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A WSN-based automatic monitoring system for the foraging behavior of honey bees and environmental factors of beehives

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ABSTRACT

The activity of a honey bee colony is heavily environmentally dependent. So, monitoring the colony activity should include the information of biological and physical factors both inside and outside of a beehive. However, using manual methods to simultaneously monitor the incoming and outgoing activities of a large amount of foragers and the environmental factors with high temporal resolution may cause drawbacks such as labor intensive and low accuracy. To cope with these difficulties, this study develops an automatic monitoring system for honey bee behavior based on wireless sensor network (WSN) technology. The monitoring system can be installed at the entrance of a beehive. The WSN-based monitoring system can not only detect the environmental factors both inside and outside the beehive, but also provide the long-term data of incoming and outgoing foraging activities of honey bees with a high temporal resolution. The results show that the average counting accuracy of incoming and outgoing behavior is 84.92% and 85.95%, respectively. Moreover, the long-term monitoring data that represent the frequencies of incoming and outgoing activities and the beehive related environmental factors are also analyzed. According to the data, honey bees become more energetic when the daily average ambient temperature is higher than 25 °C, and the average ambient relative humidity is between 60%RH and 70%RH. The experimental results show that the proposed monitoring system can reliably collect environmental data and the data related to the activities of honey bees simultaneously. This study also demonstrates that the proposed monitoring system is an excellent platform, which can be used to examine the relation between honey bees' incoming and outgoing activities and environmental factors.

1. Introduction

Honey bees are the most important pollinator on the earth. Over 1500 different kinds of crops and plants in the world are pollinated by honey bees. About 15% of daily food, including natural food and processed food, is related to the pollination of honey bees (Kremen et al., 2002; Seeley, 1985). In particular, foragers are responsible for the food source such as pollen and nectar to provide the necessary nutrition to the whole colony. The incoming and outgoing frequencies of the foragers represent an important index to determine their activity. Moreover, honey bees are sensitive to environmental changes (Abrol, 1992). Therefore, observing the frequency of pollination trips and the incoming and outgoing activities of worker bees and examining how environmental changes influence these workers' behavior are two major issues concerned by the researchers.

In the past, monitoring honey bee activities largely depended on manual inspection (Bujok et al., 2002; Al Ghamdi, 2005; Abrol, 1992; Danka and Beaman, 2007; Dukku et al., 2013). However, many drawbacks were found when using manual ways to monitor the behavior of honey bees. For example, it is extremely difficult for human eyes to catch the behavior of hundreds of honey bees flying in and out of beehives. To solve the problems, therefore, a number of studies have developed automatic and effective honey

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bee behavior monitoring systems. Some studies used the radio frequency identification (RFID) device to monitor individual honey bees (Decourtye et al., 2011; Henry et al., 2012; Streit et al., 2003). But, the doubt was raised regarding whether honey bees with the RFID tags would behave normally. Imaging techniques were also a prevalent approach to entomological behavioral research. Several imaging systems for beehive monitoring have been developed in recent years (Campbell et al., 2008; Chen et al., 2012; Chiron et al., 2013). However, these kinds of devices could only monitor the behavior of an individual bee in the colony. Moreover, a research project called "Let It Bee" initiated in Korea has proposed a prototype of the real-time beehive monitoring system (Let It Bee, 2012). The prototype was used to monitor the beehive related factors and honey bees' incoming and outgoing activities. The monitoring data were transmitted to a database through the Ethernet. Some limits, however, were found when installing such a monitoring system due to its transmission protocol.

Wireless sensor networks (WSNs), on the other hand, provide a key technology to build an automatic and remote monitoring system which collects monitoring data at a given time, transmits the sensing data in real time to a gateway that saves and manages all data, and avoids the costs associated with manual inspection. Further, wireless sensor nodes have the features of small sizes and low power consumption, and they can communicate with each other via radio frequency, rather than through wiring. To remote monitor the whole colony of a beehive, for example, Murphy et al. proposed a WSN beehive monitoring system equipped with biological sensors and physical sensors for automatically detecting important changes in beehive related factors and alerting beekeepers about potential colony threats (Murphy et al., 2015a). They also proposed another remote monitoring system for detecting beehive imagery and sound using a microphone, and accelerometer, and infrared and thermal cameras to monitor the emergency events of bees (Murphy et al., 2015b; Murphy et al., 2015c). These two beehive monitoring system can monitor the whole colony in real time by using the WSN technology, but they cannot provide quantitative data that represent the incoming and outgoing activities of honey bees.

In this study, to monitor honey bees' activities of entering and leaving their beehives, a small-scale automatic monitoring system based on WSN technology is developed. Especially, a novel passageway equipped with infrared Light-Emitting Diode (LED) modules is designed and further combined with a counting algorithm to subtly differentiate honey bees' behavior of coming in and going out of their beehives. Moreover, a number of environmental parameters, including ambient temperature and relative humidity, and the temperature and relative humidity in the beehive, are measured by the sensor nodes. More importantly, this study proposes a real-time automatic monitoring system to monitor all honey bees' incoming and outgoing activities without attaching any tags on bees' thorax.

2. Materials and methods

2.1. System architecture

The architecture of the proposed system is illustrated in Fig. 1. The honey bee behavior monitoring system can be divided into three major parts: the front-end layer, the gateway, and the back-end platform. The key merits of the proposed monitoring system are that the system provides the capabilities of wireless communication, automatic operation, high sampling, etc. The hardware design and the operation scheme of the proposed monitoring system are described as follows.

2.2. The hardware design of the proposed system

The functions and specifications of main hardware components designed for the proposed system are described as below.

2.2.1. Wireless sensor nodes

The Octopus II, was used in this study as the wireless sensor node (Sheu et al., 2008). The Octopus II wirelessly transmitted sensing data to a gateway. It mainly consisted of an MSP430 microcontroller (Texas Instruments Inc.), a wireless communication chip (CC2420, Texas Instruments Inc.), and an extended sensor board for connecting to external sensors. The Octopus II also followed the

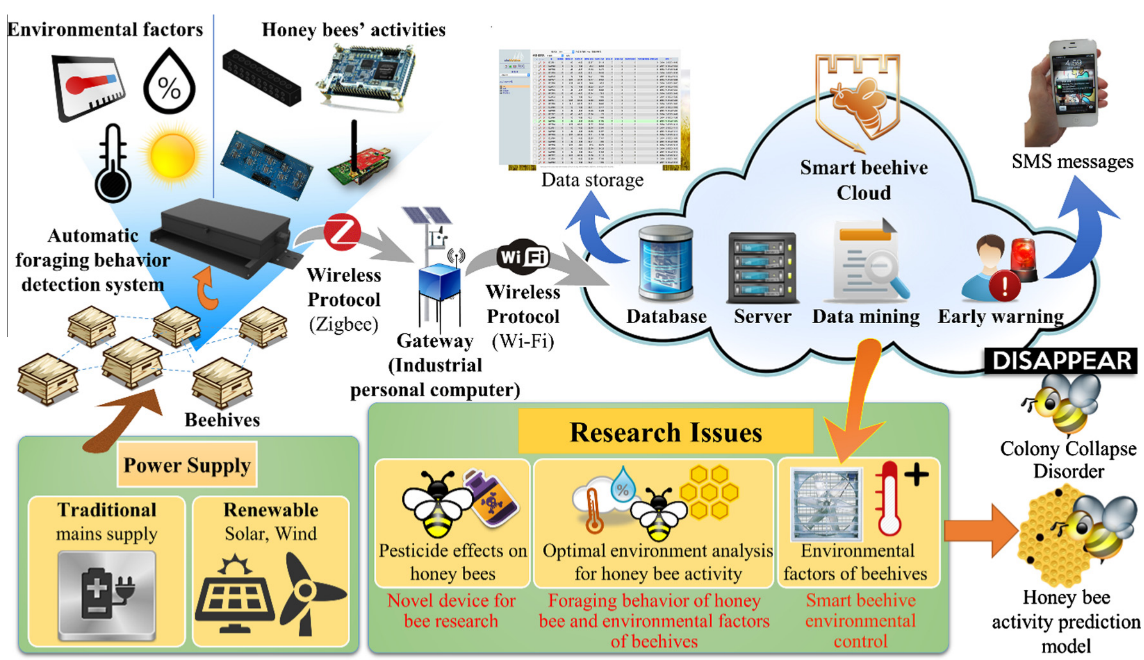

Fig. 1. The architecture of the proposed system for monitoring the incoming and outgoing activities of honey bees and environmental factors.