# UbiSpace: Prototypical Smart Space Built upon Swarm Intelligence Middleware Platform

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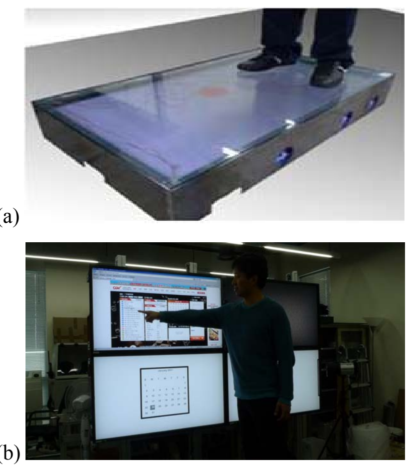
***Abstract*—A prototype of smart space consisting of network-enabled and intelligence-equipped building components is proposed in this paper. These smart building blocks could be integrated through a Swarm Intelligence Middleware Platform (SIMP) in which simple rules and local interactions are concurrently performed by taking the inspiration from the self-organized behaviors of social animals, and this would allow the formation of collective behavior for various applications of smart space. This paper shows the process of creating a smart space plus representative user scenarios based on the collaboration of these smart building components coordinated through SIMP.**

***Keywords—Building Components; Pervasive Computing; Swarm Intelligence; Ubiquitous Environment.***

## I. INTRODUCTION

The emergence of network-enabled and intelligence-equipped diverse smart building blocks can inaugurate a new type of digitized architecture, *Smart Space*. Such a system has over many years of history and miscellaneous approaches have been developed. Over many trials from an interactive floor design as shown in Fig. 1(a) to a reconfigurable wall system as shown in Fig. 1(b), diversified concepts for a smart space surrounding with digitized smart devices has been continuously developed. The smart space can be applicable to many exemplar applications such as virtual exploration on GoogleEarth and an intuitive interface for an immersive computer game. In order to realize these service applications, it is necessary to suggest how each smart device can communicate and collaborate together.

Swarm intelligence field has been rapidly grown over the last decade. Such smart objects based on swarm intelligence aims at designing robust, scalable and flexible collective behaviors through simple rules and local interactions by taking inspiration from the self-organized behaviors of social animals [1]. These smart objects have main characteristics such as autonomous, having sensing and communication capabilities, not being centralized control, taking global knowledge, and cooperative. M. Brambilla et al. [1] proposed that collective decision-making is related in letting these smart objects agree on a common decision or allocate among different parallel tasks. Collaboration evolves over collective behaviors for



(a)

(b)

Fig. 1. Diverse approaches for building a smart space. (a) Ubi-Floor as an interactive floor system [2]. (b) UbiWall as a reconfigurable ecosystem of smart blocks [3].

collective decision-making. There are two influences beneath the collective behaviors: agreement and specialization. The former is a consensus achievement which converges towards a single decision among the possible alternatives, while the latter is a task allocation to distribute them over the different possible task in order to maximize the performance of a system. In this paper, we suggest the Swarm Intelligence Middleware Platform (SIMP) in which simple rules and local interactions are concurrently gone by taking inspiration from the self-organized behaviors of social animals, and this would allow the formation of collective decision-making for supporting the communications and collaborations of smart objects in a smart space. Furthermore, we design a smart object as a digitized building component consisting of diverse electronic devices such as a LCD screen, a computing unit, sensors, communication modules, and so on. Therefore, we implement a prototype of smart space using these smart building components and realize a number of service applications through the SIMP.

In Section II, diverse approaches for building a smart space are discussed and Section III shows how we design a prototype of a smart space based on the SIMP. We then evaluate our approach through a prototype implementation. Section V

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concludes the research and describes the possibilities for future work.

## II. Related Works

As implementations for a smart floor system, diversified approaches have been developed: The oracle research laboratory (ORL) active floor system [4]; a physical sensing system called "Magic Carpet" [5], the LiteFoot tracking a dancer's steps with a proximity sensor array [6]; the Future Care Floor System integrated to a demonstration of a smart home [7]; and the Ubi-Floor system designed to provide and interactive floor system [2]. These systems are designed to allow users to enjoy an application for floor mediated interactions. Chang [8] proposed the Smart Architectural Surface as networked smart cell units equipped with various functionalities such as sensing, cognition and visualization. The Scalable Adaptive Graphics Environment [9] is known to be the most popular high resolution displaying method and is used to enable data, high-definition video and extremely high-resolution graphics to be streamed via ultra-high-speed networks. The iTILE framework [10] is also used for supporting the synchronized execution of multiple 3D graphic applications as well as various input devise on a PC clustering system. These systems are developed for wall mediated applications. In immersive display technology, there have been many approaches for making it realized. The CAVE (Cave Automatic Virtual Environment) [11] which is a system projecting images on three walls is the most popular for virtual reality display. The 3D MARS is an interactive visualization application system for Content-Based Image Retrieval [12] running on the CAVE system. The CABIN immersive multiscreen display system is also configured by using a five-projected screen, and user is able to interact at three-dimensional space [13]. Many other researches have been continued to give a user the realistic experiences in virtual environments.

In order to support smarter applications using these smart spaces, it is necessary to develop how each smart device can communicate and collaborate together. Animals that forage or travel in groups can make movement decision occasionally through social interactions among group members. Iain D. Couzin [14] has shown how pertinent information, such as knowledge about the location of a food source, or of a migration route, can be transferred within groups both without signaling and when group members do not know which individuals have information. He also revealed that only a very small proportion of high accurately informed individuals are needed to guide the group through the demonstration of the process which groups make consensus decisions and the comparison of the quality of their information with that of others. Thus only a very small proportion of informed individuals are needed to achieve close to maximal accuracy for sufficiently large groups. Swarm robotics or agents are focused on a collective decision-making or a collective behavior. Shi [15] surveyed these swarm robotic systems from such aspects as theoretical basis and physical research, simulation platform, distributed control information fusion and communications system. Above these previous efforts in the making of smart multiple objects have been contributed to our research.

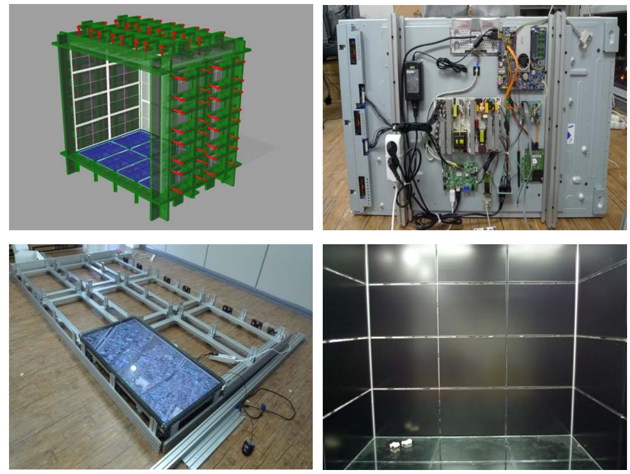


Fig. 2. A design of smart space. (a) Mechanical design. (b) A building component consisting of such diverse electronic devices as LCD screen, computing unit, sensors, communication module. (c) Installation of the smart object on the floor. (d) Completeness by stacking the 46 building components.

## III. Design A Prototype of Smart Space

As a basic building component for making a prototype of smart space like as Fig. 2(a), we have suggested the *Smart Block* in [3]. As shown in Fig. 2(b), it consists of modularized frame and diverse electronic devices as a LCD screen, an industrial computer, a microcomputer, multiple sensors, a Wi-Fi and Bluetooth communication module, and so on.

### A. Mechanical Design

The modularized frame has been designed based on the two concepts: a self-completeness of a concrete brick and the easy assembly of a LEGO block. Thus, our frames can be easily stacked and connected with other blocks and can afford to endure external shock or force while keeping the durability of internal electrical and electronics parts. In particular, our floor module consists of an aluminum supporting frame and a sheet of tempered and laminated glass which can endure user's weight when standing or moving as shown in Fig. 2(c). The completed mechanical design of a prototype of smart space is shown in Fig. 2(d).

### B. Hardware Design

The hardware of a smart space prototype consists of diversified sensor such as a temperature and relative humidity sensor, an irradiance sensor, a $CO_2$ sensor, an infra-red ranger, and a high-density camera, various communication modules such as a Wi-Fi and Bluetooth module, and an Ethernet module, and hierarchical computing units as a microcomputer for sensor signal processing, an industrial computer for local information handling, and a desktop computer for global collaboration of smart blocks. In particular, the industrial computer can process and locale information by small-scale SIMP, while desktop computers for each surface can deal with information passed from the local computer, can make a collective-decision, and

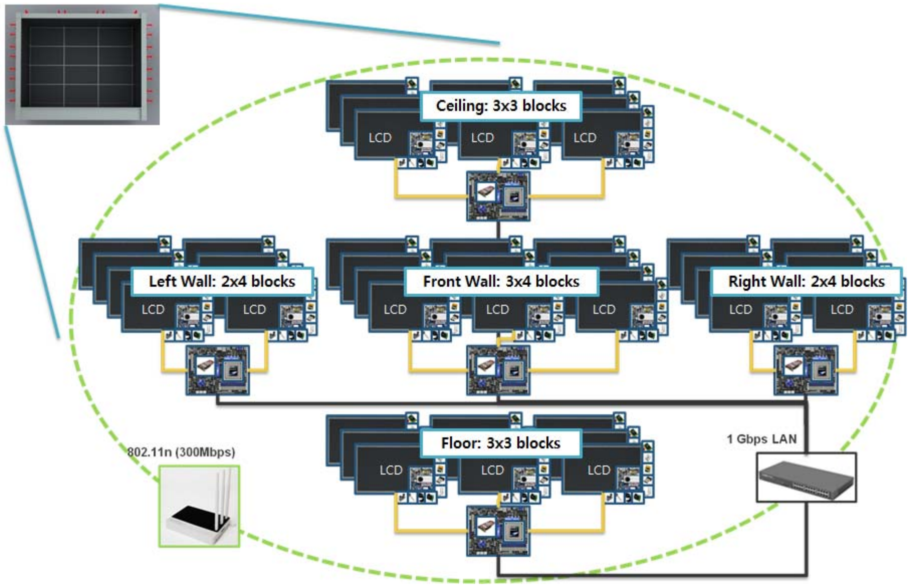



Fig. 3. Hardware architecture for a prototype of smart space for three walls, a ceiling, and a floor surface.

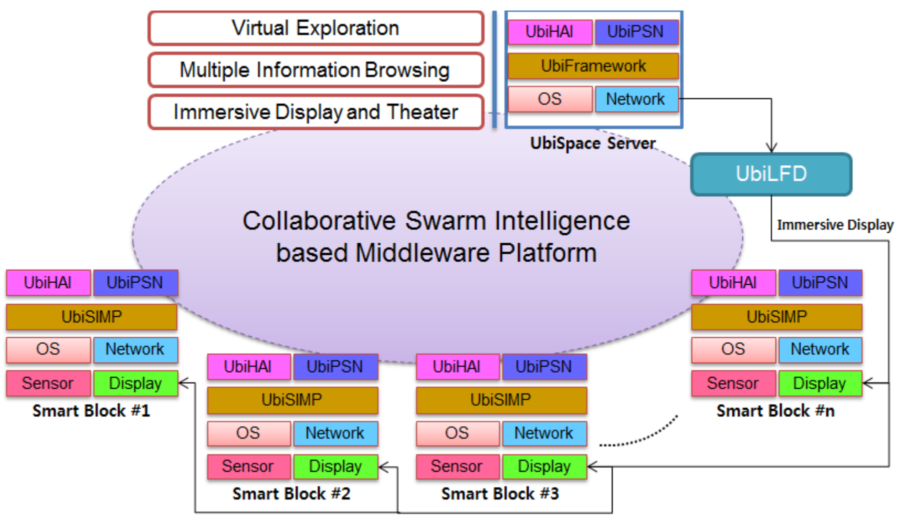



Fig. 4. Software architecture for a prototype of smart space based on swarm intelligence middleware platform.

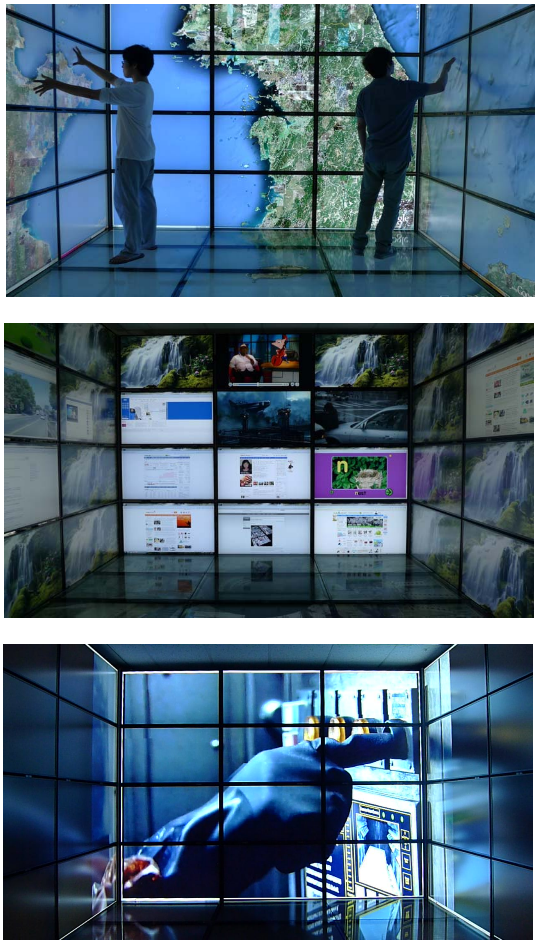
will lead a collaboration of all smart blocks for applications of the smart space. Fig. 3 shows the overall hardware architecture suggested in here. There consists of three types of surfaces: ceiling surface, wall surface, and floor surface. Each surface consists of a number of Smart Blocks which have additional components for each purpose.

### C. *Software Design*

Fig. 4 shows the software architecture of a proposed smart space in which two hierarchical SIMPs exist for each smart block and each smart surface, respectively. The small-scale SIMP as called *UbiSIMP* can deal with information such as user attention via camera or *Kinect* sensors, user current position on the floor, user pointing action via touch screen. It can estimate and process the information by using swarm intelligence, Particle Swarm Optimization-based Neural Network [16]. Furthermore, it consists of a number of middleware functions: *UbiPSN* (Ubiquitous Physical Social Network) and *UbiHAI* (Ubiquitous Human Architecture Interaction). The other hand, global scale SIMP as called Collaborative SIMP can serve many middleware services needed for smart space such as *UbiLFD* (Ubiquitous Large Format Display) and *UbiRDS* (Ubiquitous Reconfigurable Digital Space). The Collaborative SIMP works on the Ant Colony Optimization as popular swarm intelligence in the field of task allocation. Our system can communicate with each other by UbiSIMP and can collaborate for smart space applications through Collaborative SIMP. In Section IV, we show its prototype implementation and a number of applications for smart spaces such as virtual exploration, multiple-information browsing, and immersive display and theater.

## IV. Implementation of Smart Space

We devised a simple way to make a ubiquitous wall in [3], Smart Block. By stacking and connecting these smart blocks, it



(a) (b) (c)

Fig. 5. Exemplary applications of a smart space [16]. (a) Virtual exploration on GoogleEarth. (b) Multiple-information browsing. (c) Immersive display and movie theater.

is possible to make a prototype of smart space as shown in Fig. 5. These blocks are connected via wireless network and gigabit wired network in a point of hardware view, while they can communicate and collaborate for the purpose of using smart space via our proposed SIMP and Collaborative SIMP from a software perspective. Fig. 5(a) shows an example of using virtual exploration on GoogleEarth displayed on all surface. Fig. 5(b) demonstrates a scene of multiple-information browsing such as website, video clip, news, and so on. Fig. 5(c) is an implementation of immersive display system for large-scale movie theater.

## V. Conclusion and Future Work

We have presented a prototype implementation of smart space consisting of smart building components capable of dealing with flexible user interactions supported by SIMP and collaborating with all participating components through Collaborative SIMP. The prototype can serve a number of applications such as virtual exploration, multiple-information browsing, immersive display and so on. We are planning to evaluate the prototype with more complicated scenarios, for example, recognizing multiple users or allocating multiple tasks. Moreover, the system performance will be analyzed in terms of resource usage and network efficiency with the cases of using SIMP and not using it. We believe our research can greatly contribute to changing the way we build, operate and interface with such a smart space that could perform diversified digital services in a ubiquitous environment.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