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An easy-to-use 3D visualization system for planning context-aware applications in smart buildings

Jun-Ming Su [a,*], Chih-Fang Huang [b]

[a] Department of Information and Learning Technology, National University of Tainan, 33, Section 2, Shu-Lin St., Tainan 70005, Taiwan, ROC
[b] Department of Information Communications, Kainan University, 1 Kainan Road, Luzhu Shiang, Taoyuan 33857, Taiwan, ROC

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ABSTRACT

With the proliferation of wireless sensor network technologies, the context-aware applications of smart environments have become more and more popular. However, time-consuming and labor-intensive works hamper the development of smart building applications. Therefore, application developers need the proper software platforms to efficiently design the applications. Much research currently proposed the design approaches based on low-level concerns and the real-world deployments based on high-level programming abstraction are rare. Accordingly, the pressing issue is how to offer the easy-to-use tools with acceptable performance to rapidly and easily design the application scenarios for non-technical application users. Therefore, this study focuses on the application-layer simulation to propose a Visualization System of Context-aware Application Scenario Planning (VS-CaSP) for assisting non-technical developers and end-users in rapidly and easily designing the application scenario of smart buildings and in performing the acceptable and predictable simulation and evaluation. VS-CaSp applies rule-based and 3D visualization techniques to offer a 3D authoring environment integrated with real Zigbee sensor devices, where designers are able to rapidly construct immersive 3D buildings and easily plan the context-aware application scenario via GUI tool based on proposed three-tier rule hierarchy, to visually simulate and verify the planned scenario via virtual and real sensor devices, and to repeatedly modify the control strategies to enhance the deployment effectiveness. The experimental results show that VS-CaSP is easy to use for the support of quickly designing smart building applications, but not professional enough for developments of 3D modeling, animation, and rule expression. Accordingly, it is workable and expected to prove beneficial to non-technical users.

1. Introduction

With the rapid development of network and communication technologies, the context-aware smart environment [1–3] is becoming an emerging topic in the recent years. Weiser [4] firstly proposed the concept of Ubiquitous Computing (UbiComp) [3], which indicates that anyone and anything can retrieve required information via computers or terminal devices through networks at anytime and anywhere. Wireless Sensor Network (WSN) technology [5] can equip various instruments with environmental parameters sensing, computing, and storing functionalities. Furthermore, the mature technologies of Radio Frequency Identification (RFID) and ZigBee [6,7] enable the development of context-aware services in smart environments, which can provide users with active and adaptive services according to users' behaviors and preferences in the real world. Therefore, many context-aware applications and services are thus proposed and developed. For example, Home Automation uses wireless communication, RFID, and sensor devices to monitor the home situations in order to offer users the proper life information and assistance [1,8–14].

However, deploying the context-aware applications is quite time-consuming and labor-intensive, because the processes including plan, deployment, test, and modification are required to be performed in the actual target environments [15,16]. Accordingly, the design and evaluation methodologies are necessary for designing context-aware application scenarios [17]. Mottola and Picco [16] pointed out that application developers need the proper software platforms to efficiently design the applications for promoting the WSN technology although hardware advances play an important role. However, much research currently proposed the design approaches based on low-level concerns, including data collection, sensor deployment, routing algorithm, and communication simulation, to assist the design process in WSN [18–22]. For example, Shu et al. [15] developed the NetTopo, a framework integrated with virtual and real testbed, to offer both simulation and visualization functions to assist the investigation and design of algorithms in WSNs. On the contrary, the real-world deployments based on high-level programming abstraction are rare. Moreover, low-level programming-based methods not only shift the focus of application domain experts away from the application scenario, but also require a technical background rarely found among them.

* Corresponding author.
E-mail addresses: junming.su@gmail.com (J.-M. Su), jeffh@saturn.yzu.edu.tw (C.-F. Huang).

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Therefore, in order to efficiently promote the technology of smart building applications, the pressing issue is how to offer the easy-to-use programming platforms with acceptable and predictable performance and reliability to rapidly and easily design the application scenarios for non-technical application domain experts [16]. Thus, Mocofan et al. [23] and Jouve et al. [24] developed the systems based on high-level application concerns to assist users in configuring application scenarios of smart buildings. However, the application scenario configuration methods using parameters adjustment of predefined scenarios confined the variety and flexibility of applications. Furthermore, to improve this issue, Bischoff et al. [25] and Guo et al. [26] applied rich rule-based languages to edit application scenarios of the smart homes, but the text-based editing method is still difficult to edit for the non-technical end-users and designers. However, aforementioned approaches either support the 2D simulation only [24–27], or cannot support the 3D model authoring [23]. Therefore, the immersive and flexible degrees may be insufficient for the early-stage deployment of context-aware applications. Afterwards, Kaldeli et al. [28] and O'Neill et al. [29] developed systems employed with professional rule engines and 3D modeling tools to support the applications deployment of smart buildings. Similarly, rule-based scenarios also need to be edited by text-based writing. Besides, professional 3D modeling tools may not be easy enough to be learned and used for the non-technical end-users.

Therefore, this study aims to develop an easy-to-use 3D Visualization System of Context-aware Application Scenario Planning (VS-CaSP) to assist non-technical developers and end-users in rapidly and easily designing the application scenario of smart buildings and in performing the acceptable and predictable simulation and evaluation. Based on high-level programming abstraction and application-layer simulation, VS-CaSp applies rule-based and 3D visualization techniques to offer a 3D authoring environment integrated with real Zigbee sensor devices, where designers are able to rapidly construct immersive 3D buildings and easily plan the context-aware application scenario via GUI tool based on proposed three-tier rule hierarchy, to visually simulate and verify the planned scenario via virtual and real sensor devices, and to repeatedly modify the control strategies to enhance the deployment effectiveness and reduce the cost of time and work.

2. Related works

Due to the vigorous development of WSN, much research has been proposed to visualize and simulate the sensing, data processing, and communication of sensor devices for supporting the WSN deployment [30,31]. In order to maximize the network lifetime of WSN, Chang and Tassiulas [32] formulated the routing decision as a linear programming problem to propose the shortest cost path routing algorithm, which can achieve approximate optimal network lifetime according to simulation results. Afterwards, many simulation tools of WSN have been developed. NS-2 (Network Simulator) [21] tool can be used to support the simulation of TCP, routing, and multicast protocols over wired and wireless networks, and to simulate the user-defined algorithm according to user-defined network status, parameter setting, and communication protocol. By means of the Nam and Xgraph tools, the simulation results of NS-2 can be visualized, e.g., flow and drop of packet. J-Sim [18,22,33], a simulation environment for WSNs, was also developed entirely in Java. gEditor, a graphical editor, uses the J-Sim simulation engine to actually run the simulation. Users can use gEditor to graphically create and edit a Model for the WSN simulation. Besides, for a collaborative ubiquitous computing environment, Kang et al. [34] developed a monitoring system, called USS Monitor, to monitor and visualize the applications participating in this environment, where a set of applications collaborate to achieve a service goal. USS Monitor collected the state of the member applications and the resource state of the machines for the collaboration to visualize the correspondence among them. Shu et al. [15] developed the NetTopo, a framework integrated with virtual and real testbed, to offer both simulation and visualization functions to assist the investigation and design of algorithms in WSNs. Gross and Marquardt [35] proposed a CollaborationBus to allow experts as well as non-experts to configure the desired scenario in the ubiquitous computing environments for both home and work environments. Users can use a pipelines-based graphical editor to compose the service scenario by easily specifying the information flows from selected sensors to actuators changing the system behavior. Besides, those tools and techniques mentioned above do not allow users to interactively design and simulate a WSN in a 3D environment. Therefore, Kockara and Dagtas [19] developed an immersive, virtual reality-based 3D design tool using CAVE for facilitating the optimized design of buildings equipped with wireless sensors. They proposed the optimization approach of node placement for optimized energy consumption and coverage in the 3D immersive environment. However, although aforementioned WSN simulation tools and research can efficiently simulate and visualize the status of the deployed WSN, they more focused on the low-level context, i.e., network-layer or physical-layer simulation of WSN. The high-level context and application-layer simulation of context-aware application scenario based on WSN to support the context-aware smart environment [1] are not taken into account yet.

Mottola and Picco [16] depicted that the real-world deployments based on high-level programming abstraction are rare and low-level programming-based methods not only shift the focus of application domain experts away from the application scenario, but also require a technical background rarely found among them. Therefore, to assist non-technical end-users in easily planning their own application scenarios, Ubiwise [36], a first-person interactive simulator, employed professional 3D game engine was developed to allow users to simulate prototypes of new device in the 3D environments. Mocofan et al. [23] developed a multimedia interface connected with an equipment database to control and set the scenarios of smart buildings, and to navigate the result in a virtual 3D scene. Similarly, to relieve the costly and time-consuming deployment process, DiaSim simulator was implemented by Jouve et al. [24] for prototyping ubicomp applications. It allows users to define the simulation scenario using a scenario editor by a library of predefined behaviors, and to visually monitor and debug the designed scenario by the 2D simulation of virtual-real integration. However, the application scenario configuration methods using parameters adjustment of predefined scenarios confined the variety and flexibility of applications.

Rule-based technique seems like a suitable approach to solve the above issue. Therefore, Sohn and Dey [27] developed a graphical tool to visually create the simple rules of simple application scenario. To support more complex application scenario creation, Bischoff et al. [25] applied rich rule-based language to edit application scenarios of the smart home, but the text-based editing method is difficult to edit for the non-technical end-user and designer. Accordingly, based on the meta-design concept, Guo et al. [26] built an iplumber system using the Jess rule engine to assist non-technical end-user in (co-)designing, sharing, and testing the desired ubicomp application scenarios through the Web. Furthermore, for easily configuring application scenarios, a web-based form filling interface can be created by technical developers using Jess rule language to minimize the learning cost of end-users. However, the experimental feedbacks shown that its text-based rules editing is still hard to write for developers and predefined form filling format is too inflexible to meet the diverse requirements for end-users. Consequently, a flexible graphical rule editing method is required for the non-technical designer and end-user. Besides, these tools in [25–27] support the simulation by 2D method only, so their immersive and flexible degree may not be sufficient for the early-stage deployment of context-aware applications.

Afterwards, Kaldeli et al. [28] applied the Service-Oriented Computing techniques to develop a portable software architecture for the smart home applications. It collects the events of heterogeneous