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Design of Rural Road Lighting System Based on Internet of Things and Deep Learning

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Abstract. With the promotion of China's new rural construction and beautiful countryside movements, there is a growing demand to improve the living environment of residents in rural areas and meet the requirements for energy efficiency and sustainability by implementing novel technologies. The internet of things (IOT) that allows real-time monitoring, measurement, and control while ensuring sustainability has become the trend in the field of lighting management. On the other hand, deep learning algorithms could help to eliminate the labor-intensive and time-consuming mining and feature extraction of high-dimensional complex data, and provide analysis and optimization of control strategies in a much shorter time. In this study, we put forward a new lighting design model by integrating IOT and deep learning, and theoretically analyzed its feasibility and discussed its advantages, with the goal to provide a new scheme for the design of rural road lighting system that is energy-efficient with improved reliability, robust functionality and satisfying performance.

Keywords: Internet of Things; Deep Learning; Road Lighting; rural infrastructure;

1. Introduction

With the promotion of China's new rural construction and beautiful countryside movements , there is a growing demand to improve the living environment of residents in rural areas and meet the requirements for energy efficiency and sustainability by implementing novel technologies. As an important part of rural infrastructure, road lighting has a profound impact on the daily lives of the residents by affecting night traffic safety, energy consumption, and light pollution, which is significantly under-developed currently compared with that in the cities [1-2]. Previous studies have demonstrated that the adoption of green lighting in rural areas was mediated by a number of complex factors which have to be considered simultaneously [3]. Therefore, it’s urgent to design energy-saving road lighting system with intelligent control to offer improved reliability, robust functionality and satisfying performance at the same time. In the past years, road lighting management system has transformed from manual control to computer-aided automatic control achieving energy saving and management automation to a certain extent, but there is still a lot of room for improvement [4]. Among different system network designs, IOT has been proved to be one of the most important innovations in the field of information technology in recent years [5]. It has been applied to build road light systems with intelligent control and remote communication capabilities, providing monitoring, measuring and control between the terminal road lights, the connecting modules and the central control system, through wired or wireless communications [6]. On the other hand, deep learning, which is one of the most popular subsets in machine learning, has seen a tremendous growth in all aspects of current industry, allowing the automatic learning from representative data and performance optimization that surpasses the human capabilities [7]. It helps to eliminate the labor-intensive and time-consuming mining and feature extraction of high-dimensional complex data, and provide analysis and optimization in a much shorter time. This study focused on the theoretical design of an intelligent road lighting system for rural areas by integrating IOT and deep learning, which could provide a superior solution for the design and management of complex road lighting systems in rural areas of China.

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2. Overview of Internet of things technology

2.1 Concept of Internet of things

At present, there are three main approaches for controlling the road lights in most rural areas: manual control, pre-defined timing control in the power distribution cabinet, and automatic control based on the ambient lighting levels. These light control systems cannot meet the requirements for the management and control of the rural road lighting system at this stage, which poses an urgent demand for a more advanced rural road lighting system design [8]. IOT is thus proposed to be a superior solution. Different from the Internet, IOT is aimed to create an intelligent network that allows more effective communication between human-beings and objects with intelligent processing at terminals through the network [9]. Figure 1 shows the conceptual model of IOT.

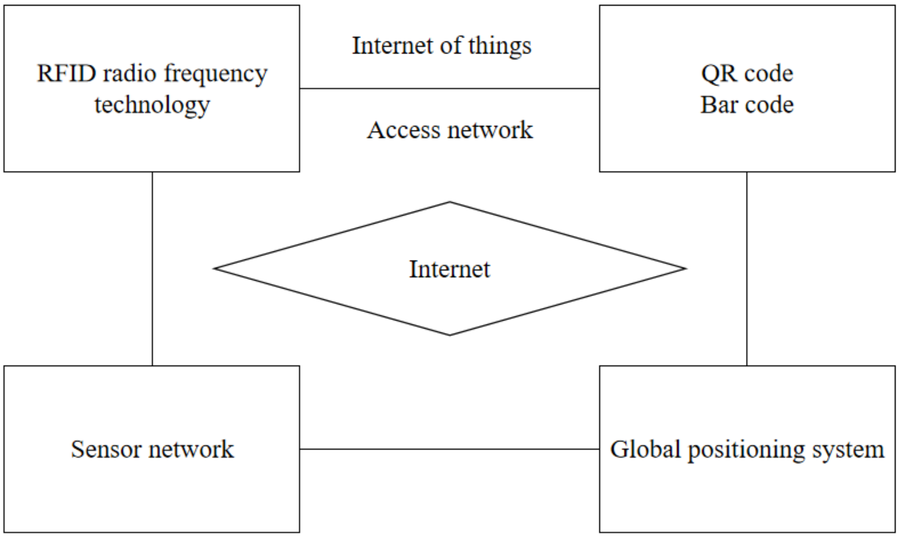

Figure 1 conceptual model of IOT

As seen from figure 1, the functional components for IOT can be divided into three main parts: perception and recognition which uses sensor equipment, two-dimensional code, and RFID as the main tools to perform the identification of objects; transmission network which transfer information through the communication network on the internet; and intelligent processing which uses cloud computing, middleware and data mining to achieve intelligent management and automatic control of the terminal objects.

2.2 System of Internet of Things

Due to the wide application of IOT, there are many kinds of IOT architectures with different model design and features. For the current study, we select one of the most common architectures which is based on a three-layer design, as shown in Figure 2.

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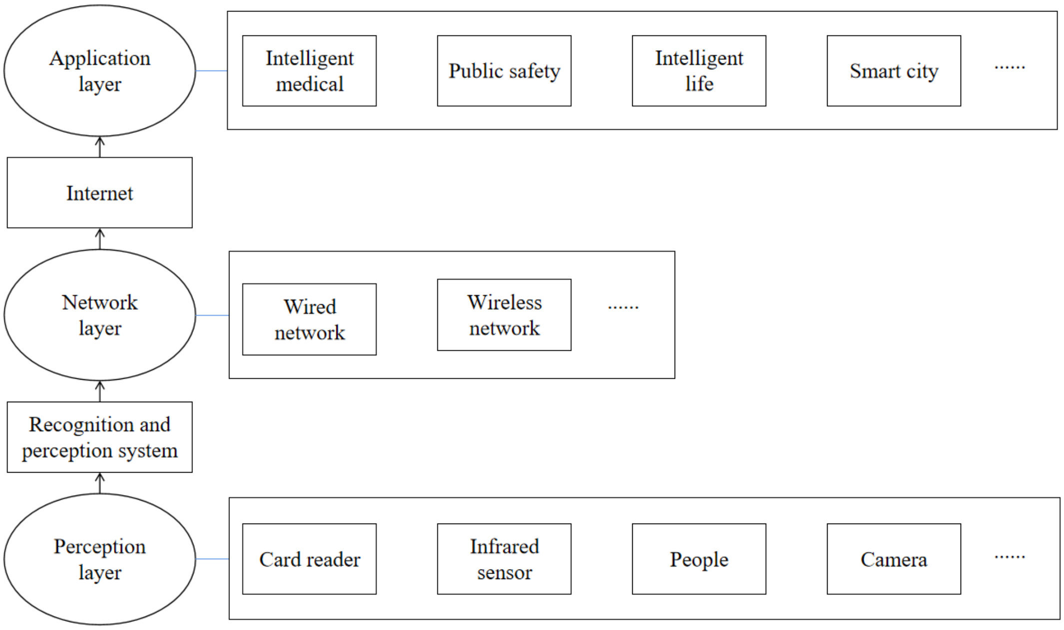

Figure 2 Architecture of the IOT model used in this study

In the architecture of IOT shown in Figure 2, three layers including perception layer, network layer and application layer function together to complete the tasks of data collection, transmission and processing. Perception layer is the data collector of the IOT interacting with the outside world, which identifies the objects or situations and collects useful information through the physical terminal equipment [10]. Network layer is the data processing layer performing information transmission and distribution, which is mainly completed through existing Internet, long- and short-distance wireless networks, satellite communications or network resource management [11]. Application layer is an intelligent interface of the IOT in the fields, which is created based on the industrial requirements to achieve intelligent management and provide more convenient and intelligent services for human beings [12]. In the IOT, diverse information can be transmitted multidirectional and interacted among these three layers, with each layer being independent and flexible. On top of the basic three layers, the intelligent processing layer and the IoT access layer can be added to result in a new five-layer architecture.

3. Application of Deep Learning in Rural Road Lighting System

The concept of deep learning comes from neural network. Neural network was first proposed from the artificial neuron model in 1943, which was used to simulate the neural structure of human brain, and later used in binary classification, which is commonly referred to as perceptron. Since it is only a shallow neural network, it can only deal with linear classification problems and cannot do anything for nonlinear classification [13]. Figure 3 below shows the relationship between deep learning and machine learning and artificial intelligence.

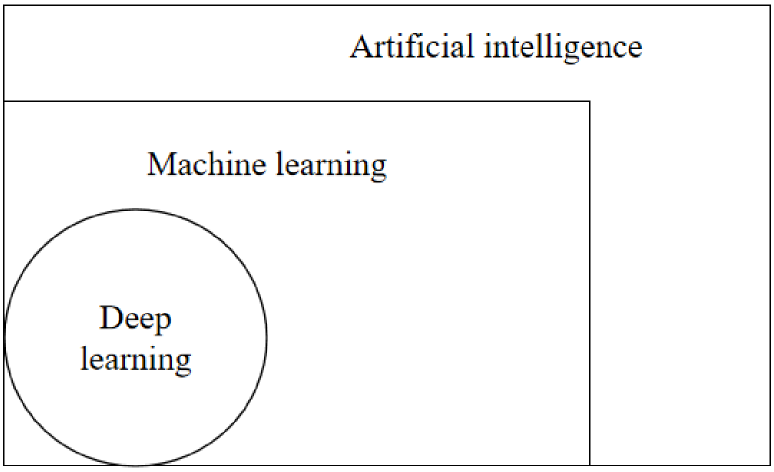

Figure 3 Diagram of the relationship between deep learning and machine learning and artificial intelligence

Introducing artificial intelligence technologies such as deep learning into rural road lighting system design can alleviate the problems of mining and feature extraction of high-dimensional and complex data in rural road lighting system design on the one hand, and make up for the problems of insufficient training data and poor generalization ability of traditional machine learning methods in practical application on the other hand [14]. Taking the time series data prediction of rural road lighting system design as an example, due to the new energy power generation connection, the increase of space load, the diversification of power sales entities, etc., the data source and data amount have increased greatly, and the difficulty of load prediction and new energy power prediction has increased accordingly.

Deep learning abstracts and learns features layer by layer through a multi-layer structure. This process does not require manual participation. Through a specific mathematical expression, the features can be converted into valuable information to guide the machine to complete the learning work. For a deep neural network with n layer $\{S_1, S_2, ..., S_n\}$, set its input as I and output as O, and the data processing process is shown in Figure 4.

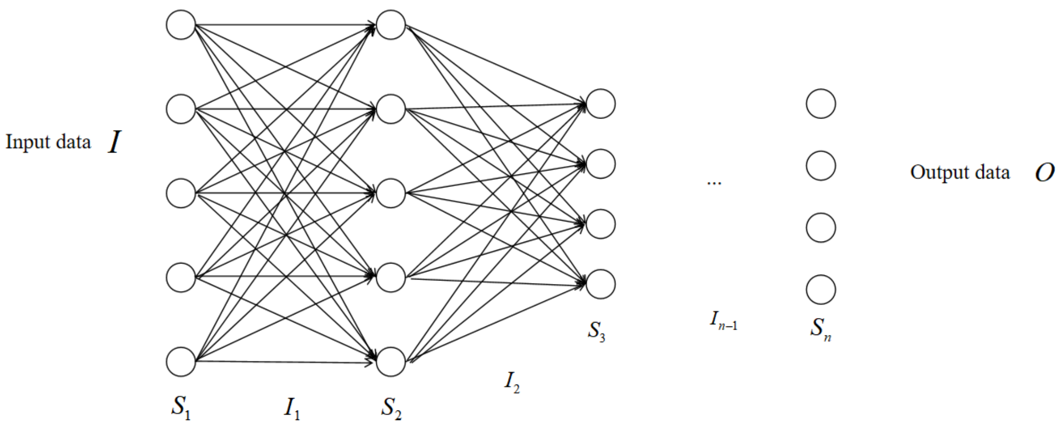

Figure 4 network construction of deep learning

Since deep learning adopts a mechanism oriented to the underlying data, it ensures the integrity of information to the greatest extent [15]. Deep learning establishes the mapping relationship between input I and output O, which provides an effective means of expressing features for the underlying

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data with complex features and difficult to manually extract [16]. For the rural road lighting system with dynamic characteristics, the intrinsic characteristics that are beneficial to reflect the system behavior can be extracted through this unsupervised training, and then the expression of the characteristics can be improved through supervised training.

4. Design of rural road lighting system

Rural road lighting system is mainly composed of six parts: street lamp node controller, central controller, cloud server, background management system, app and database [17]. Therefore, this paper systematically evaluates and analyzes the model from the aspects of data collection and processing mode, and the processing efficiency of electric energy. Among them, multiple street lamp node controllers and the central controller form a ZigBee local area network through the Zig Bee network topology, and they perform wireless data transmission through Zig Bee; the central controller uses GPRS to communicate remotely with the cloud server; The communication protocol between the server and the background management system and APP is TCP/IP protocol. This system installs a street lamp node controller on the street lamp pole, which is responsible for controlling the dimming of street lamps and collecting information such as electricity, light intensity, traffic flow, etc., and then sending the collected information to the central controller, and one central controller can manage multiple The street lamp node controller, after receiving the uploaded data, transmits it to the cloud server for backup through GPRS, and the cloud server sends the data to the background management system and APP. The background management system uses the DAG-SVM algorithm to analyze and process the uploaded data, The processing result is automatically fed back to the street light node controller and the street light is dimmed or displayed on the system interface. If it is fault information, the system will issue an alarm, and at the same time, the rural road lighting system APP will also issue a warning message to remind managers.

Due to the problem of power waste caused by inaccurate dimming and unable to adjust the brightness of street lamps in real time with the changes of street lamp environment, this paper will design an energy-saving hardware module with the functions of data acquisition, real-time monitoring of traffic flow around street lamps, data transmission and street lamp control. The node controller of street lamp is responsible for collecting data such as light intensity and traffic flow around the street lamp, and can adjust the light independently according to the light intensity and traffic flow. The GPRS module, central controller and Zig Bee coordinator are responsible for data communication, uploading the data collected by the street lamp node controller to the background management system and the smart lighting system APP. Specific data transmission flow between hardware modules: firstly, the street lamp node controller sends the collected data to the Zig Bee coordinator through Zig Bee network; Then Zig Bee coordinator transmits the data to the central controller through serial port; Finally, the central controller also transmits the data to GPRS module through USART.

In addition, due to the need for all-weather real-time monitoring, a stable and reliable storage system is required as the support for the system designed in this paper. The storage system designed in this paper is divided into three parts, namely the running data interface, the historical data interface and the data dump mechanism. The running data interface mainly provides data operations in MySQL, while the historical data interface provides HDFS-based data The data query and statistics operation in the data dump mechanism is used to realize the data dump of My SQL and HDFS. As mentioned above, in the intelligent lighting safety service platform based on the Internet of Things, we store user data, project data, equipment data and control strategy data in My SQL, and at the same time, the current real-time data will also be stored in My SQL, and only the historical real-time working condition data will be transferred to HDFS in one direction. PID control is the most common control algorithm used in industrial production at present, and the utilization rate is as high as 85% - 90%. PID control algorithm is applicable to the scene with unclear control object. With the continuous improvement of technology, relevant researchers further improved and optimized the PID control algorithm. Compared with other control algorithms, PID control has the advantages of strong

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adaptability, strong robustness, simple principle and convenient use. Due to its wide use, PID has a complete set of parameter tuning and design methods, and users can easily master and be familiar with the algorithm. . In the analog PID control algorithm, $u(t)$ can be expressed by the following formula:

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)\right]dt + T_d\frac{d_e(t)}{dt} \tag{1}$$

Its transfer function is:

$$G(S) = \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{2}$$

Where K_p、T_i、T_d、$u(t)$、$e(t)$ is the proportional coefficient, integral time constant, differential time constant, control output and control input respectively. Then, the differential and integral terms in PID need to be discretized. The PID control algorithm after discretization can be expressed by the following formula:

$$u(k) = K_p e_k + K_I\sum_{j=0}^{k} e_j + K_D(e_k - e_{k-1}) + u_0 \tag{3}$$

Since we can get the three important parameters of K_p、K_I、K_D in the above formula, these three parameters play a key role in the performance and stability of the system.

5. Conclusions

In this study, we proposed a new strategy for the design of rural lighting system by integrating IOT with deep learning. With IOT, real-time monitoring and measurement about the road lighting could be easily realized, generating rich information that could be fed into deep learning algorithms for model training. The resulted model could be thus used for the design and optimization of the rural lighting system, meeting the goal of providing reliable, satisfying road lighting which is energy-efficient and sustainable.

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