monitoring system with wearable sensor devices including RFID readers. In this section, we describe the concept, features, and architecture of our proposed system.

2.1 Concept

The concept of our farm operation monitoring system is to provide a versatile, expansible, practical, and user-friendly monitoring system that recognizes users' behavior in detail under various situations. To develop a useful monitoring system, we must consider the following requirements:

- The system should not encumber farmers' activities during farming operations.
- The system should be simple to use for non-experts without complicated processes.
- The system should be available without changing the facilities or equipment.
- The system should monitor detailed farming operations under various conditions.
- The system should be able to cooperate with various applications easily.

To meet these requirements, we propose a recognition method for farming operations by using RFID-reader-embedded wearable devices that are comfortable to wear, have unimpeded access to the farming situations they're supposed to monitor, and have sufficient sensitivity to RFID tags. Typical RFID systems, which can identify or track objects without contact, are used for individual recognition in some areas of logistics, security control, and traceability system (Finkenzeller, 2003; Rizzotto & Wolfram, 2002; Wang, et al., 2006; Whitaker, et al., 2007). For example, in the livestock industry, RFID tags are attached to or embedded in animal bodies, and some applications such as health control, fattening management, milking management, and tracking behavior are implemented by checking the detected RFID tags and using that data in combination with other measurement data (Gebhardt-Henrich, et al., 2008; Murray, et al., 2009; Trevarthen & Michael, 2008). In our system, however, we adapted an RFID system for use in the recognition of farming operations by analyzing patterns of the detected RFID tags. The procedure has the following steps:

1. RFID tags are attached to all relevant objects of farming operations such as farming materials, implements, machinery, facilities, plants, and fields.
2. A farmer performs farming operations with wearable devices that have RFID readers on them.
3. A sequence of RFID tags is detected throughout the farmer's activities.
4. The system deduces the farming operations by analyzing the pattern of the data.

In the conventional applications, RFID tags are attached to objects which themselves are important targets to be observed. In our system, however, a farmer puts on not an RFID tag but an RFID reader in order to apply this system to various operations easily. Also, in this system, not just single detected tags but series of detected tags are utilized to derive the desired information, unlike the conventional applications.

2.2 Features

The proposed system has some advantages and features. This method is flexible and available under various conditions without changing the facilities or equipment. All that is required is to attach RFID tags to existing objects and to perform farming operations while wearing the appropriately designed devices. For example, only by attaching RFID tags to many kinds of materials such as fertilizer and pesticide bottles, this method can

automatically record which materials a farmer selects without interrupting his operations. With this system, we can easily collect an enormous amount of data about farming operations, and it helps to solve a shortage of case data for decision support systems (Cox, 1996). In the case of monitoring people who come and go at various facilities, in the conventional method the people carry RFID tags and RFID readers are set up at the gates to detect people's entrances and exits. In our proposed method, however, people wear RFID readers, and RFID tags, which are cheaper than the RFID readers, are attached to the gates. This will be effective in the situation in which a few people work in many facilities, such as in greenhouses. It can also be applied to monitoring operations with machinery at a low cost by attaching RFID tags to parts of operation panels such as buttons, keys, levers, and handles. The sequence of detected RFID tags tells us how a farmer operates agricultural implements.

By combining the data of RFID tags and other sensors, this system can monitor more detailed farming operations. For example, if an RFID tag is attached to a lever on a diffuser, we cannot distinguish between just holding the lever and actually spraying the pesticide. However, by using the data collected by wearable devices with finger pressure sensors, this system can distinguish between just holding the lever and actually spraying the pesticide accurately and specifically. Moreover, by connecting a GPS receiver to wearable devices, we can monitor when and where a farmer sprays the pesticide precisely. This information is now required to ensure the traceability of pesticides, and this system is expected to be an effective solution to the requirement of traceability, especially, when farmers manually perform the cultivation management (Opara & Mazaud, 2001). When attaching RFID tags to plants, trays, and partitions, we can also monitor the locations of farmers' operations in greenhouses where a GPS sometimes does not function well, and we can monitor even the time required for manual operations such as picking and checking of plants. The information about the progress and speed of farming operation can help in setting up efficient scheduling and labor management (Itoh et al., 2003). This system is effective for monitoring farming operations in detail, especially manual tasks that are difficult to record automatically in a conventional system.

2.3 Architecture

In our proposed system, a core wearable device is equipped with an RFID reader, an expansion unit for sensing devices, and a wireless communication unit (Fig. 2). The wireless communication unit enables the separation of heavy tasks such as data analysis and management processing from the wearable device. That is, the detected data can be analyzed at a remote site via a network instead of by an internal computer, so the wearable device becomes a simple, compact, and lightweight unit the farmer can easily wear. This distributed architecture allows for the implementation of a flexible management system and facilitates the easy mounting of various support applications that can provide useful information in response to recognized farming operations.

Thanks to the distributed architecture, the remote management system can be operated with high-performance processing. Therefore, the management system can recognize farming operations based on the patterns of detected RFID tags and sensing data with a complicated estimation algorithm. We can choose various types of algorithms such as pattern matching, Bayesian filtering, principal component analysis, and support vector machines by modifying the recognition function. A basic estimation algorithm is pattern matching in which a certain operation is defined by a series of data set with or without consideration of order and time

interval. For example, an operation consisting of the preparation of a pesticide is recognized when the RFID tags attached on a pesticide bottle, a spray tank, and a faucet handle are detected within a few minutes in random order. Some estimation algorithms classify the data in groups of farming operations based on supervised learning, and they enable very accurate recognition, even though missed detection or false detection sometimes occurs.
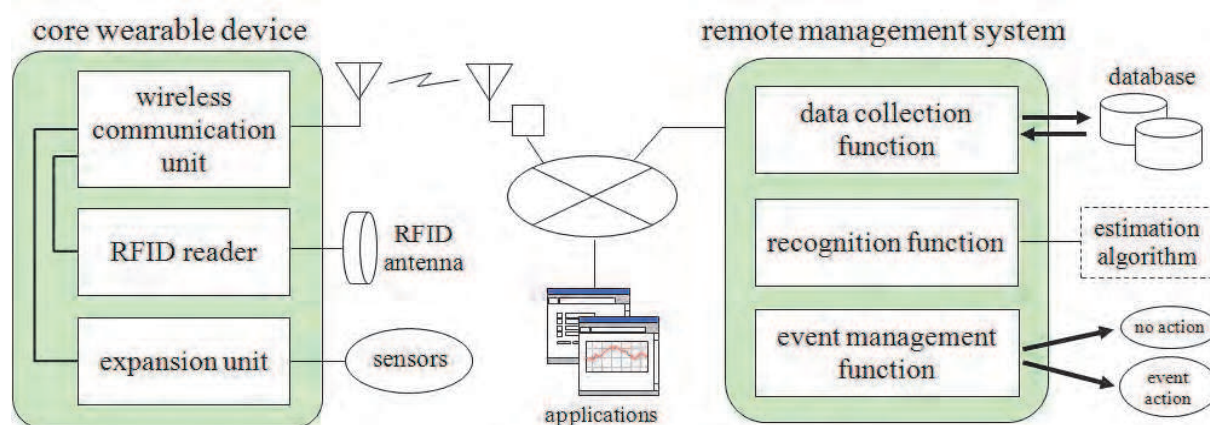

Fig. 2. Architecture of the farm operation monitoring system comprised of a core wearable device and a remote management system.

3. Prototype system

In our proposed system, farming operations are deduced by analyzing the patterns of detected RFID tags. To evaluate the possibility and effectiveness of this system, we developed a prototype system constructed of a glove-type wearable device, Field Servers for providing hotspot area, and a remote management system. With this prototype system, we conducted several experiments to demonstrate the system's functionality. In this section, we describe the architecture and performance of the prototype system and the results of the recognition experiments that involved a transplanting operation and greenhouse access.

3.1 System design

Figure 3 shows an overview of the prototype system and the wearable device which a farmer puts on his right arm. At a field site, we deployed several Field Servers that offer Internet access over a wireless local area network (LAN) so that the wearable device could be managed by a management system at a remote site. RFID tags were attached to some objects the farmer might come into contact with during certain operations. The information of the attached RFID tags and the objects including their category, was preliminarily registered in a database (DBMS: Microsoft Access 2003) named Defined DB in the management system. The remote management system constantly monitored the wearable device via the network, stored the data of detected RFID tags, and analyzed the farmer's operations.

The wearable device was equipped with a wireless LAN for communicating with the management system, an RFID reader for detecting relevant objects, and an analog-to-digital (A/D) converter with sensors for monitoring a farmer's motion. The RFID reader consisted of a micro reader (RI-STU-MRD1, Texas Instruments) and a modified antenna. The A/D converter consisted of an electric circuit including a microcomputer (PIC16F877, Microchip

Technology) with four input channels. A device server (WiPort, Lantronix), which served the function of a wireless LAN and enabled monitoring of the RFID reader and the A/D converter via the network, was also embedded. This wearable device worked for up to two hours when a set of four AA batteries was used. The battery life was able to be extended by using energy-saving units and modifying the always-on management. In some experiments, we added sensors such as pressure sensors to monitor the farmer's fingers and other wearable devices such as a network camera unit to collect user-viewed image data and a wearable computer display unit to provide useful information in real-time.

Fig. 3. Overview of the prototype system and the wearable device.

The type of RFID reader and the antenna shape are important factors for detecting RFID tags accurately without encumbering farmers' activities in various situations. There are RFID tags available with different frequencies (e.g., 2.45 GHz, 13.56 MHz, and 134.2 kHz) that differ in terms of communication distance, tag shape, antenna size, and broadcasting regulations (Khaw, et al., 2004). In this prototype system, the 134.2-kHz RFID was used because of the emphasis on the communication distance and the radio broadcasting laws in Japan. A bracelet-type antenna (85 mm in diameter) was developed with consideration of an easily wearable shape and adequate inductance of the antenna coil (47 uH for 134.2 kHz). The antenna had sufficient accessible distance (more than 100 mm) to detect RFID tags without any conscious actions.

Figure 4 shows a block diagram of the remote management system. It accessed the RFID reader and the A/D converter at high frequency (200 ms interval) and stored the data in a database (DBMS: Microsoft Access 2003) named Cache DB. In this system, we simply chose pattern matching as an estimation algorithm. The rules of expected farming operations were preliminarily defined into a pattern table with combinations or sequences of objects or categories that had already been registered in Defined DB. The management system checked the time-series data of Cache DB against the pattern table to detect defined farming operations. When the system recognized a certain farming operation, the information of the recognition result was recorded, and appropriate actions in response to the results were executed.
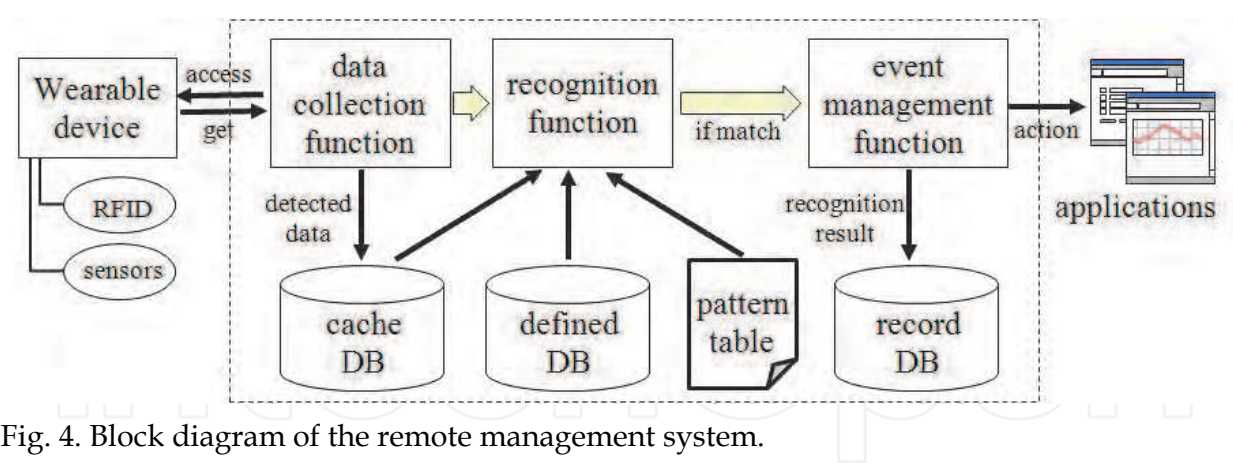
Fig. 4. Block diagram of the remote management system.

3.2 Recognition experiments
3.2.1 Transplanting operation
To evaluate the feasibility and the basic performance of this system, we performed a fundamental experiment to recognize transplanting operations in a field environment. In this experiment, a user took each potted seedling, checked the seedling's condition, and transplanted it to a large pot if it was growing well. RFID tags were attached to every pot including empty pots for transplanting, and a user performed the operation with the wearable device. Field Servers were deployed in the experimental area, and the remote management system accessed the wearable device via the Field Servers. We arranged twelve potted seedlings including two immature ones and tested whether the detailed information about this operation could be obtained by using our proposed system.

Figure 5 illustrates some results from this experiment. The white circle shows the detected RFID tags corresponding to each pot. The pots labeled pot-A to pot-E (categorized as small pots) were potted seedling, while the pots labeled pot-I to pot-IV (categorized as large pots) were empty pots for transplanting. The seedling in pot-B was an immature one that did not need to be transplanted. The transplanting operation was defined as occurring when a detected small pot was transplanted to a large pot detected within ten seconds, but only if the large pot was detected for over three seconds. The system was able to correctly identify every target pot that a user touched during the operation without any problem.
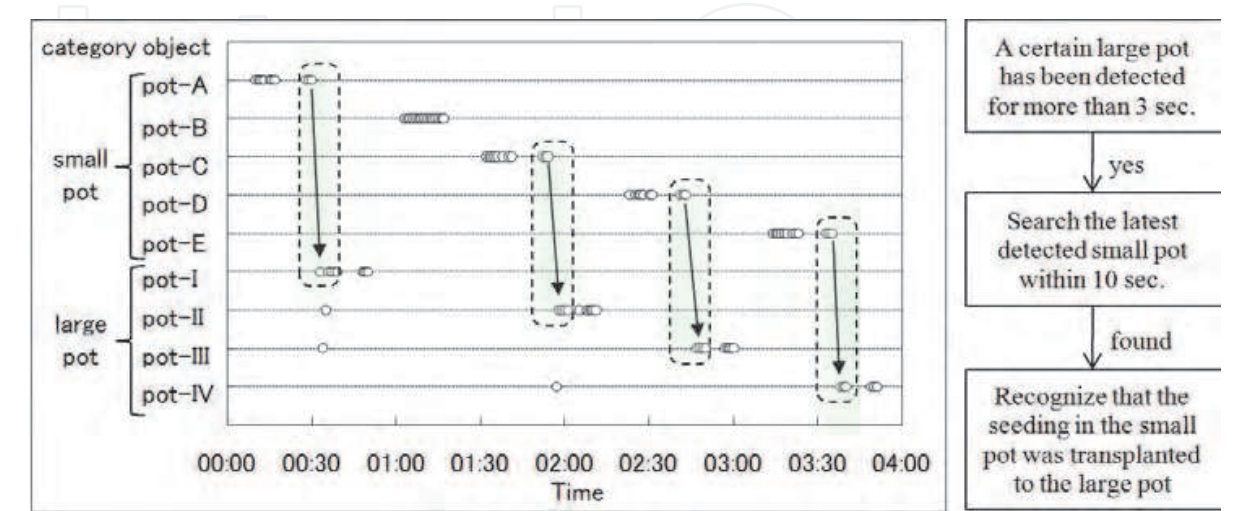

Fig. 5. Result of a recognition experiment about transplanting operation.

When a user took a large pot, an RFID tag of another large pot was mistakenly detected once in a while because these large pots were piled up. However, the defined rule was able to filter out the false detection, so this system was accurately able to recognize the operation. In this experiment, our proposed system was also able to recognize the correspondence relation of which large pot a seeding in a small pot was transplanted to. For example, the seedlings in pot-A, -C, -D, and -E were transplanted to pot-I, -II, -III, and –IV (the user didn't transplant pot-B, so that pot didn't have a corresponding large pot). In this system, not only the detected RFID tag identification number but also the detected time was stored in the database. By subtracting the first detected time of the small pot from the last detected time of the corresponding large pot, we were also able to obtain the process time of the transplanting operation as detailed information.

3.2.2 Greenhouse access

The next experiment was recognition of people entering and leaving greenhouses. In this experiment, RFID tags were attached to both sides of sliding doors (tag-A: outside; tag-B: inside) of greenhouses. A user equipped with the prototype wearable device entered and exited two different greenhouses eight times each to work inside and outside them. This system judged a greenhouse access by checking the sequence pattern of the detected RFID tags with pattern matching. The entering action was defined as occurring when the tag-B of either greenhouse had been detected for more than one second within ten seconds after the tag-A of the greenhouse was detected. The leaving action was defined as the opposite pattern of the entering action.

Figure 6 illustrates some results from the experiment. In this experiment, this system couldn't perfectly detect the entering and leaving actions; the percentage of accurate recognition in total was 87.5% for entering and 81.3% for leaving. The main reason for misrecognition was not missed detection due to inadequate antenna sensitivity but false detection caused by the excessive antenna range, which resulted in the antenna mistakenly detecting a far-side tag through the door once in a while. In this condition, the system was
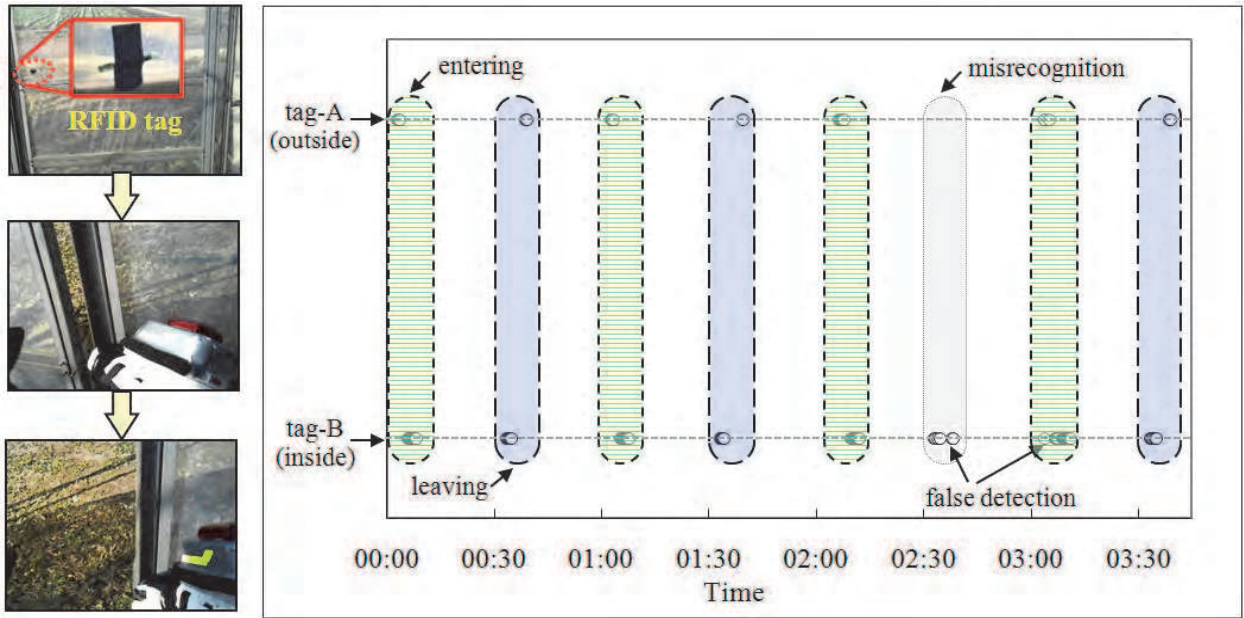

Fig. 6. Result of a recognition experiment about greenhouse access.

able to deduce the correct operations based on the detected patterns, even though false detections were included in them. At other times, the system was not able to deduce the correct operations that included false detections. To solve this problem, we must consider the allocation of the attached RFID tags so that the antennas can avoid false detections.

4. Applications

Our proposed system can recognize farming operations from the patterns of detected RFID tags. The farm operation monitoring system has the potential to be used effectively and to be implemented in a wide variety of applications. By using some sensor devices together, this system can recognize farming operation more accurately. By coordinating with Field Servers, we can also obtain more detailed information about farming operations. Moreover, this system enables us to provide useful information in response to the recognized operation by cooperating with agricultural support tools. In this section, we describe several applications of the system and the results of the experiments.

4.1 Recognition with RFID and sensing devices

Our prototype wearable device had an A/D converter with four input channels and an expansion port for RS232C. We used a pressure sensor to monitor the condition of the farmer's hand and a network camera unit to record user-viewed image data during farming operations. By using the enhanced wearable device, this system can recognize complicated farming operations and obtain useful information in detail. To evaluate the feasibility and effectiveness of the system, we conducted a recognition experiment of the snipping operation with a pair of scissors.

In this experiment, a user equipped with the enhanced wearable device took a plant tray, checked the condition of a plant in the tray, and snipped off unwanted leaves with scissors. RFID tags were attached to each plant tray and to the handle of the scissors. The system recognized the snipping operation when the RFID tag of the scissors was detected and simultaneously the value of the pressure sensor for the forefinger exceeded a certain threshold level that was set by preliminary test. By using the detected data of the RFID tag attached to the plant tray, this system deduced which plant was sniped off. The network camera unit on the user's shoulder captured several pictures of the operation after it was recognized.

Figure 7 illustrates some results from the experiment, which tested the snipping operation five times each in two kinds of plant tray. By using RFID tags and the pressure sensor together, this system was able to distinguish the status between just holding the scissors and actually using the scissors. In this experiment, the system had 80% accurate recognition of the snipping operation. The main reason for any misrecognition was that sometimes the value of the pressure sensor did not exceed the threshold level because the position of the sensor attached to the glove was not accurate for the user. The image data was adequately collected just when the user snipped a target leaf, and it enabled us to provide useful information about how the user performed the operation. In this experiment, the data of the pressure sensor was shown as an 8-bit raw data item with no calibration data. If we calibrated the sensor, we could get more detailed information about the user's technique with the scissors.
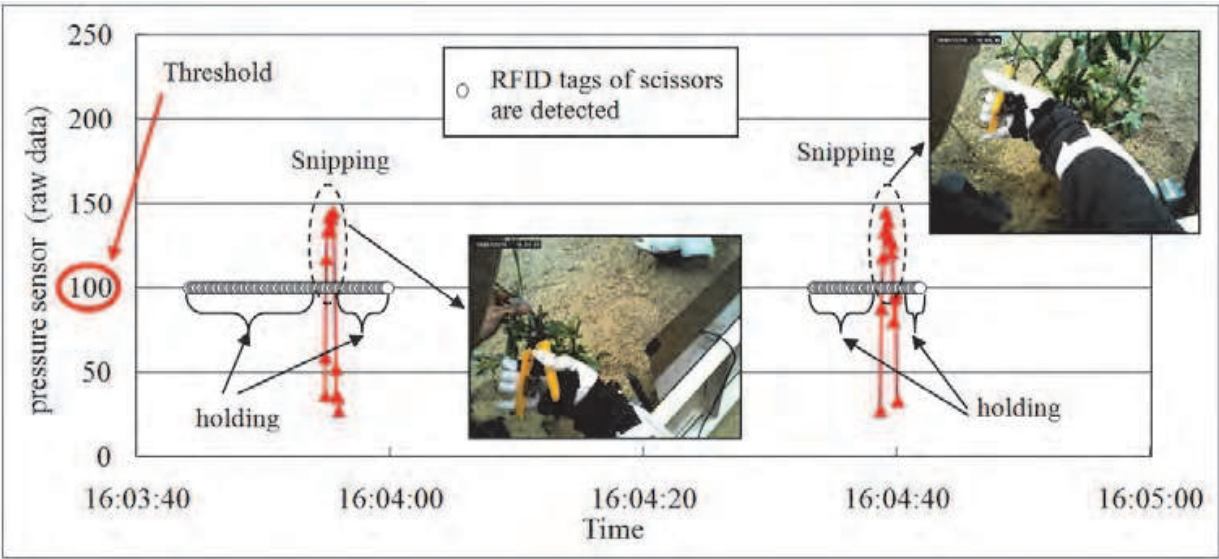
Fig. 7. Result of a recognition experiment about snipping operation.

4.2 Multi monitoring with field servers

Image data provides useful and helpful information for agricultural users to check crop conditions and to comprehend farming operations. Especially, recording operations of skilled farmers visually is very important for new farmers and agricultural researchers to understand practical techniques. We previously developed Field Servers with controllable cameras that can realize the distributed monitoring system. By using the Field Servers in cooperation with our proposed system, we can record the processes of farming operations carefully from a number of different directions in response to the results of recorded data. To evaluate the feasibility and effectiveness of the system in cooperation with Field Servers, we conducted an experiment in which the system collected pictures of recognized farming operation by controlling the camera of the surrounding Field Servers.

In this experiment, RFID tags were attached to a warehouse door, to some points on a rack in the warehouse, and to stored farming materials such as pesticide bottles. One Field Server equipped with a controllable camera was deployed near the warehouse. The Field Server periodically monitored field and crop conditions as part of a scheduled operation. The system recognized the preparing operation when a certain RFID tag of farming materials was detected after the RFID tag on the warehouse door was detected. We had previously registered the material places and preset camera positions and settings. When the system recognized that a certain material was being taken, it performed an event operation to record the target process by using the Field Server camera with a zoom function.

When two management systems share one controllable camera, there is a potential conflict between scheduled operations and event operations that require monitoring a different target. To solve this problem, we introduced a multi-management system (Fukatsu et al., 2007, Fukatsu et al., 2010). Figure 8 shows the operation status flow of the multi-management system and illustrates some results from the experiment designed to test the system. One management system (Agent-A) monitored the Field Server on the basis of its scheduled operation and the other system (Agent-B) periodically checked the RFID database. When a defined operation was recognized, Agent-B sent a stop signal to Agent-A to avoid access collision, and Agent-B preferentially directed the camera of the Field Server to the defined position.
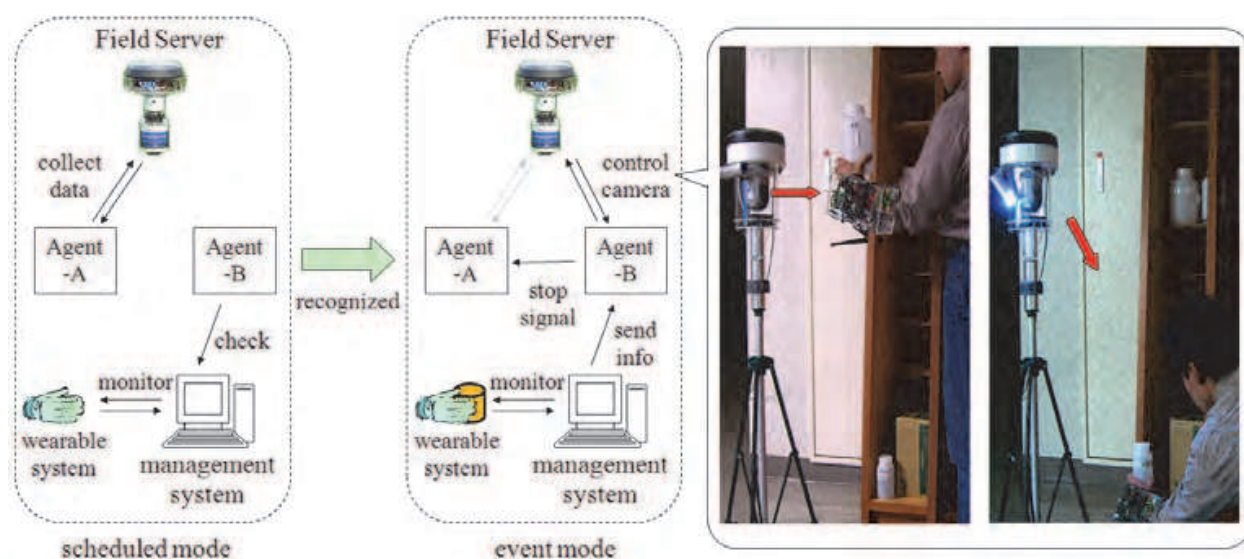
Fig. 8. Operation status flow of the multi-management system.

When a user with a wearable device tried to bring out the materials randomly, the system was able to record the target operation procedure as the image data. In some cases, it couldn't acquire desirable image data because the speed of the camera was not fast enough. To avoid the delay of the camera moving, we modified the camera control algorithm in which the camera was preliminarily directed to the expected position when the rack-attached RFID tag was detected. By introducing the modified algorithm, we were able to get more image data that included the scene of the operation.

4.3 Cooperation with support application

In agriculture, many support applications that provide useful information to farmers have been developed. Some support applications, such as a navigation system for appropriate pesticide use (Nanseki & Sugahara, 2006), are provided as Web application services, which are available for our proposed system. By combining our system and Web-based support applications, we can provide appropriate information in real-time in response to farming operations. For example, it is helpful for a farmer to get pointed advice regarding proper usage of a pesticide to avoid misuse of the pesticide.

To evaluate whether the system was able to cooperate with a Web-based support application easily, we conducted an experiment in which the system provided detailed information about the pesticide held by a farmer via a wearable computer display in real-time. In this experiment, we prepared a Web application service for pesticide management that outputted a target pesticide name, its detailed information including history of usage, and relevant links to information about the appropriate pesticide to use in response to an inputted query. By using the Web application service, we were also able to register and update target pesticide information via the Internet. When the system recognized that a certain pesticide bottle was taken, it sent the recognized pesticide ID to the Web application service and received detailed information about it with an HTML format. Then, the system outputted the information to the wearable computer display connected to the Internet via the Field Server.

Figure 9 illustrates some results from the experiment. RFID tags were attached to five kinds of pesticide bottle and a spray tank. A user with the prototype wearable device and a

wearable computer display conducted the pesticide preparation. When the RFID tag attached to the pesticide bottle was detected, the system was able to provide the appropriate information to the user. When the RFID tag of the spray tank was detected after the recognition, the system judged that the pesticide was used, and it updated information about the pesticide's use history by accessing the Web application service. We confirmed that the target history information was automatically updated without problems when the user poured a certain pesticide into the spray tank.
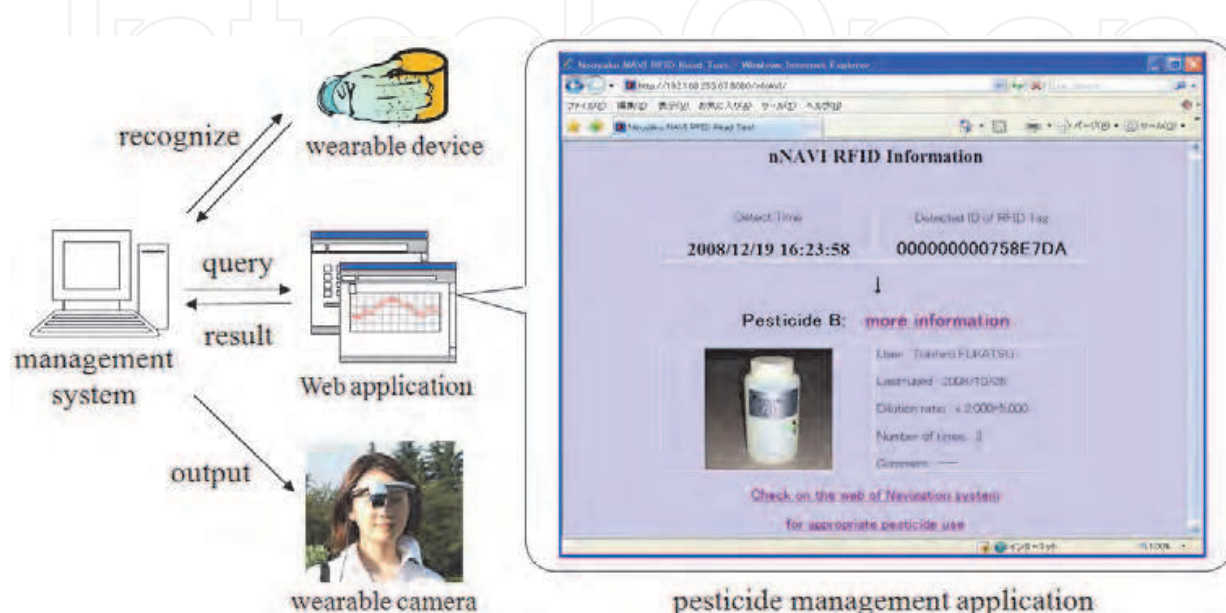

Fig. 9. Support application of providing useful information.

4.4 Extension of the system: the farming visualization system

Several types of the farm operation monitoring system have been developed according to the varied needs of farms. All of these systems are designed to record and replay all the information of farming operations based on combinations of data from several kinds of sensors, including RFID readers. Some farms need a low-end type of system with only a few sensors. This type of system is simple to use and has a low introduction cost. On the other hand, some farms need a high-end system with many sensors. This type of system can monitor many kinds of farming operations with high accuracy and frequency. Our proposed system can be modified to suit both kinds of farm.

Our system can also be extended in various directions within the field of agriculture, and one such extension is the farming visualization system (FVS) that has been developed based on our previous research (Fukatsu & Nanseki 2009b; Nanseki et al., 2007). One of the major application fields is to record precious and detailed farming history for good agricultural practice (GAP) and food traceability. Another major application field is the human development of young farming operators. These applications fields of the FVS are especially important in large farm cooperations, and the government has aided us in developing several types of FVS. The NoshoNavi project, begun in 2010 as a five-year period, is one such national research project (http://www.agr.kyushu-u.ac.jp/keiei/NoshoNavi/).

Figure 10 shows images of a high-end type of FVS. The wearable devices of the system include two wearable RFID readers (Wellcat), two cameras (Logicool), one differential GPS (Hemisphere), one mobile PC (Panasonic) and one head mount display (Mikomoto). The

two RFID readers on both hands enable us to distinguish whether the right or left hand touches the RFID tags. One of the cameras captures a wide view of the farming environment, and the other camera captures a narrow view, focusing on the area immediately around the operator's hand. The differential GPS has 50-cm accuracy. The mobile PC controls each sensor and manages all the data, so this particular system does not need a network connection. The visualization software of the FVS can show an integrated view of all the data of these sensors.
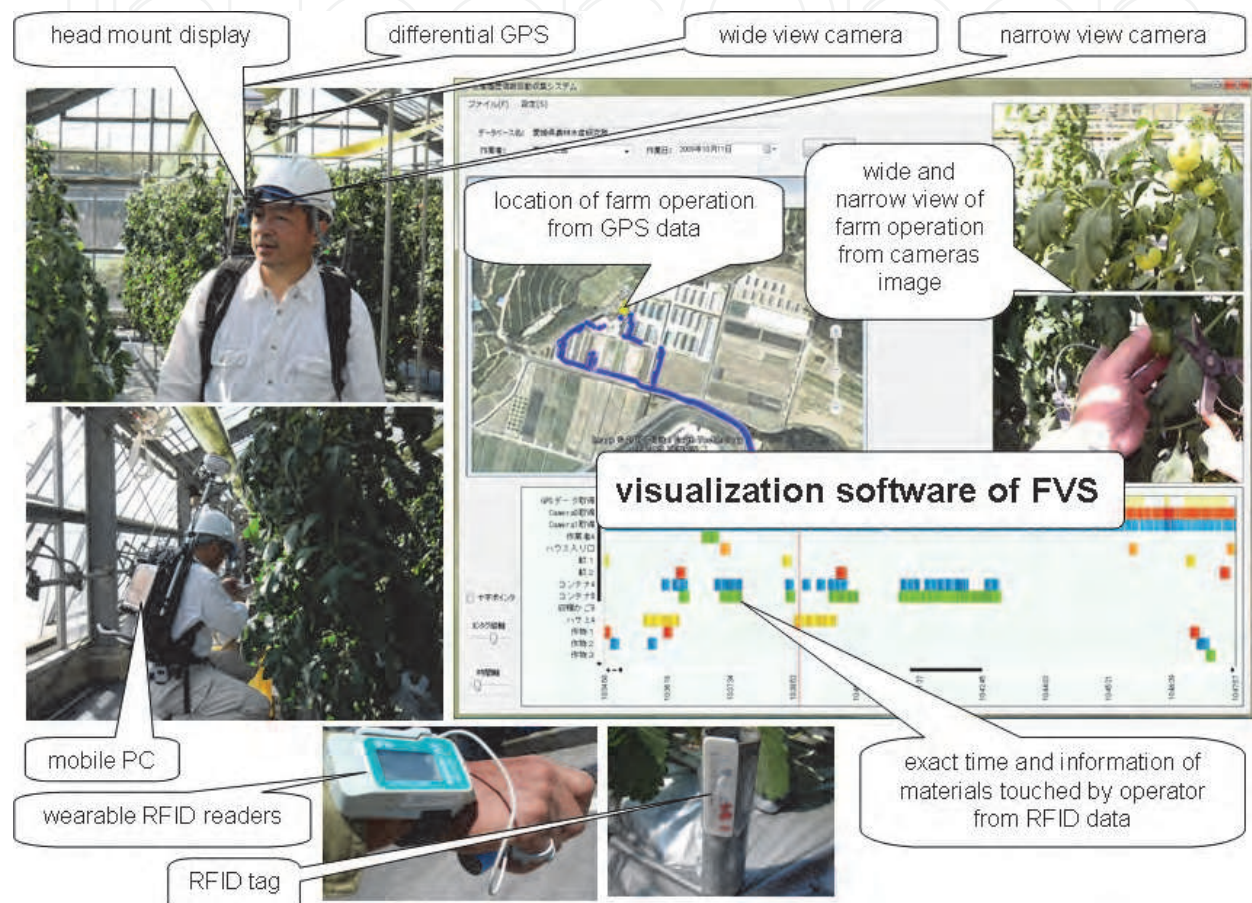

Fig. 10. High-end type of the farming visualization system.

The system enables a fully automatic recording of Five W's and one H information of the whole farming operation. With this system, non-skilled operators can learn farming skills based on recorded visual and audio data of a skilled operator, for example. The data of RFID readers gives exact information about the materials touched by a skilled operator. The data of the differential GPS gives the exact location where an operation is done. Images of farm operation from the viewpoint of the skilled operator give good guidance to non-skilled operators.

The low-end type of system has only one RFID reader with one GPS mobile phone. This type of system is suitable for automatic recording of the location of a farming operation and materials touched by operators. The system is now being tested on several farms, including one of the biggest rice farms in Japan. The farm grows many varieties of rice with several cultivation methods requested by the buyers, in 150 ha of paddy fields. There are more than 20 farming operators. One of the major issues of the farm management is the passing on of

the farming skills of the skilled operators. The FVS is expected to be helpful in solving this problem.

5. Discussion and future work

We have proposed a farm operation monitoring system with wearable devices including RFID readers and conducted some experiments with a prototype system. These experiments show that the system can recognize farming operations appropriately and can provide useful information to users in response to the recognized operations. The feasibility and effectiveness of our proposed system has been evaluated experimentally, and we have discussed issues remaining to be solved future works, and the potential of the system for practical use.

One of the main issues of the system is recognition accuracy. In our experiments, false detection of RFID tags occurred once in a while because of excessive antenna sensitivity. To avoid false or missed detection, adequate design of an RFID antenna is required. For example, a ring-type or a fingertip-type antenna is capable of detecting only fingered objects selectively. By using another type of shaped antenna or combining several types of antennas, we can solve the problem. Adequate tag allocation is also important. Attaching many RFID tags while avoiding the mutual interference and false detection helps the system to increase the recognition accuracy, even when some RFID tags are not detected. We should also consider the position at which we attach RFID tags and the reading interval of RFID readers depending on the operation contents and farmers' activities, so that key RFID tags will not be missed.

To recognize farming operations more accurately, it is important not only to detect RFID tags adequately but also to estimate the farming operation effectively from detected data, including that from motion sensors. In our experiments, we appended a pressure sensor to the wearable device to recognize complicated operations and to interpolate the data of RFID tags. By using many kinds of motion sensors such as finger-bending sensors, acceleration sensors, capacitive sensors, and myogenic potential sensors depending on the situation, this system will be able to recognize farming operations with a high degree of accuracy. With regard to an estimation algorithm of farming operations, we use pattern matching in our experiments, because we attached a minimum amount of RFID tags for this testing. If we had many RFID tags attached to relevant objects, useful motion sensors, detailed rules with many steps for recognizing operations, and preliminary data for supervised learning, we could apply various kinds of estimation algorithms. These algorithms should be customized and adjusted on the basis of the performance of the wearable device, tag allocation, operation contents, and user requirements. It is also important to consider what farming operation should be recognized, how we should define the rules for the farming operation, and which tags and sensors we should use for the recognition. The preparation of registering many kinds of rules and tag information needs careful consideration and a lot of effort. To recognize various farming operations, some support tools for registering these data easily will be needed.

Another problem is the need to overcome fitting difficulties with the wearable devices. In our experiment, the glove with a pressure sensor didn't fit the target user and the sensor data sometimes indicated wrong values that caused mistaken recognition. In general, it is difficult to fit a wearable device to every user, so wearable devices should be designed with a target user in mind or have some key components such as the sensor position be adjustable. Where

and how a wearable camera is set to record clear and desirable image data is also important. A wearable camera may be swung in response to the user's motion, and the position and direction of the camera may easily be changed. The desirable angle and direction of the camera also differs according to the operation and the user's request. For example, a head-mounted camera can record from the user's viewpoint, but the user's head will move frequently during some operations. In some situations, it is better to use a camera with a wide field of view mounted on the user's chest pocket or waist belt. It will be important to design a wearable device with ergonomics, operation contents, and each user's individual features.

Though the proposed system has some open issues, the system in its current form can record a farmer's operation easily and automatically. It is effective for realizing agricultural support applications such as labor control, precision management, and food traceability. To make improvements in farm management, it is important to know how long farmers perform each operation in detail. Our system enables farmers to record labor information easily. In some countries, large-scale farming is popular, so precision management can easily be conducted by using the automatic and mechanized operation system. On the other hand, manual operation tasks are still required in many countries and on many farms, so our proposed system helps to realize precision management in these situations. Especially in Japan, there are many small-scale farms on which it is difficult to perform mechanized farming. Moreover, to grow high-quality crops, practical farmers operate some implements manually, because each crop needs a different amount of fertilizer and chemicals. In food traceability, not only the supply chain but also farmers are required to record the processing of products (Smith & Furness, 2008). The record of cultivation management, especially pesticide use, has become increasingly important, but the task requires much effort. For a farmer to meet the legal requirements, this system is helpful to establish traceability and to provide detailed information such as image data.

This system also enables the production of advanced applications such as controlling equipment in a coordinated manner, useful databases of operation techniques, and navigation and attention systems for new farmers. Field Servers have a function to control peripheral equipment such as greenhouse heaters and sprays. By combining with Field Servers, our proposed system can control suitable machines automatically to reduce farmers' efforts in response to recognized farming operations. By combining the information of operation history and other monitoring information such as crop growth data, we can analyze the effects of operations on the crops. Practical farmers check various conditions with their senses based on their experience, and this system can record data of farming operations of skilled farmers. If we can obtain information not only on farming operations but also on the farmers' behavior, e.g., what they pay attention to and how they interact with crops and fields, the database will become an important tool for understanding their techniques and wisdom. Especially in Japan, the age of the farming population is increasing, and the number of farmers is rapidly decreasing. Therefore, practical techniques of skilled farmers are vanishing, and new generations of farmers lose an opportunity to learn from them. By storing a lot of information on farming operations in detail, this system can provide a useful digital archive of the agricultural system. By using our proposed system, we can realize an advanced decision support system such as the navigation and attention systems. Such a system can provide useful and suitable information such as a tutorial about the next operation in a sequence, the needed data for decision-making, and warnings about misuse to a farmer in real-time in response to recognized operations. Such a system will enhance the farmer's sensitivity, judgment, and activity.

We have proposed an innovative monitoring system to recognize farming operations easily, and have demonstrated the effectiveness and feasibility of a farm operation monitoring system with RFID readers and tags. Our proposed system can be applied to a wide variety of situations and purposes not only in agriculture but also in other fields. It is expected to be used as an effective tool for monitoring humans' behavior and experiences.
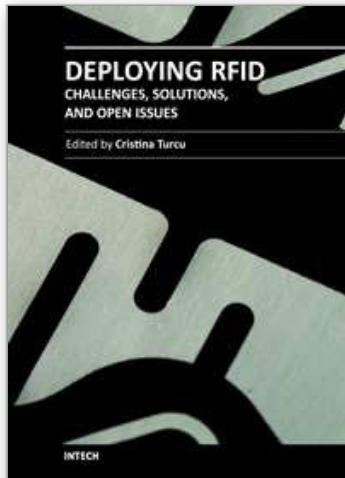
6. Conclusion

To monitor farming operations easily and automatically, we proposed a farm operation monitoring system with wearable sensor devices including RFID readers and tags. By attaching RFID tags to various objects such as farming equipment and performing farm operations with wearable devices including RFID readers, the system can recognize the operation by analyzing the pattern of detected RFID tags and sensor data. This proposed system can monitor farmers' operations flexibly without interrupting their activities or the necessity of changing their facilities or equipment. Moreover, this system can facilitate effective support applications that provide useful information to farmers in response to the recognized operations. To evaluate the feasibility of the system, we conducted several experiments with a prototype system. Through the experiments, we demonstrated the effectiveness and potentiality of our proposed system.

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Deploying RFID - Challenges, Solutions, and Open Issues

Edited by Dr. Cristina Turcu

Radio frequency identification (RFID) is a technology that is rapidly gaining popularity due to its several benefits in a wide area of applications like inventory tracking, supply chain management, automated manufacturing, healthcare, etc. The benefits of implementing RFID technologies can be seen in terms of efficiency (increased speed in production, reduced shrinkage, lower error rates, improved asset tracking etc.) or effectiveness (services that companies provide to the customers). Leading to considerable operational and strategic benefits, RFID technology continues to bring new levels of intelligence and information, strengthening the experience of all participants in this research domain, and serving as a valuable authentication technology. We hope this book will be useful for engineers, researchers and industry personnel, and provide them with some new ideas to address current and future issues they might be facing.

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Tokihiro Fukatsu and Teruaki Nanseki (2011). Farm Operation Monitoring System with Wearable Sensor Devices Including RFID, Deploying RFID - Challenges, Solutions, and Open Issues, Dr. Cristina Turcu (Ed.), ISBN: 978-953-307-380-4, InTech, Available from: http://www.intechopen.com/books/deploying-rfid-challenges-solutions-and-open-issues/farm-operation-monitoring-system-with-wearable-sensor-devices-including-rfid

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