Smart Libraries

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With the rapid development of artificial intelligence (AI) and Internet-of-Things (IoT), thousands of smart devices can be interconnected with each other. A series of innovative concepts have emerged and penetrated into all aspects of human life, e.g., "Smarter Planet", "Smart City", "Smart Community", and "Smart Campus". As a key and indispensable field, librarianship has become a convenient scenario aided by AI and IoT. Distinctive advanced AI-based approaches applied in libraries include, but are not limited to, natural language processing (NLP), deep learning (DL), recommender systems, machine vision, and smart acquisition.

Keywords: Internet-of-Things ; artificial intelligence ; smart libraries

1. Smart Library

Structure

From the viewpoint of functionality, the "Smart Library" can be divided into the "smart public library" and the "smart academic library" (in most cases referring to the "smart university library"). The "smart public library", as a key application of the "smart city", holds the majority of the aspects of the "smart city" [1][2][3], which mainly includes "smart public service", "smart public security" and "smart public sustainability". In general, these features rely on AI-aided IoT as their foundation. The "smart academic library", as a critical application of the "smart campus", holds not only the three features mentioned above as the "smart public library", but also the peculiar focus of the promotion of cultural education and scientific research as aforementioned. In general, the researchers unify both the "smart public library" and the "smart academic library" as the "Smart Library", and further review the related works from three aspects: "smart service", "smart security", and "smart sustainability". The researchers appropriately reconcile the peculiar promotion service to cultural education and scientific research to smart service. In **Figure 1**, the researchers describe the relationship among the "Smart City", the "Smart Library", and the smart campus, from the aspect of AI and IoT applications.

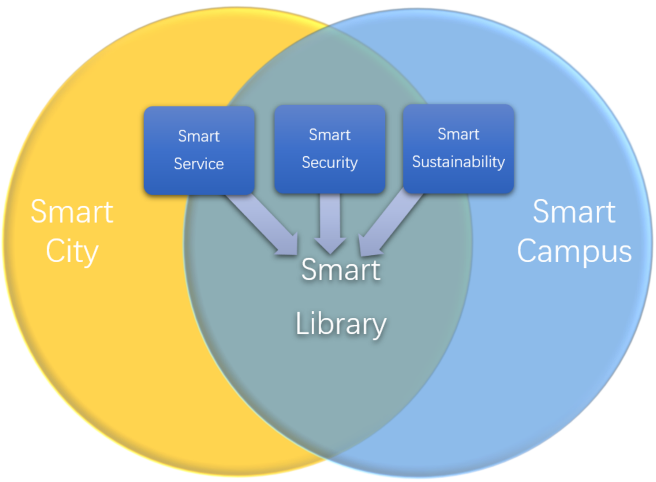

Figure 1. The relationship between smart city, smart library, and smart campus from the viewpoint of applying AI and IoT.

Unfortunately, there hardly exists a formal and generally accepted definition for "Smart Library" yet. By reviewing a considerable amount of works, the "Smart Library" was defined as a smart entity with AI-aided IoT technology deeply deployed to efficiently promote all aspects of operational efficiencies, for improvements of readers' needs and sustainable social responsibilities [1][4][5][6][7][8][9][10][11][12][13][14][15][16].

The concept of a "Smart Library" was originally reported in [17] as a practical location-aware scenario, where the readers want to find the optimal route to approach the intended books in the library. The readers only need a personal digital assistant (PDA) to confirm the position of the target book(s) by the smart circulation service supported by the library.

Compared to the traditional way of searching for books with manual queuing, it is much more efficient to adopt AI-aided IoT technologies [17].

2. Key Technologies of Smart Libraries

Since the innovative trial in [17] successfully drew attention from librarians, more IoT- and AI-based techniques have been applied in almost all aspects of librarianship, as elaborated below.

2.1. Fundamental IoT Technologies

IoT technologies have a deep impact on the routine management and operation of the library. For simplicity, the researchers mainly elaborate on the core and most representative techniques.

2.1.1. RFID

As a widely adopted IoT technology, RFID can trace its history back more than 70 years. Owing to the rapid growth of the integrated circuit industry, the feature size of semiconductors decreases year by year, and so does its cost. That greatly encourages RFID applications. A typical RFID system applied in a library can be divided into passive RFID tags, RFID readers, and central process devices. The identification of RFID tags can be concisely interpreted. The passive RFID tag relies on the electromagnetic induction field induced by the radio frequency signal emitted from an RFID reader to generate power for further two-way communication and data transmission. In the scenario of the smart library, the RFID technology has been widely applied in access control, book self borrowing and returning, smart shelves, etc. [18][19][20][21].

2.1.2. Wi-Fi

As one of the standard configurations for almost all public infrastructure, the IEEE 802.11 standard, namely Wi-Fi, has been deeply deployed and applied in all kinds of practical indoor scenarios in modern society, e.g., in libraries, supermarkets, banks, restaurants, hospitals, etc. By resorting to Wi-Fi with powerful networking capabilities, people can conveniently connect to the internet with any smart device to realize all kinds of web-based social or business intentions. Meanwhile, Wi-Fi is reported to have a wide coverage with up to 1 kilometer (km). Although Wi-Fi is generally deployed for communication, Wi-Fi-based localization technology has already become a hot topic. The main reason for the generality of Wi-Fi-based localization is due to the localization system that can be directly built with Wi-Fi access points originally deployed for communications, without needing any extra resources [22][23][24][25][26]. In the scenario of the smart library, Wi-Fi has been widely applied in navigation for finding the books.

2.1.3. BLE

As the novel version of Bluetooth, BLE has already been widely deployed and used for localization, context proximity detection, activity sensing, etc. As can be intuitively sensed from the name, the low power can be a key advantage for BLE and can thus be a natural choice for being deployed into IoT application scenarios with power constrained. In addition, BLE can have a coverage of up to 100 m, while providing a data transmission rate of up to 24 Mbps. Due to the powerful features on low power, long range coverage, affordable data rate, and low production cost, the BLE technology has an overwhelming advantage over the other solutions for some specific scenarios, e.g., localization in the power and cost constrained scenario [27][28][29][30][31]. In the scenario of the smart library, BLE can be mainly applied in navigation for finding specific places, and social interconnection for discussion and learning among the students [32].

2.2. Fundamental AI Technologies

There have also been a number of AI-based techniques applied in the smart library, among which the most adopted ones are concisely introduced as follows.

2.2.1. NLP

NLP is a promising technology which helps the machine understand, process, and even generate human language. A machine can understand and interact with humans under advanced concepts, algorithms, and formulations defined by NLP. Thus, NLP has been widely applied in search engines, automatic question answering systems, and intelligent robots. In the scenario of the smart library, the NLP technology can be generally used in all kinds of traditionally manual techniques, e.g., a chat robot with embedded NLP technology can be deployed for consulting in the reception of library, and also for navigation systems used for finding the intended books [33][34][35][36][37][38].

2.2.2. Deep Learning

Deep learning can be one of the most important machine learning (ML) technologies, which greatly impacts AI development. As a representative method, the deep neural network is powerful, with deep layers connected to form a hierarchical abstract representation structure. Deep learning-based variants include, but are not limited to, a convolutional neural network (CNN), recurrent neural network (RNN), graph neural network (GNN), as generally applied in the area of computer vision (CV), NLP, and graph-related data structure processing, respectively [39][40][41]. In the scenario of the smart library, deep learning technology can be applied in all kinds of domains with statistical data generated to learn and represent the implied features and rules [42][43][44].

2.2.3. Recommender Systems

The technology of recommender systems is a practical and efficient solution to the information overload related problem. The ideology of recommender systems technology is based on a fundamental assumption that people generally rely on suggestions from others when faced with important decisions. Based on the premise, web-based retail businesses can generally adopt recommender systems for recommending people with more useful and related commodities while gaining profits via either content-based recommendations or neighborhood-based collaborative filtering (CF) recommendations. In the scenario of the smart library, the recommender systems can be used as the core engine for recommending more valuable books and research papers to the readers to improve the efficiency of operations and also the loyalties of readers [45][46][47][48][49].

3. AI-Aided IoT Technologies

Apparently, both IoT and AI have greatly advanced librarianship. However, relying solely on any unilateral technique still cannot realize the full potential in practice.

In a practical case of service aspect, the introduction to the RFID-based self-borrowing-and-returning machine has no doubt improved the efficiency compared with the traditional manual works of librarian staff. However, if the self-borrowing-and-returning machine is deployed in an unsuitable location, the promoted efficiency can be considerably limited without sufficient usage. Aided by AI, the management of placements of self-borrowing-and-returning machines can be appropriately scheduled and dynamically optimized by analyzing the data of historical usage and reader trajectory with AI algorithms.

In a practical case of the sustainability aspect, the high level of light brightness in the corner of the reading room can be seen as a waste of resources if the books are rarely used. With the aid of AI, the level of brightness can be smartly adjusted according to the smart analysis on historical sensing data of reader trajectories. Furthermore, for keeping a steady environment, many air conditioners that consume a considerable amount of energy are densely deployed in the reading rooms, compact stacks, and data centers. This can be a severe resource waste if the usages are insufficient. Such a low efficient sustainability consumption problem can also be suitably handled by deploying an appropriate number of air conditioners or dynamically scheduling the operation mode based on the smart analysis of the historical environment data.

In a practical case of the security aspect, the malicious borrowing transactions can be detected in advance under the smart analysis on the historical borrowing data collected from the RFID self-borrowing-and-returning machine, and subsequently trigger the further requirement of verification, e.g., check out and confirm the reminder message sent by the AI system. In general, an anomaly can be quickly detected by AI once there exists a significant deviation from the normal operation mode.

On the other hand, relying solely on AI cannot be flawless. As discussed in the earlier case, malicious borrowing transactions may be risky. The malicious person can be alarmed by the RFID access control system and subsequently trapped by security guards even if they pretend that they are a legitimate user with stolen books deeply packed in their bag when they attempt to leave out of the library directly. In another case, the historical data of readers used to feed AI algorithms cannot be collected and analysed without the help of all kinds of IoT devices [50][51][52][53].

In general, Both AI and IoT are closely interconnected and can enhance each other when applied in the constructions of the “Smart Library”.

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