Design of a Smart Greenhouse System based on MAPE-K and ISO/IEC-11179

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***Abstract*— A smart greenhouse monitors the internal and external context information of the greenhouse in real time and keeps the internal environment in an optimal condition for the growth of crops. In this paper, we propose a smart greenhouse system based on MAPE-K that can automatically control the greenhouse. All information of the proposed system is stored and managed through an ontology knowledge repository based on ISO-IEC 11179 (metadata registry, MDR). Furthermore, we design a low cost smart greenhouse by interoperating the smart devices.**

I. Introduction

A smart greenhouse is necessary to maintain the interior of a greenhouse as the optimal environment for the growth of crops. The internal and external context information of the greenhouse is monitored in real time using various sensors [1].

In this study, we define adaptation knowledge (AK) as all the information that a smart greenhouse needs to operate smoothly, such as context information and automatic control strategies. We store and manage the AKs of a smart greenhouse system using an ontology repository based on ISO/IEC-11179 (metadata registry, MDR) [2]. Further, we propose a smart greenhouse system utilizing the MAPE-K loop [4]. Finally, to reduce the system cost, our smart greenhouse system determines the most appropriate strategy for the environment by operating smart devices. The smart greenhouse only collects context information, while the implementation strategies are determined by smart devices.

The main contributions of this paper are as follows:

- Our MDR-based ontology repository for the smart greenhouse can solve data interoperability problems between the systems. Further, it is easy to show the association between various AKs that arise in a smart greenhouse system.
- We apply the concept of a self-adaptive system, specifically the MAPE-K model, to smart greenhouse systems. Therefore, our smart greenhouse system enables efficient and automatic control for the greenhouse environment.
- Our smart greenhouse system interworks with smart devices to perform complex operations using their CPU. The smart greenhouse itself only monitors the context information and performs determined strategies, thereby reducing the system cost.

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II. Background

A. Self-Adaptive system and MAPE-K

A self-adaptive system is a system that can diagnose and solve problems on its own. As the size and complexity of modern software systems have increased, such system have been developed to address the current limitations of system management [3]. Most self-adaptive systems are based on MAPE-K models (Monitor, Analyze, Plan, Execute, and Knowledge) from IBM [4]. MAPE-K consists of K, that contains all knowledge of the adaptation process, and MAPE, that provides control loop functions.

B. Metadata Registry

Metadata is defined as data for defining specific data. If metadata is defined differently for each system, then it brings about interoperability and reusability problem between systems. To solve these problems, ISO/IEC 11179 (metadata registry, MDR) was developed as an international standard for the registration and sharing of metadata in ISO/IEC JTC1/SC32 (Data management and interchange) [2]. Metadata can be defined, registered and managed based on one standard framework by applying the MDR standard, thereby we improve reusability between metadata.

III. Smart greenhouse System

In this study, we propose a smart greenhouse system based on MAPE-K and ISO-IEC 11179. The AK management for our system can solve interoperability issues since we designed the AK through the ontology based on ISO/IEC-11179, an international standard for metadata. Further, the concept of self-adaptation, especially the MAPE-K model, is utilized for automatic control of the greenhouse environment. Finally, we reduce the system cost by interworking with smart devices.

A. Knowledge Management for Smart Greenhouse

We aim to design an AK for a smart greenhouse by using an ontology knowledge repository based on the MDR standard. Designing a knowledge repository requires two steps as follows: 1) registration of the AK in the MDR, 2) ontology design based on the MDR.

First, in the “registration of the AK in the MDR” step, all AKs generated in the smart greenhouse system are registered in the MDR. AKs include context information of the interior and exterior of the greenhouse, automatic control strategies,

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and the information of crops in the greenhouse. When exchanging data between multiple smart greenhouse systems, interoperability issues can be solved with the AK's metadata management based on international standards. Table I lists the specification of the MDR object class for the AKs of the smart greenhouse system.

TABLE I
MDR OBJECT CLASS FOR SMART GREENHOUSE SYSTEM

Object	Description
TemperatureControl	Object of the temperature control system
WindowControl	Object of the window control system
VentilatorControl	Object of the ventilator control system
GasControl	Object of the CO_2, O_2 control system
HumidityControl	Object of the humidity control system
LightControl	Object of the light control system
SoilConditionControl	Object of the management of soil condition
MonitoringSystem	Object of the system for monitoring the internal and external conditions of a greenhouse
Crop	Object of the crop information

The properties of the objects are expressed in “Data Element Concept,” “Data Element,” and “Value Domain,” in accordance with the MDR standard [2].

In the second step, we design an ontology based on the AK registered in the MDR by using OWL language. Ontology can be used to express connections between the AKs, and place constraints on input values. In other words, the ontology knowledge repository contains all the AKs of the single devices as well as their relationship information in the smart greenhouse system.

B. *Smart Greenhouse based on MAPE-K*

To utilize the previously designed AK repository, we propose a smart greenhouse system based on the MAPE-K model to automatically control the environment interior the greenhouse. Fig. 1 shows the framework of the proposed smart greenhouse.

A description of the MAPE-K step-by-step processes are as follows:

- **Monitoring (M)** collects context information of the interior and exterior of the greenhouse through sensors, such as temperature, humidity, light, and gas (O_2, CO_2).
- **Analysis (A)** analyzes the monitoring data, and determines when the internal environment of the greenhouse needs to change.
- **Plan (P)** finds all the adaptation strategies in the AK repository when environmental changes in the greenhouse are needed, and selects the optimal strategies through computation by the smart devices.
- **Execute (E)** operates the control systems based on the adaptation strategy determined in the previous step.
- **Knowledge (K)** is an ontology repository based on the MDR. Our repository is based on the cloud. Therefore, it is possible to exchange the AKs among smart device, repository, and greenhouse.

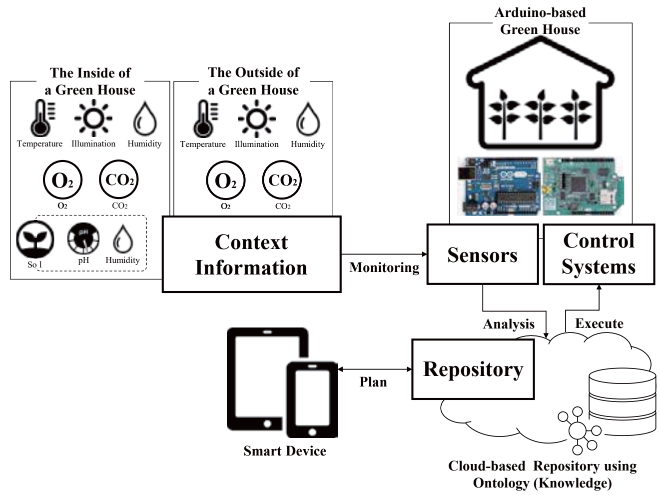

Fig. 1. The framework of the proposed smart greenhouse based on MAPE-K

The MAPE process executes repeatedly and K can be changed through the iteration of MAPE process. Finding an appropriate strategy in AKs requires complex computations. In our smart greenhouse system, smart devices perform a complex operation to maintain the environment inside the greenhouse, while the smart greenhouse itself performs simple tasks such as sensing and controlling system operation.

IV. CONCLUSION AND FUTURE WORK

In this study, we proposed a low cost smart greenhouse system with the MDR and MAPE-K model. The AKs for the system is stored and managed in a cloud knowledge repository based on both the MDR and ontology. Further, our system is based on the MAPE-K model to automatically control the system. Finally, complicated operations are performed by the smart devices. The greenhouse itself only performs simple tasks such as sensing and operation of the control system.

Future study will involve developing a smart greenhouse based on a design presented in this paper using Arduino. We will focus on constructing the knowledge repository and interworking with the smart devices.

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