A communication protocol for collaboration among the measurement and control nodes in a decentralized autonomous environment control system of greenhouses

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Abstract

In this paper, we propose a communication protocol named the “Common Corresponding Message” (CCM) to collaborate among the nodes in a decentralized autonomous greenhouse environment control system, which was developed to reduce the installation cost and realize reliable high-performance greenhouse environment control. The developed system is named the “Ubiquitous Environment Control System” (UECS), and consists of nodes in a network. CCM is delivered as a broadcast or unicast UDP packet through the Ethernet, and uses XML to state the apparatus identification, priority, measurement values, control set-points and condition values in each node. The standardized type name in CCM packet description is able to automatically recognize many nodes by different manufacturers as the same type of node. If the nodes correspond to the CCM standard, growers can install their preferred nodes in a greenhouse regardless of the manufacturer. We constructed two trial systems to evaluate the protocol: a time-programmed multi-environment control system and a hydroponic nutrient control system using CCM for collaborating among the nodes. Performances of the systems exceeded the conventional concentrated environment control systems. These results prove that the protocol using CCM for collaboration among the nodes has high performance.

Keywords: Embedded microcomputer, Internet, Protected horticulture, Ubiquitous computing, XML

Introduction

Computerized environment control systems are now considered indispensable for large greenhouses of more than 3,000 m² floor area in Japan. A decentralized autonomous environment control system was developed to reduce the installation cost and realize a reliable high-performance greenhouse environment control (Hoshi et al. 2004, Hoshi 2007). The developed system is named the “Ubiquitous Environment Control System” (UECS), and consists of nodes in a network. A node that incorporates a low-cost microcomputer board (Fig. 1) into each...
greenhouse environment measurement and control device (i.e., climate sensors, roof ventilators, heaters, etc.) performs its own measurement and control functions independently. Because each node for measurement and control in the greenhouse environment works autonomously, UECS is more reliable and flexible than conventional environment control systems. Conversely, this advantage means that collaboration among the nodes is difficult. Conventional concentrated environment control systems (e.g., Udink ten Cate et al. 1978, Takakura et al. 1979) and hierarchical distributed environment control systems (e.g., Weaving, 1980) are easier to collaborate whole measurement and control devices in a greenhouse than are decentralized autonomous environment control systems such as the UECS. Therefore, to realize integrated environment control by collaborating nodes, it is necessary to establish a specific communication protocol among the nodes. In this paper, we propose a communication protocol to collaborate among the nodes, and confirm the protocol’s capability by tests on two trial systems.

**Communication protocol for collaboration**

Each node in the UECS is connected with the other nodes by 10Base-T Ethernet (IEEE 802.3) cables and hubs. In our proposed protocol, the communication message is named the “Common Corresponding Message” (CCM). CCM is delivered as a broadcast or unicast UDP packet through the LAN in the vicinity of greenhouses, and the packet information consists of the measurement and control device identifier, its priority, measurement values, control set-points and condition values in each node, all of which are written in XML (World Wide Web Consortium 2000). The XML tags and attributes in the CCM are shown in Table 1 and Table 2. Table 1 also shows the packet type and port number of the transport layer (the fourth layer) in the OSI reference model. Almost all CCM packets are grouped hierarchically by the greenhouse room, region and order attributes in the XML tag. The microcomputer boards of each node are also incused these attributes. Only the node that these attributes match can receive the CCM packet. However, each attribute having a 0 value indicates a wildcard that enables the packet to be received by all nodes with any number for that attribute.

A CCM packet sample is shown in Fig. 2. In this example, the measured inside air temperature is 23.5°C by the inside climate measurement node in section No. 1 of greenhouse No. 1. The priority attribute means the order of precedence in cases where there is a conflict with packets belonging to the same group; here, the value 15 indicates a standard priority (Table 2). Especially, the type attribute is important to distinguish the type of measurement and control information, as standardized in the UECS consortium (http://www.uecs.info/, verified May 28, 2008). The standardized description enables information sharing between nodes from different manufacturers. If the nodes correspond to the CCM standard, greenhouse growers can install their preferred nodes freely in a greenhouse regardless of the manufacturer.

The trigger for the dispatch of the CCM packet can be one of three levels, depending on the importance of the information in the packet (Table 3). The level is named a data sharing level, and described such as A-10S, B-0, C-1, etc. with type attribute name. The traffic of the network can be suppressed by arranging a reasonable level of importance for each packet.

```
<?xml version="1.0"?>
<UECS>
  <DATA type="inAirTemp" room="1" region="1" order="0" priority="15">23.5</DATA>
</UECS>
```

Fig.2 An example of the CCM packet for transmitting data by the DATA XML tag.
<table>
<thead>
<tr>
<th>XML attribute Name</th>
<th>Content</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>CCM name</td>
<td>String greater than 3 characters</td>
<td>A token for a discrimination of the other data</td>
</tr>
<tr>
<td>room</td>
<td>Greenhouse number</td>
<td>Integer, 0 to 16</td>
<td>A greenhouse number (0: wildcard number)</td>
</tr>
<tr>
<td>region</td>
<td>Section number</td>
<td>Integer, 0 to 16</td>
<td>A section number in the greenhouse (0: wildcard number)</td>
</tr>
<tr>
<td>order</td>
<td>Reference number</td>
<td>Integer, 0 to 32</td>
<td>A node reference number in the same section (0: wildcard number)</td>
</tr>
<tr>
<td>priority</td>
<td>Priority number</td>
<td>Integer, 0 (highest) to 29 (lowest)</td>
<td>Acceptance priority of the data having the same CCM name (15: standard priority)</td>
</tr>
<tr>
<td>page</td>
<td>Page number</td>
<td>Integer, 1 to 32</td>
<td>A specific page request in the full dataset</td>
</tr>
<tr>
<td>total</td>
<td>Number of page</td>
<td>Integer, 1 to 32</td>
<td>Total page number of the full dataset</td>
</tr>
<tr>
<td>No</td>
<td>Serial number</td>
<td>Integer, 0 to 128</td>
<td>Order in each data item</td>
</tr>
<tr>
<td>element</td>
<td>Element name</td>
<td>String greater than 3 characters</td>
<td>Name of the functional component in a node</td>
</tr>
<tr>
<td>cycle</td>
<td>Recording interval</td>
<td>1s to 509 or 1m to 59m or 1h to 24h</td>
<td>Suffix character shows a unit of time (s: seconds, m: minutes, h: hours)</td>
</tr>
<tr>
<td>date</td>
<td>Date</td>
<td>ymmmd</td>
<td>yy means under 2 digit of the domimical year, mm means month, and dd means day number</td>
</tr>
<tr>
<td>time</td>
<td>Time of day</td>
<td>hmmmms</td>
<td>lh means hours, mm means minutes, and ss means seconds in the day</td>
</tr>
</tbody>
</table>

Table 3. Data sharing levels among the UECS nodes in the Data transmission type of the CCM packets.

<table>
<thead>
<tr>
<th>Level Options (trigger of data share)</th>
<th>Packet type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A -1: every 1 second, -10S: every 10 sec., -1M: every 1 minute</td>
<td>UDP broadcast</td>
<td>Asynchronous data sharing</td>
</tr>
<tr>
<td>B -0: data request CCM packet received, -1: -0 plus data changed</td>
<td>UDP broadcast</td>
<td>Timely data sharing</td>
</tr>
<tr>
<td>C -0: data request CCM packet received, -1: -0 plus data changed</td>
<td>UDP unicast</td>
<td>Timely and closed data sharing</td>
</tr>
</tbody>
</table>
Verification test systems and methods

The communication software based on the proposed protocol was implemented on a microcomputer board (Fig. 1) as firmware with other UECS library software. The software, named “Embedded Operating Library for Ubiquitous-control System (EOLUS),” was developed using Cygwin ver. 2.457.2.2, Eclipse ver. 3.0.2, Eclipse-CDT ver. 2.0.2, gcc ver. 3.4.3, binutilis ver. 2.15 and openTCP ver.1.0.4.

We set up two different systems to confirm the node collaboration. One system was a time-programmed multi-environment control system and the other was a hydroponic nutrient control system. The EOLUS and measurement control software for each greenhouse environment measurement and control device was installed on each microcomputer board. We employed a total of 19 nodes for the tests.

In the first system, the test for forced operations and time-programmed multi-environment control using CCM was performed. A remote control switch node and a program controller node (Fig. 3) were manufactured for remote control of many nodes in a greenhouse. All of the nodes had three states in their operation: an autonomic control state, a remote control state, and a remote operation state. When no specific CCM packet for remote control or remote operation was received, the node operated autonomously according to the embedded measurement and control software. If specific CCM packets were received, the node then operated according to the packets’ forced operation orders or control set-points. The remote control CCM packets were sent as orders of the program controller nodes and application software in the PCs, and the valid time for receiving a packet was 3 minutes. The remote operation CCM packets were sent as orders of the remote control switch nodes, and their valid time was 3 seconds, and the priority of the packets was higher than that of the remote control CCM packets. This system has been in the testing stage at a tomato production greenhouse (floor area: 1,782 m²) since Dec. 19, 2007. In the test, 16 sets of different manufacturer’s nodes were connected through the LAN (Fig. 4). The program controller node functions as the commander, and the system works as a time-programmed multi-environment control system.

Fig. 3 Exterior views of the trial manufactured remote control switch node (left) and the program controller node (right).
The second system, a hydroponic nutrient control system, was developed to test peer-to-peer communication using the CCM handshake. A nutrient maker node and nutrient bed nodes were manufactured. The system was able to connect one nutrient supply node to a maximum of seven nutrient bed nodes (Fig. 5). The nutrient maker node supplied specific nutrient solutions during negotiations with the nutrient bed nodes and monitored for problems in the hydroponic nutrient control system. The nutrient bed node controlled the hydroponic cultivation environment, and also processed crop cultivation information such as the following: days after planting, preferred nutrient compositions of each growth stage, etc. Three kinds of data transmission CCM packet were designed to avoid demand conflicts between the nutrient

Fig. 5 The UECS nodes in the test of the hydroponic nutrient control system.
bed nodes. An example sequence of a CCM exchange by data handshake is shown in Fig. 6. One nutrient maker node and two nutrient bed nodes were installed in a greenhouse to test the system. Each nutrient bed node was attached to a deep-flow technique (DFT) type hydroponic cultivation bed (1.2 m wide x 1.8 m length). A spinach cultivation test was performed from June 16 to July 6 in 2007.

Results and discussion

All nodes that were programmed as measurement control modes of the three states were confirmed to perform their prescribed operation in the greenhouse. For example, we could operate the roof ventilator manually after setting the remote control switch node connected to any greenhouse LAN connector, and the roof ventilator node returned to autonomous control using its control set-point within 3 seconds when the remote control switch node was disconnected. Because the remote control switch node was of a convenient size, it was easy to check and adjust the measurement and control devices anywhere only connected to the LAN.

Furthermore, the corroboration environment control of all measurement control nodes by mechanisms of the CCM and program controller node functioned satisfactorily. The program controller node delivered the CCM packets for remote operation orders and control set-points, and each node worked according to these (Fig. 7). Figure 7 also shows that the dehumidification control for operation three times per day by cooperation of the air heater nodes and roof ventilator node was confirmed. If the program controller node stopped the CCM packet transmission due to failure or power-off, all nodes returned automatically to the autonomous control state after 3 minutes. UECS was able to complete triple fail-safe control by the communication protocol. The result showed that the programmed multi-environment control system by UECS was superior to the conventional control system in reliability.

The nutrient maker node was able to handle any conflicting demands for nutrient supply from the hydroponic cultivation bed nodes by the exchange of CCM packets. In the test period, hydroponic nutrient solution was supplied a total of 12 times through the node collaboration, and the spinach on two cultivation beds grew normally (Fig. 8).
These results prove that the CCM protocol for collaboration among the UECS nodes has high performance. All measurement and control information are transmitted through the LAN, and therefore we are able to obtain a system operation log simply by connecting to a PC with packet capture software. Because the CCM packets are described in XML, the XML and Web application software systems (e.g., Hoshi et al., 2003) are easy to link the UECS using the CCM packets.

Fig. 7 Time courses of measurement, control and set-point values on the programmed multi-environment control system on Feb. 14, 2008.

Fig. 8 A spinach cultivation test of the hydroponic nutrient control system. A white cube box under the bed is the nutrient bed node.
Acknowledgement

We express our thanks to Mr. Masahiro Hiraki, Agribest Co., and Mr. Kazuo Tsuchiya, Taiyo Kogyou Co., for permitting us to use the test greenhouses and hydroponic cultivation systems, and Dr. Hidehito Kurosaki, NIVTS for permitting us to use the CCM packet monitor software. The work was supported in part by a research project for utilizing advanced technologies in Agricultural, Forestry and Fisheries under Grant No. 1652, Agricultural, Forestry and Fisheries Research Council.

References


