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Development of Practical Smart House Scenario Control System

Abstract. *Smart houses have received significant attention in recent years because they are considered to be an ideal living environment. The key point of smart space is that it is self-adjustable to an optimal state through interactions between people and electronic devices. Object detection technology was applied to efficiently calculate the exact number and location of people. The concurrent RFID authentication mechanisms were examined to identify their security threats, and a two-factor RFID security authentication framework is proposed to be integrated into the central controls. The proposed system also combines heterogeneous appliances so that they could adjust themselves correspondingly to various scenarios.*

Streszczenie. *W artykule przedstawiono projekt systemu kontroli inteligentnego domu, opartego na wykorzystaniu czujników, określających ilość i rozmieszczenie ludzi w pomieszczeniach. Wykorzystano także radiowy system zabezpieczeń RFID w celu uwierzytelnienia lokatorów, który w trybie dwu-parametrowym proponowany jest do jednostki sterującej. Zastosowana dodatkowo, niejednorodna struktura urządzenia pozwala mu dopasowywać się do zmieniających się warunków.* ***(Praktyczny system sterowania dla inteligentnego domu)***.

Keywords: object detection, RFID, scenario control, smart house
Słowa kluczowe: detekcja obiektów, RFID, sterowanie zdarzeniami, inteligentny dom

Introduction

A future that people have always envisioned is available through smart appliances that allow people to enjoy a safe, comfortable, convenient, and energy-saving life and environment. This can be achieved by recording the history of user motion so that an appliance is capable of prediction, which permits the automation of interactions between the user and the devices [1]. An alternative approach is to install a sensor in front of the door. When the home owner enters the door, the sensor sends a wireless signal to the central control. It then sends a signal to turn on the light [2]. Two-dimensional (2D) image processing can be used to capture space allocation, allowing easier development of smart houses [3].

The automation of appliances relies on information regarding the position and movement of the inhabitant as the basis of judgment. Das et al. [4] and Heierman and Cook [5] analyzed movement behavior by using data mining to form a meaningful action model. Helal et al. [6] installed pressure sensor devices under the floor to obtain the exact location of the inhabitant. However, this approach is too complicated and hard to maintain. Multiple cameras were used to obtain the exact location and number of inhabitants. This information can then be sent to the appliances enabling them to offer appropriate services, such as lighting, gas, and air conditioning.

Chung et al. [7] and Mäyrä et al. [8] believe that it is essential for smart houses to customize the environment to each person. To achieve scenario control, the smart house system must identify the inhabitant is who has entered the house so that the personal scenario mode can be activated. Röcker et al. [9] used four basic scenarios to install this fundamental requirement of smart houses in the future. Two primary paths are followed in the research. Das and Cook [10] emphasized using artificial intelligence to predict the home owner's requirements. Brumitt et al. [11] emphasized the interactions and integration among appliances to offer convenient and comfortable living.

Currently, smart living spaces are uncommon in the lives of most ordinary people. Prior research shows that the following difficulties must be overcome in practice: (1) physical security in access control, (2) collision problems when multiple radio frequency identification (RFID) tags are read simultaneously, (3) unstable connections between RFID reading and servers, or when the interface is difficult to control, (4) the difficulty of judging and dominating scenarios, (5) the difficulty of pre-defining all possible scenarios, (6) user customization issues, (7) and the integration of heterogeneous systems in smart houses.

This paper presents a solution to these problems in both theory and practice, and constructs a model control system integrated with an actual smart house to validate its efficiency. First, an RFID security mechanism (RSM) was constructed to enhance the access control that can solve problems (1), (2), and (3). Second, an efficient indoor human body monitor and control (HBMC) system was designed to detect the number and location of people indoors to solve problems (4) and (5). Finally, for problems (5), (6), and (7), a scenario control mechanism (SCM) was designed, which emphasizes the integration of RSM and HBMC, to carry out the automation of smart house control.

System Architecture

The smart house scenario control (SHSC) automation system was designed and implemented. The architecture can be divided into three parts, as shown in Fig. 1.

1. RFID security mechanism: RSM consists of RFID key management, RFID door lock/reader, and user authentication server. An EPC Class 1 Generation 2 (gen2) RFID tag in RSM was used because it has the advantage of a longer reading distance compared to low-frequency tags.

2. An HBMC was used to detect dynamic objects efficiently, and calculate the number and locations of people in the room. This information was then sent to the smart house central control to be used as the basis for adjusting home appliances. HBMC consists of human body monitoring units (HBMUs), object detection interface (ODI), object detection algorithms (ODA), and object positioning algorithms (OPA).

3. SCM: this sub-system consists of a user identification unit, personal scenarios, and appliance controls. It uses the user identification (UID) information on the RFID tag to identify who is at home, and activates a pre-set scenario mode to offer a comfortable environment. The SCM sub-system can also obtain the resulting information of RSM and HBMC from the database within the SHSC. In the following sections, the design of RSM, HBMC and SCM is explored in greater detail.

RFID Security Mechanism

Most of the authentication mechanisms for information security require at least 1700-20000 logic gates to operate; AES needs 3600-30000 logic gates [12]. However, Jihoon [13] points out there are only 250-1000 logic gates for a

Gen2 tag. Therefore, many authentication mechanisms cannot be implemented on the current RFID tag.

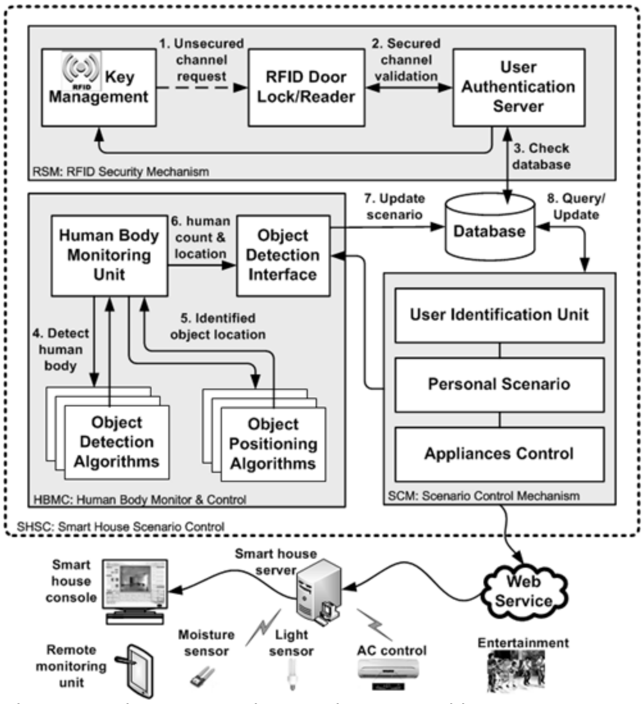

Fig.1. Smart house scenario control system architecture

Chien and Chen [14] have designed a protocol for RFID communication that satisfies forward security and prevents the security gap of Dang et al. [15], which can be exposed to asynchronous denial of service (DoS) attacks. Suleyman and Muhammed [16] point out that Chen and Deng's mechanism cannot prevent hackers from counterfeiting both the tag and the reader, neither can it resist tag tracking. To solve this issue, Burmester and De Medeiros [17] use pseudo-random functions (PRFs) to enhance the security of RFID communication.

Related research showed that the RFID tag is easy to steal by unauthorized users. To enhance its security in theory and practice, RSM was implemented with an RFID password lock. To enter the door, the user must use their RFID, and enter a personal password. After confirmation in the backend database, the door can then be opened. This mechanism provides an efficient and strong two-factor authentication pact for the smart house [18].

Human Body Monitor and Control

The goal of the HBMC is to receive streamed data from the camera in the smart house, and to determine the amount of people in the room and their specific locations. Malagón-Borja and Fuentes [19] used principal component analysis (PCA) to extract the feature information of pedestrians, with good results. Bugeau and Pérez [20] successfully captured human motion from indistinguishable backgrounds using a staged approach. Elgammal, Harwood, and Davis [21] designed a non-parametric model to exclude superfluous information.

The design of HBMC is based on the human locomotion model [22], and is designed to improve the Otsu [23] method by extracting the foreground, and computing the number of objects. The advantage of Otsu is that the foreground and background can be partitioned easily; however, the quality of the results relies on the background. The HBMC uses digital image processing theory to overcome this shortcoming through actual implementation, and through testing to verify whether the information obtained by HBMC can contribute to appliance management. In the following text, the HBMC is discussed from two viewpoints: ODI and HBMU.

1. Object detection interface:

ODI includes various adjustable parameters that are suitable in various environments, such as object size and sensitivity. A background updating mechanism was designed to reduce false-judgments by setting the thresholds of the consecutive images, to decide whether the background is updated.

2. Human Body Monitoring Unit

HBMU object detection and positioning consists of eight steps. They are discussed below.

(1) Initialize the background by obtaining scene recognition from the surveillance camera to acquire the background.
(2) Acquire a real-time image: capture real-time images each second. Obtain the absolute value of the difference of the background and the foreground, and then convert the image to grayscale.
(3) Enhance the foreground and weaken the background. Highlight the differences between the foreground pixels and the background pixels using a statistical method. To reduce the noise from the background pixels, the following formula is used to estimate the mean μ and standard deviation σ,

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad \sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \mu\right)^2}$$

where N stands for the total number of pixels; x_i is every grayscale pixel according to the characteristics of normal distributions.
(4) Apply Gauss low-pass filtering to reduce noise and maintain the integrity of the foreground, and improve the Otsu method in the following step to obtain a better partition effect.
(5) Binariazation: Use the Otsu method to convert a grayscale image into a binary image with dynamic adjustment.
(6) Compute the number of objects: Locate the bounding box [24] of the objects, and compute the count.
(7) Identify the main object by computing the area of each object, and then fine-tune them according to room size, depth of field, and resolution.
(8)

Fig.2. Grayscale images comparison for σ = 0.0967

For this experiment, when σ < 0.1, the number of pixels with a value of 1 is less than normal. The pixels with a value greater than $\mu+2\sigma$ can be treated as the foreground; pixels with a value less than $\mu+0.5\sigma$ can be treated as the background. The experimental results are shown in Fig. 2. The image on the left is the original image with σ = 0.0967. The image in the center shows the results after setting the threshold value equal to $\mu+\sigma$. The image on the right sets the threshold equal to $\mu+2\sigma$, which is significantly better than the center threshold.

The last step is further fine-tuning to filter out noise. Together with the initial location of each object calculated by OPA, the location of the objects in the room can be calculated using a triangulation method. The experimental smart house field test results are shown in Fig. 3.

Fig.3. Object detection and positioning field test in the smart house

Scenario Control Mechanism

To extend the application of the RFID tag, the UID of the tag is used as the base of appliance scenario controls. As soon as the inhabitant passes authentication in RSM, it then triggers an event in the database to activate the pre-defined personal favorite scenario. SCM receives this signal and sends command sequences to the integrated heterogeneous appliances to implement automation. This mechanism improves the convenience, and shortens the waiting time, which offers the inhabitants a comfortable environment, and completes the characteristics that an ideal smart house must have.

Conclusion

This study presents an integration of the critical technology of wireless sensor networks, intelligent living, and digital content to propose a user-centric design for smart houses. In addition to the benefit of convenience, through the integration of RFID access control, object detection, and scenario control, the proposed system not only provides energy savings, but also meets security requirements. Three main contributions are presented in this study. First, RSM offers a secured solution and integration of the RFID door lock in the smart house, which promotes its popularity. Second, HBMC computes the exact number and location of the people in the house efficiently, which provides accurate information to the smart house system. Finally, SCM integrates RSM, HBMC, and home appliances to adjust the home appliances according to various scenarios, which automatically achieve energy savings, without compromising comfortable living.

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