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Research paper

A wireless communication system for automated greenhouse operations

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ABSTRACT

The objective of this research was to develop a wireless system enabling communication between a Central Control Unit and four robots that worked in a model greenhouse. The wireless system could be applied to control multiple robots in fruit picking, pesticide spraying, and resource transportation. Two of the robots were designated as “work-robots”, traveling in work ways between plants. The other two “assist-robots”, moving in two passage ways, had the task of carrying the work-robots to designated work ways. The results showed that the success rate of system operations under varying conditions was consistently above 95%. The developed wireless control system has shown potential for application in real life greenhouse operations and as an educational tool.

1. Introduction

Wireless sensor networking technologies have been widely applied in communication, control, and environmental monitoring. Common sensor network technologies are Bluetooth, ZigBee®, EnOcean, and TransferJet. ZigBee®, which is based on the IEEE 802.15.4-2003 standard for wireless personal area networks (WPANs), features a low-cost, low-power, wireless machine to machine (M2M) mesh networking proprietary standard, combined with easy installation and maintenance. The low-cost allows the technology to be deployed widely in wireless control and monitoring applications. The low-power usage implies a long operating life enabling battery power, and the mesh networking provides high reliability and extended range. It is also simpler and less expensive than other WPANs, such as Bluetooth®. ZigBee® is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking, which is a specification for a suite of high level communication protocols using small, low-power digital radios.

ZigBee® wireless sensor networks have been applied in the development of control and monitoring systems in agriculture such as in environmental monitoring in precision viticulture (Morais et al., 2007), irrigation and fertilizer control of plants (Coates and Delwiche, 2009), crop canopy temperature monitoring (O'Shaughnessy and Evett, 2010), monitoring of herd motion (Nadimi et al., 2008), monitoring of cows' presence and pasture time in an extended area covered by a strip of new grass (Nadimi et al., 2007), real-time monitoring in precision horticulture (López Riquelme et al., 2009), monitoring body temperature of dairy cows (Ipema et al., 2008), monitoring and modeling of silage temperature (Green et al., 2009).

Greenhouse vegetable and fruit cultivation has the advantage of yielding high-quality products and high-productivity, but it is labor-intensive and requires higher investments than open field production systems. In addition, tasks such as harvesting, spraying, and pruning can be tedious and hazardous. These circumstances decrease the operational efficiency and could affect the operator's health (González et al., 2009). Therefore, in recent years, greenhouse automation of internal transport, spraying and crop harvesting has become an important topic. Some researchers focused on the development of robotic systems for specific tasks in the greenhouse industries. For instance, Singh et al. (2005) developed an autonomous robotic vehicle for greenhouse spraying, where the spraying system was mounted on a pull-behind trailer that was towed down the aisle. González et al. (2009) designed a mobile robot that moved autonomously between lanes of crops in greenhouses. Here the robot served as a carrier for spraying, pruning, and crop transport tools. Van Henten et al. (2003) developed an autonomous harvesting robot for greenhouse cucumbers, as well as a manipulator for cucumber harvesting (Van Henten et al., 2008). Van Henten et al. (2006) also developed an autonomous robot for

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de-leafing cucumber plants grown in a high-wire cultivation system in a greenhouse. In Japan, Shiigi et al. (2008) developed a table top culture strawberry harvesting robot, which the end-effector consisted of a suction head combined with two rotating mechanical fingers. Kondo et al. (2007, 2008) studied robotic tomato cluster harvesting in Dutch-style greenhouses, including image processing, and design of a manipulator and end-effector.

The references cited show automation and robotics trends in greenhouses, but they do not reach the level of multiple robot systems. To allow for the development of multiple robot systems that can be used for internal transport tasks, and in the future for other greenhouse tasks, a wireless communication system is required. This research focused on developing the communication infrastructure, together with a model that demonstrated the capabilities of such a system.

The objectives of this study were to develop a wireless system enabling communication between a Central Control Unit (CCU) and four robots, and to demonstrate basic operations in a model greenhouse.

2. System description

Fig. 1 shows a diagram of the wireless communication system. The system comprises two assist-robots (Robot-X1, Robot-X2) that feature a mounting platform on which two work-robots (Robot-Y1, Robot-Y2) can be carried from one work way to another. Each robot contains a communication chip (ZigBee®), sensors for guidance, drive motors, a microcontroller, and software. A Central Control Unit (CCU) was contained in a PC that served as a command dispatcher, and overall system supervisor. The wireless communication system was developed using LabVIEW® 8.6 in combination with ZigBee® wireless communication technology.

2.1. Robots work pattern

Among the four robots, two termed Robot-Y1 and Robot-Y2 were designated as work-robots that travel in work ways (*Y*-direction). These work-robots in reality would perform tasks such as picking fruits, spraying plants, as well as transporting resources in work ways between standing/hanging plants or plant-benches. After the work-robots have finished a work way, they need to be moved to the next designated work way. For this purpose, two assist-robots termed Robot-X1 and Robot-X2 were built, which traversed the passage ways (*X*-direction) while carrying the work-robots (Fig. 2). The model greenhouse was made from Medium Density Fiberboard (MDF) with a dimension of 2465 mm by 1765 mm. It comprises eight work ways, and two transverse passage ways that are used to transport the work-robots to and from various work ways. Guidance lines made from black tape were added, and stages on the board were delineated by crosses in the guidance lines. These four stages were identified by unique messages to the CCU, I) leaving the carrying assist-robot and traveling along a work way in a forward direction, II) entering a waiting assist-robot in a forward direction, III) leaving the carrying assist-robot and traveling along a work way in a backward direction, IV) entering a waiting assist-robot in a backward direction.

SolidWorks® was used to design the system including the model greenhouse, work-robots, assist-robots and the mounting-platforms (Fig. 3). The robots were made from aluminum, and fitted with two drive wheels and a caster. The passage ways were lowered, such that a work-robot could enter the mounting platform of an assist-robot and be transported to a designated work way. Fig. 4 shows two photos that indicate how a work-robot is being

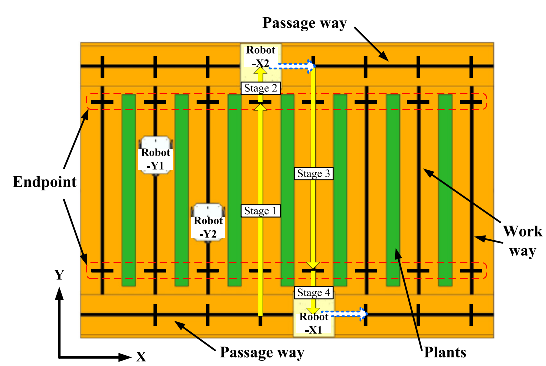

Fig. 2. The experimental greenhouse model.

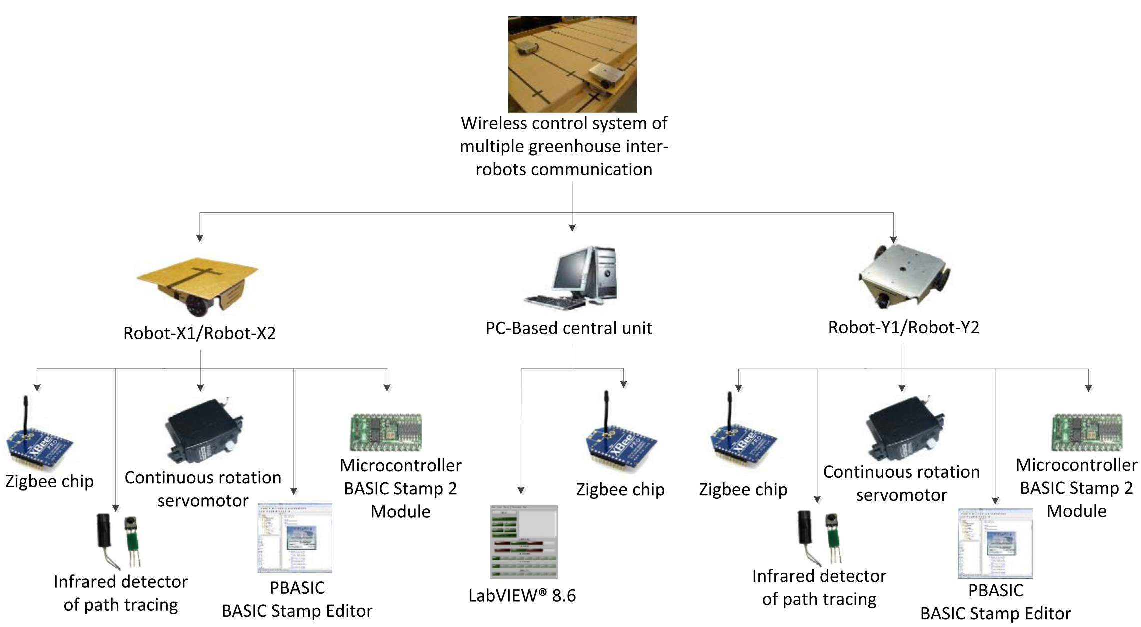

Fig. 1. The wireless communication system comprises 2 assist-robots (left), 2 work-robots (center) and a Central Control Unit (CCU, right).