UNIVERSITI PUTRA MALAYSIA

IMPROVED ACCESSIBILITY AND CONNECTIVITY PLATFORM FOR ASSISTIVE INDOOR PLANT MONITORING SYSTEMS

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IMPROVED ACCESSIBILITY AND CONNECTIVITY PLATFORM FOR ASSISTIVE INDOOR PLANT MONITORING SYSTEMS

By

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June 2016

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Indoor plant has been identified to have positive effects on human wellbeing (physically, psychologically, and economically). However this organism needs special requirement and each type has its own unique condition to thrive. Thus, plant's care without enough knowledge and usage of suitable tools would be difficult, inaccurate, inefficient, unpleasant and even impossible. Previously a number of web-based or phone-based monitoring systems were developed to assist indoor plant lovers, but those systems are not usable due to the accessibility and connectivity issues.

In this work, an indoor plant monitoring system was proposed by focusing on accessibility and connectivity issues. To achieve the objectives, three modules were developed and evaluated. The first one (Plant Monitoring module) emulates Internet connected plant's pot, the second one (the Ambient User Interface module) aggregates appropriate contexts from two separate online sources from the Internet, performs reasoning on the obtained data and implicitly informs the latest condition of the plant to the user. The online database service module was also developed to store/share sensor data and provide plant's care information which will be consumed by the Ambient UI module.

Experimental results show that the developed assistive system worked correctly as it was expected. Additionally, performance of the system was investigated by measuring and analyzing execution time, response time and network overhead of the developed embedded systems and online web services.

The result shows that the data handling and communication of the embedded systems was stable and reliable. Although network overhead and a few number of latency were observed from online web servers, but the whole operation was less than 2 seconds which is more than adequate for a plant monitoring system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENAMBAHBAIKAN KEBOLEHCAPAIAN DAN KESALINGHUBUNGAN PLATFOM UNTUK MEMBANTU SISTEM-SISTEM PEMANTAUAN TUMBUHAN DALAM RUMAH

Oleh

HAMIDREZA PARVARESH

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Tumbuhan dalam rumah dikenalpasti mempunyai kesan positif terhadap kesejahteraan manusia (secara fizikal, psikologi dan ekonomi). Walau bagaimanapun organisma ini memerlukan keperluan khas dan setiap jenis mempunyai syarat tersendiri untuk berkembang maju. Oleh itu, penjagaan tanaman tanpa pengetahuan dan penggunaan alat-alat yang sesuai adalah menyukarkan, tidak tepat, tidak cekap, tidak menyenangkan dan bahkan mustahil. Sebelum ini beberapa sistem pemantauan berasaskan laman web dan telefon dibangunkan untuk membantu pencinta tumbuhan dalam rumah, tetapi sistem tersebut tidak boleh digunakan kerana isu-isu kebolehcapaian dan kesalinghubungan.

Dalam kerja ini, sistem pemantauan tumbuhan dalam rumah dicadangkan dengan memberi tumpuan kepada isu-isu kebolehcapaian dan kesalinghubungan. Untuk mencapai objektif, tiga modul telah dibangunkan dan dinilai. Yang pertama (modul pemantuan tumbuhan) mengemulasi pasu tumbuhan yang berhubung dengan Internet, yang kedua (modul ambien antaramuka pengguna) agregat konteks sesuai dari dua sumber dalam talian yang berasingan dari Internet, melakukan pertimbangan terhadap data yang diperolehi dan memberitahu keadaan terkini tumbuhan secara tersirat kepada pengguna. Modul perkhidmatan pangkalan data secara dalam talian juga dibangunkan untuk menyimpan / berkongsi data sensor dan memberi maklumat penjagaan tumbuhan yang akan digunakan oleh modul ambien antarmuka pengguna.

Keputusan eksperimen menunjukkan bahawa sistem bantuan yang dibangunkan berjalan dengan betul seperti yang dijangka. Selain itu, prestasi sistem dikaji dengan mengukur dan menganalisis masa pelaksanaan, masa tindak balas dan overhead rangkaian sistem ynag dibangunkan dan perkhidmatan web dalam talian. Hasil menunjukkan bahawa pengendalian data dan komunikasi sistem adalah stabil dan boleh dipercayai. Walaupun overhead rangkaian dan beberapa bilangan kependaman telah diperhatikan dari pelayan web dalam talian, tetapi keseluruhan operasi adalah

kurang daripada 2 saat iaitu lebih daripada mencukupi untuk sistem pemantauan tumbuhan.

I certify that a Thesis Examination Committee has met on 1 June 2016 to conduct the final examination of Hamidreza Parvaresh on his thesis entitled "Improved Accessibility and Connectivity Platform for Assistive Indoor Plant Monitoring Systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This is to confirm that:

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
AUI	Ambient User Interface
DB	Database
FIN	Finish
HCI	Human Computer Interaction
HTTP	Hyper Text Transfer Protocol
IR	Information Retrieval
IP	Internet Protocol
QoS	Quality of Service
SYN	Synchronize
TCP	Transport Control Protocol
UDP	User Datagram Protocol
UI	User Interface
URI	Uniform Resource Identifier
VOIP	Voice over Internet Protocol
XML	Extensible Markup Language
XSLT	Extensible Stylesheet Language Transformation

CHAPTER 1

INTRODUCTION

1.1 Overview

It has been shown that living, green, or flowering indoor plant has a positive effect on human health and wellbeing. Indoor plants can reduce air pollution [1], improve mental health [2], increase productivity [3], improve recovery time and pain tolerance of patients [4], and even increase financial benefit for commercial sectors by improving business image where plants are used as decoration [5] .

However, indoor plants unlike other living organisms (e.g. animals) are unable to search for foods or leave their unpleasant condition to thrive. Improper watering, unstable temperature, darkness or light intensity and lack of proper humidity are the common reasons for indoor plant's health problems [6]. Although care giving itself (as a mutual benefit) has positive effects on human wellbeing [7], [8], but according to [9] essential conditions (light, temperature, relative humidity and soil moisture) are different and unique for each plant which make plant's' care a difficult task for people.

1.2 Problem Statement

Learning and remembering plant care data for a large number of indoor plants is not a reasonable or even possible task to be done by people. Even if they have enough knowledge, checking condition of plants without any measurement tool is not an accurate and easy task. In addition, improper plant care contributes to many plant diseases and problems which consequently imposes negative health effects (e.g. anxiety, stress and depression) on the plant's caregivers. Thus, indoor plant care without using an assistive system would not be a usable, efficient, pleasant or even possible task.

Indoor plant care makes people feel satisfied and happy and contributes to their longevity when they have the responsibly of their plants and perform final decision-making themselves [10], [11] . Thus, autonomous systems such as [12] would not be an appropriate solution for this requirement. Accordingly instead of using robot or fully automated systems, monitoring can be applied as a more suitable and affordable plant's care method.

Current indoor plant monitoring systems are developed based on Web or Phone (voice call, SMS or Applications) architecture. However, these systems have a number of problems related to accessibility and connectivity.

In web based systems [13] users are needed to access online web sites explicitly to gather care information and monitor plant condition. In addition, they must have interest and enough knowledge to work with the web (digital world) and access online web pages. Furthermore, as a result of the new generation of diseases like technophobia [14], [15], lack of digital literacy [16] and physical barriers [17], usage of Tablets for monitoring indoor plants (e.g. [12], [18]–[20]) would be a hard and unpleasant task.

On the other hand, although phone call or SMS notification by plants might be entertaining at first sight, scalability issue will arise when every plant tries to call [21] every few minutes and occupies phone lines to complain about its unwanted situation and consequently disturbs the user. In addition, this type of notification would not be accessible to all users due to design constraints (e.g. small screen and keypad size) of handheld devices and difficulties in usage of cell phones [22]–[24].

In addition, connectivity is another issue in design and development of monitoring systems, especially for people in under developed countries or in rural areas. Speed of execution, response time (delay) and connection stability are a number of factors which affect system connectivity, responsiveness, cost of usage (e.g. Internet bandwidth) and maintenance (e.g. changing battery) in Internet-connected systems. Thus, it is considerably needed to develop an accessible assistive monitoring system which reduces plant's care difficulties for all users.

1.3 Objectives

The main objectives in this study were as follows:

1. To propose a system architecture for monitoring of indoor plants.
2. To develop and evaluate performance of an embedded appliance which emulates sensor data measurement from plant pot and sends information to the internet,
3. To develop and evaluate performance of an embedded appliance which aggregates needed information from online sources, makes decision and implicitly informs plant's condition to the user through an ambient user interface.

1.4 Research Scope and Limits

The reason for choosing this research is the importance of indoor plants, their verified positive effects on human wellbeing, difficulties and problems of existing plant care systems and the need for an accessible plant monitoring system. This study reports the development of an Indoor Plant Monitoring system by focusing on accessibility and connectivity issues with lab setup (wired network) while excluding power (energy) measurement, sensors and real plant data.

For the development of the system, an open hardware physical computing platform (Arduino board) was used with its Wiznet Ethernet shield. This setup provides performing sensor emulation, Internet connection, data sending/receiving and aggregation processes. Selected embedded system uses an inexpensive 8-bit ATMEL AVR microcontroller (cost less than $2) which makes the system development affordable for large scale implementation. To increase speed of testing and reduce cost of system development, artificial sensors data was injected by generating random value inside embedded system instead of using physical sensor components. These data randomly were generated inside the embedded system in specific and controlled range, to emulate environmental condition of plant.

The online web broker service (Xively) was used as the database for storage and sharing emulated plant's environmental sensor data. In addition, a simple and machine friendly website was also developed and implemented (using .Net framework and XSLT) to provide caring information for each plant. This database as the second online source will be used for decision making by the ambient UI module. For testing the developed system, nine sample (artificial) plant type and their caring information were stored in this online plant care web site and the embedded system (UI) was limited to access plant's web page address which was manually specified (programmed) inside microcontroller.

The explicit interaction with human is out of current work scope and the applied HCI method is based on implicit interaction in its simplest form (light and color) by using LEDs (Green, Yellow and Red) attached to four side of designed UI. This ambient interface is restricted only to two states of turning on/off the LEDs and other methods of interaction (e.g. changing intensity of LEDs or blinking) are out of current work scope.
To clearly quantify overhead and network packets the embedded system was connected to local network using wired LAN cable. However, it could easily switch to Wi-Fi for connecting directly to the internet.

Embedded systems operate in four states of idling, executing, transmitting and receiving [25]. Microcontrollers consume notably less energy when they are in sleep mode, while data communication (send/receive) in networked system uses high proportion of energy [26]. In addition, latency from online services makes a battery powered system to wake up (stay active) and to be connected to the Internet for longer time and consequently wastes more energy from resources-constrained embedded system. Clearly, when the microcontroller executes slowly or performs data communication (e.g. sending/receiving ACK packet to/from a remote server) with delay, the embedded system cannot go to sleep mode and should remain active till the end of operation.

In this work and in the course of testing connectivity of developed modules, the embedded system was limited to powering up by connecting to a laptop PC (5V USB port) as power supply and the power consumption was not measured in real time.

Depending on complexity of system, reasoning section of a plant care application might include a simple decision making process to an advanced/complicated mechanism (e.g. machine learning). In a complex and very accurate plant monitoring system, each condition could affect another (i.e. high humidity affect low soil moisture). In addition, the plant might needs different condition in its early growing season than other life stage and even night condition might be different than daily condition. However, in this work the embedded system (AUI) is limited to performing its decision making by applying a rule-based technique and mentioned issues are out of the current work scope.

The rules are defined inside the embedded system and used aggregated high priority variables (temperature, humidity and light), in real-time (dynamically) from two online sources as the facts. However, for the enhanced criteria (soil moisture) a static optimal value is defined inside embedded system for reasoning on all plants. In addition, for decision making process, the system is limited to compare the conditions (e.g. temperature vs. light) separately without considering their effects on each other.

Unlike human related monitoring system, security and privacy is not an essential issue for monitoring indoor plant and have not been considered as a requirement in this work at this level. Selected resource constraint embedded system has limited processing power and memory. Thus encryption method was only applied from the online sensor brokerage service which needs authentication for connecting embedded systems to it and no more security/privacy consideration has been applied in development of the system.

1.5 Thesis Outline

This thesis organized in five chapters:

Chapter 1 provides an introduction to the thesis. The problem statement, the objective, the scope and the outline of thesis are stated on this chapter.

Chapter 2 provides a comprehensive literature review on related works, fundamental concepts, difficulties and issues of system's development.

Chapter 3 presents method of design, development and configuration of the system. System's design discussed by presenting architecture of the proposed indoor plant monitoring platform and explaining selected methods and tools. Method of development discussed in details about the plant monitoring module, the online DB services and the ambient UI module. Performance metrics and measurements tools also explained in the last section of this chapter.

Chapter 4 presents obtained experimental results for each module of the developed system. Performance result of the system also presented and discussed by investigating execution and network data transmission. In addition, stability and reliability of the plant monitoring module, online DB services and the ambient UI module presented and discussed in the last section of this chapter.

Chapter 5 summarizes the thesis and presents future works.

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