THE GATEWAY TO INTEGRATING USER BEHAVIOR DATA IN "COGNITIVE FACILITY MANAGEMENT"

Jinying Xu[1], Weisheng Lu[2], and Jing Wang[3]

1) Ph.D. Candidate, Department of Real Estate and Construction, The University of Hong Kong, Hong Kong. Email: jinyingxu@connect.hku.hk
2) Ph.D., Assoc. Prof., Department of Real Estate and Construction, The University of Hong Kong, Hong Kong. Email: wilsonlu@hku.hk
3) Ph.D. Candidate, Department of Real Estate and Construction, The University of Hong Kong, Hong Kong. Email: jingww@connect.hku.hk

Abstract: In the face of current predicaments of facility management (FM), the concept of cognitive FM is proposed with a view to providing active intelligent management of a facility. In order to achieve such cognitive FM, how to integrate user behavior data into a cognitive FM system has to be solved. This paper serves as method guidance for it by putting forward the idea that location can serve as a gateway for the integration. Ultra-wideband (UWB) is recommended as the device layer to construct the 3D local positioning system for the cognitive FM system after comparison between different local positioning technologies from the accuracy, scalability, and cost dimensions. The way to bridge the user behavior data with facilities through coordinate transformation and location/distance computation is briefly introduced. Such of a uniform 3D coordinate system with high accuracy and scalability for FM situation can provide a common language for communication and computational applications. Finally, application scenarios for various facilities such as commercial building, office building, hospitals, warehouses, airports, and transportation stations are discussed.

Keywords: Facility management, cognitive system, data integration, user behavior, local positioning system, UWB.

1. INTRODUCTION

Cognitive facility management (FM) is defined as the active intelligent management of a facility, which can perceive through cognitive systems, learn in the manner of human cognition with the power of cognitive computing, and act actively, adaptively, and efficiently via automated actuators, to improve the quality of people's life and productivity of core business (Xu et al., 2019). The proposition of cognitive FM is to shift the current predicament that a facility fails to provide satisfactory services to people, organizations, and businesses (Wang et al., 2018). The tight spot is caused by the passiveness of current FM systems which cannot meet the differentiated and changing requirements of users in a facility. Various passive FM systems are pre-programmed, which cannot respond to complicated, flexible, changing situations in real life. FM needs to be updated with intelligence to a higher level akin to human beings' cognitive capability (e.g., to perceive, to learn, and to act). Cognitive FM is a cyber-physical-social system (CPSS) where cyber (e.g., facility model, computer-aided FM system), physical (e.g., furniture, air conditioning system), and social (e.g., user behavior) information are integrated. The first step for cognitive FM to proactively perceive the requirements of users is to collect user behavior data, with which user preference and requirements can be learned.

However, user behavior data is hard to collect due to privacy issues and the lack of appropriate mature technologies. Cameras are ideal equipment to capture user behavior but limited by the notoriety of privacy encroachment (Chen et al., 2018), especially for private buildings. Many research and practices have made plenty efforts to collect user behavior data using portable devices (e.g., smartphones) and wearable devices (e.g., smart watches) (Lee et al., 2016; Liu & Huang, 2016; Rosenberger et al., 2016; Anjomshoa et al., 2017; Doryab et al., 2018). The lack of GPS information can also constrain it for location-based behavior data since GPS usually cannot work properly for indoor areas. Therefore, the collection of location-based behavior data at indoor environment remains a gap to be filled. A further gap is the integration of user data into an FM system. Majority of the FM systems neglect the consideration of user data (Kang & Choi, 2015). Thus the integration of user behavior data from the social aspect and the cyber and physical data in FM is, by and large, an uncharted territory.

This paper aims to develop an appropriate way to collect location-based behavior data at indoor environment using Ultra Wideband (UWB) technology and furthermore find out a gateway to integrate user behavior data (social) with the cyber and physical FM information system for further cognitive FM application. The rest of the paper is organized as follows: Section 2 is a detailed literature review of location-based user behavior data collection technologies and the user behavior data integration approaches; Section 3 is the deployment of location-based user behavior data collection system; Section 4 is the gateway development for user behavior data integration in FM information system. Section 5 is the discussion and conclusion.

2. LITERATURE REVIEW

2.1 Location-based User Behavior Data Collection Technologies

Commercial analysts and consultants have long studied user behavior data collection. Log (Cheng et al., 2017), search (Kim et al., 2015), payment (Liébana-Cabanillas et al., 2018), and click (Wang et al., 2017) behaviors of web or mobile users are the most common behavior studied among others. Recently, with the rise of emerging pervasive wearable and smart devices such as smartwatches and smartphones, the behavior data of movement (Vuković et al., 2018), eating (Kalantarian & Sarrafzadeh, 2015), and sleeping (Alfeo et al., 2018) becomes possible to be collected. The detection of movement is facilitated by the motion sensor, mostly triaxial gyroscopes, embedded in smartphones or smartwatches (Kalantarian et al., 2015).

Meanwhile, location information is becoming an indispensable part of smart services (Niu et al., 2016). In current practices, the location information of users is detected by the GPS module, satellite-based positioning system, in the smart devices. However, a weak point of GPS is that it can't work properly inside buildings and other places because line-of-sight transmission between receivers and satellites is not possible in an indoor environment (Gu et al., 2009). The failure of GPS is featured by either the loss of signal or low accuracy, which weakens the usability of smart devices that are supported by GPS for location-based services.

Facilities, especially buildings, are the common cases where GPS fails, which makes indoor navigation a bottleneck problem troubling both business and academia. Many efforts have been made to tackle the issue by developing indoor positioning systems (Liu et al., 2017). Techniques used for indoor positioning systems include infrared (Aitenbichler & Muhlhauser, 2003), vision analysis (Kawaji et al., 2010), magnetic signals (Li et al., 2012), audible sound (Mandal et al., 2005), ultrasound (Hazas & Hopper, 2006), Bluetooth (Feldmann et al., 2003), RFID (radio-frequency identification) (Saab & Nakad, 2010), WLAN (wireless local area network) (Yang & Shao, 2015), and UWB (ultra wideband) (Mahfouz et al., 2008). Some research also tried hybrid methods of different techniques. The comparison of the main features of the technologies is shown in Figure 1 (Maute, 2012; Sakpere et al., 2017). Among the three main features, accuracy denotes the typical resolution of a positioning technology, scalability means the capacity a local positioning system (LPS) can be scaled up, and cost is the investment of devices. The choice of technology is dependent on the targeted applications. For cognitive FM, the accuracy required in, pedestrian navigation, product tracking, ambient assisted living applications should be cm-m level, the scalability of the system should be relatively high, but the cost can be limited. To synthesize these three features and requirements of cognitive FM applications, UWB can be an acceptable choice to collect location data.

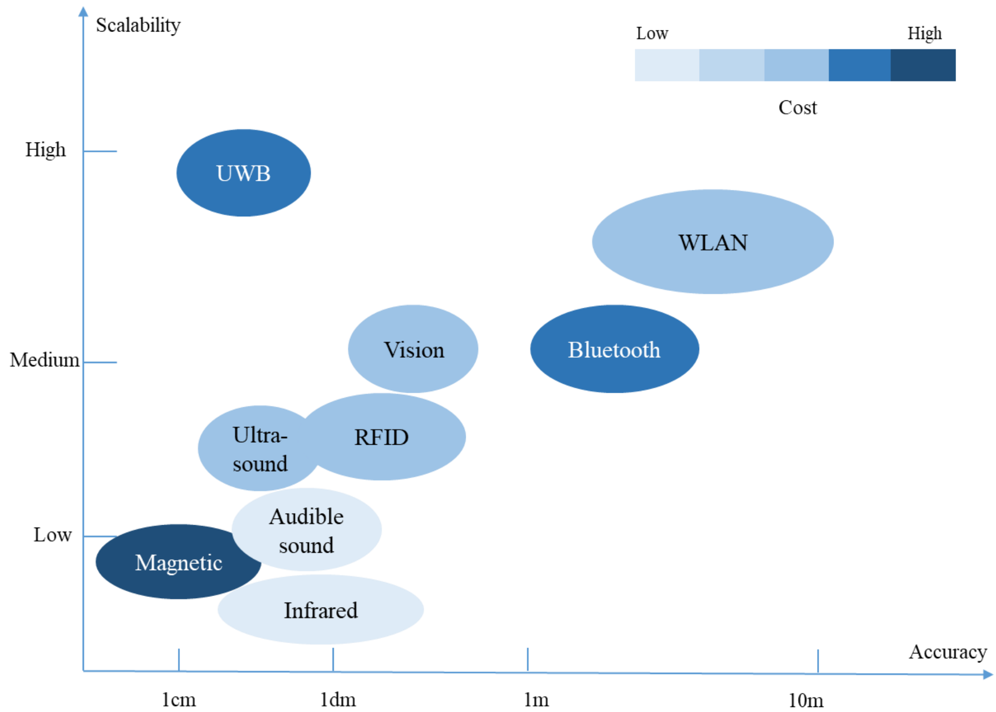

Figure 1. Comparison of different indoor positioning technologies

2.2 User Behavior Data Integration Approaches

To collect user behavior data is one important thing, to integrate such data for further analysis and application is another more significant problem. Current user behavior analysis and modeling are mostly based on online behavior data, be they social network data, mobile data, or web data. The integration of such data with customized services can be found at the field of intelligence business, such as search engine optimization (Ghose et al., 2012), customized recommendations of products and services for online shopping, reading, and entertainment (Besbes et al., 2015).

Some energy use studies also pay much attention to user behavior (Hoes et al., 2009). Such research mainly investigates the impact of user behaviors (e.g., presence, movement, and use of control system) on building energy performance by simulation or correlation analyses (Zhang et al., 2018). However, the integration of user behavior data with location-based services is still unattended. Therefore, the customized comfort and convenience services for facility users is still on its way. This paper aims to develop the gateway to integrating the location of facility user with user behavior and preference for better facility management such as energy management, security services, and indoor navigation.

3. UWB SYSTEM FOR LOCATION-BASED USER BEHAVIOR DATA COLLECTION

As discussed at Section 2, UWB is a relatively optimal choice for indoor positioning services regarding its high accuracy (several to tens centimeters level), high scalability (its signal can research 30 to 50 meters), and medium cost ($50 per tag which requires low energy). UWB is a mature technology for real-time indoor positioning system based on trilateration (Sakpere et al., 2017). The advantages of UWB, despite the high accuracy and scalability, include low power transmission, multi-path fading robustness, ultra-fine time resolution, and multiple simultaneous transmissions (Chu & Ganz, 2005). However, metallic and liquid materials may cause UWB signal interference, the use of more UWB anchors, and strategic placement of UWB anchors could overcome this disadvantage (Liu et al., 2007). Moreover, UWB was proved to have the ability to support real-time 3D dynamic indoor positioning (Li & Yang, 2015).

The working mechanism of UWB 3D indoor positioning system is as illustrated in Figure 2. At least four anchors will be installed, among which three of them are at the same height for the calculation of x and y coordinates, while the other is at a different height for the calculating of z coordinate. Tags can transmit signals with the anchors; the anchors can also transmit the received signals sent back by the tags to the datum anchor, based on the TDOA (time difference of arrival) and trilateration principle, the 3D coordinates of the tags can be calculated.

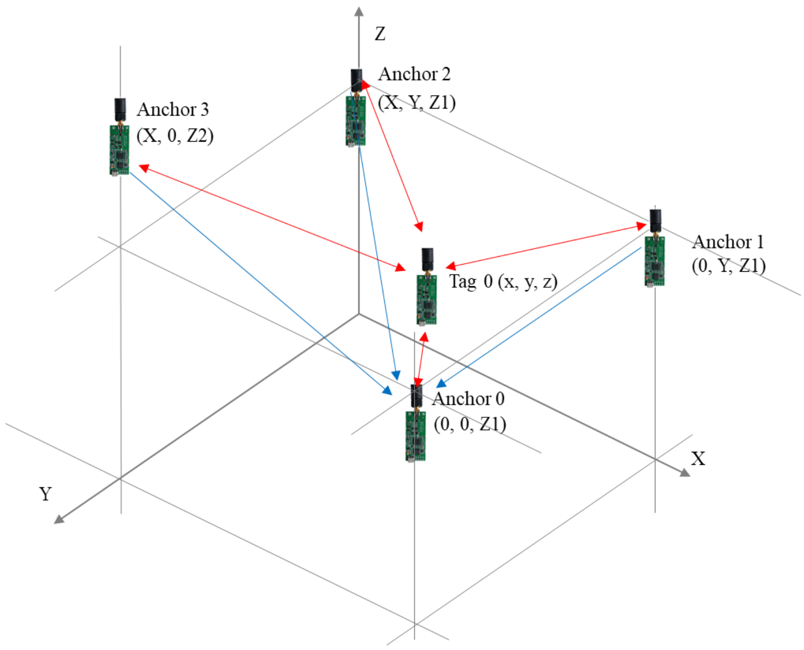

Figure 2. Mechanism of UWB 3D positioning system

Users equipped with the UWB tags can be tracked at real time with high accuracy. With the accurate real-time location data of users, their spatial-temporal database and behavior patterns (e.g., going to room 724 around 9:30 am every; buying fruits at the supermarket every Saturday morning) can be collected and analyzed. Therefore, services relating to the location (e.g., controlling of lights, air conditioning system based on occupancy, scheduling elevators, auto parking license, intelligent access control, and indoor navigation) can be provided proactively and efficiently. Besides, when an emergency happens, the accurate location will make precise and in-time notification, alert, and rescue possible. Additionally, the positions of facilities and assets can also be recorded and traced for further interaction between users. In a word, the UWB 3D LPS gives visibility and traceability of facilities and users for cognitive FM.

4. THE GATEWAY OF USER BEHAVIOR DATA INTEGRATION IN COGNITIVE FM SYSTEM

After collecting user behavior data, a gateway is required to integrate such data into the cognitive FM system for further FM application processing and actuating (Chen et al., 2015). Location is argued in this paper as the gateway. With every facility and sub-facility having their location, the location of users can be attached to the facility as a gateway to link the users and the facilities. In the cognitive FM system, the location of sub-facilities serves as the reference system of applications for users. That is to say, given every facility has its coordinate information in the cognitive FM system, once users' locations are tracked, the relative position of users to the facilities is determined. The coordinate information of facilities could be marked and stored in a facility information model. The coordinate information of users collected by the UWB LPS can be registered and computed in the coordinate system of the facilities by coordinate transformation (Tiemann et al., 2015). The transformation of a triplet coordinate in the UWB LPS to the facility coordinate system is shown in Equations (1) to (6). Thus, the indoor positioning information of users will be integrated into the cognitive FM system with the facility coordinaKANGte system as a reference system. Similarly, the facility coordinate system can also be transformed to the universal coordinate system to link up with GPS (Global Positioning System) to ensure the seamless connection between the LPS with GPS.

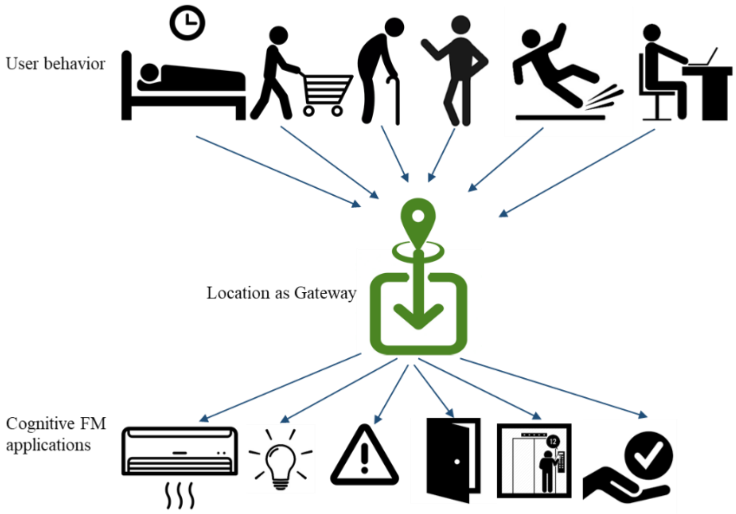

Figure 3. The gateway between user behavior to cognitive FM applications

$$DX_{i,j} = |lx_i - lx_j|, \quad \forall i,j \in \{1,I\}, i \neq j \tag{1}$$

$$DY_{i,j} = |ly_i - ly_j|, \quad \forall i,j \in \{1,I\}, i \neq j \tag{2}$$

$$DZ_{i,j} = |lz_i - lz_j|, \quad \forall i,j \in \{1,I\}, i \neq j \tag{3}$$

$$fx_i = \begin{cases} ox_j + DX_{i,j}, lx_i > lx_j \\ ox_j - DX_{i,j}, lx_i < lx_j \end{cases}, \quad \forall i,j \in \{1,I\}, i \neq j \tag{4}$$

$$fy_i = \begin{cases} oy_j + DY_{i,j}, ly_i > ly_j \\ oy_j - DY_{i,j}, ly_i < ly_j \end{cases}, \quad \forall i,j \in \{1,I\}, i \neq j \tag{5}$$

$$fz_i = \begin{cases} oz_j + DZ_{i,j}, lz_i > lz_j \\ oz_j - DZ_{i,j}, lz_i < lz_j \end{cases}, \quad \forall i,j \in \{1,I\}, i \neq j \tag{6}$$

Where

i, j Indoor point numbers;
I The total number of indoor points;
$DX_{i,j}$ Distance between point *i* and *j* in *x* axis;
$DY_{i,j}$ Distance between point *i* and *j* in *y* axis;
$DV_{i,j}$ Distance between point *i* and *j* in *z* axis;
lx_i Local coordinate of point *i* in *x* axis;
ly_i Local coordinate of point *i* in *y* axis;
lz_i Local coordinate of point *i* in *z* axis;
fx_i Facility coordinate of point *i* in *x* axis;
fy_i Facility coordinate of point *i* in *y* axis;
fz_i Facility coordinate of point *i* in *z* axis;
ox_j Facility coordinate of original point *j* in *x* axis;

oy_j Facility coordinate of original point *j* in *y* axis;
oz_j Facility coordinate of original point *j* in *z* axis.

By attaching UWB tags to users, the indoor location of users will be easily traced. Assigning every tag a unique ID, the user ID and his/her tag ID can be bonded together, which will make the identification and traceability of the users at fingertips. The UWB LPS itself can record sort of user behaviors such as moving from place *A* (lx_a, ly_a, lz_a) to place *B* (lx_b, ly_b, lz_b), staying at place *C* (lx_c, ly_c, lz_c) for a duration *Tc*, or waiting at place *D* (lx_d, ly_d, lz_d) for elevator *E* at (lx_e, ly_e, lz_e). Therefore, the user behavior data and the facility data will be bridged by the location data after coordinate transformation in the cognitive FM system. When computing for cognitive FM applications, the path of the users, their accurate location in the facility, their distance from facilities and assets can be used as essential parameters in algorithms. For example, the smart access control application will need the location data and ID of the user to match with the access authentication database for auto-control of entrances of restricted areas when authorized user is at the entrance. To sum up, the uniformed system with every point has its unique 3D coordinate has the following advantages:

(1) The triplets of points are more precise than GPS information and therefore more suitable for FM uses. Moreover, it is contextualized in a specific facility than the GPS to provide a more situated understanding.

(2) The 3D coordinate system provides a uniform positioning methodology that is scalable across the facility rather than focusing on a smaller area such as a corridor or a room. Very often, cognitive FM applications (e.g., targeted safety alerts when an emergency happens) should coordinate different facilities rather than a smaller part only.

(3) When communicating something (e.g., positions of the facility entrance or an elevator, or users) in the facility, the cognitive FM system can have a uniform coordinate system to which they can refer. The chance of miscommunication can be significantly reduced.

(4) When developing AI or robotics to perform cognitive FM applications and services (e.g., automatically calling elevators, path recommendation, smart access control, etc.) in the facility, developers can have a coordinate system with spatial-temporal information as the underlying elements to develop their algorithms.

Such a uniform coordinate system for cognitive FM has the potential to be adopted in various facilities, such as commercial buildings, hospitals, office buildings, warehouses, railway stations, and airports. Used in commercial buildings, by being aware of the location and path of the customers, it can guide customers find their way to a specific store or even a specific product, help merchants study the preference of customers and send out customized recommendations and advertisements, and further analyze the efficiency of the streamline design and FM. For hospitals and other healthcare facilities, cognitive FM system with uniform coordinates offers an undisruptive solution to track the patients with dementia, detect falling-down, guide the way to find the right room, locate the nearest nurse for smart nurse calling, and find an important asset faster to save lives. For office buildings, automatic elevator calling, smart access control, parking lot guidance for guests, and auto-control of HVAC (Heating, Ventilation, and Air Conditioning) systems for energy saving become easier to implement. The accurate locating of vehicles and items will lay a solid foundation for the unmanned warehouses. Additionally, at airports and railway/bus/underground transportation stations, an accurate indoor positioning system will support smart guidance for passengers, premier services for important guests, and the locating of baggage.

5. DISCUSSION AND CONCLUSIONS

This paper serves as method guidance for the user behavior data integration in cognitive FM system to disrupt the stagnant development of FM domain. It puts forward the idea that temporal-spatial information can serve as a gateway for the integration between the physical aspects of the facility and the social aspects of the users and their behaviors in the cyber aspects of the FM. Besides, by comparing the accuracy, scalability, and cost of different local positioning technologies including infrared, vision analysis, magnetic signals, audible sound, ultrasound, Bluetooth, RFID, WLAN, and UWB, UWB is recommended as the device layer to construct the 3D LPS, a uniform 3D coordinate system for the cognitive FM system. User behavior data marked associated with location data can be bridged with facilities, which also has their coordinate by coordinate transformation and computation. Thus, the relative position and distance of users and facilities can be recorded and computed for cognitive FM applications. The advantages of such a uniform 3D coordinate system include high accuracy and scalability for FM situation, providing a common language for communication, constructing a uniform coordinate system for algorithms development of AI and robotics. Application scenarios for different facilities such as commercial buildings, hospitals, office buildings, warehouses, railway stations, and airports are also furtherly discussed. Future research should try to develop a prototype or do experiments to demonstrate the implementation of such a system and validate its feasibility, and develop system architecture and implementation methods to execute its aims in different application scenarios. The validation and evaluation of the system is still under development but based on similar research and practical applications, its realization can be expected.

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