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A Smart Design Based on User Experience for Lighting System in Smart Home

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Abstract: *Smart home and the Internet of Things (IoT) have become integral parts of our daily lives. This paper provides an overview of the concept, development history, application scenarios, and future trends of smart home and IoT. The paper introduces the fundamental concepts of smart home and IoT, including the use of sensors, communication technology, and cloud computing. It presents the design of a highly automated smart home lighting system that incorporates traditional smart home technology and IoT technology, allowing the system to use big data to determine when to turn on the lights. The proposed method is tested through a mathematical model and theoretical simulations, followed by an actual simulation using a 51 microcomputer. The paper discusses potential future developments in the field of smart home and IoT, such as the integration of artificial intelligence and machine learning.*

Keywords: *Smart home, Internet of Thing, STM51, ESP8266, Digital twins*

1. Introduction

The new smart home product series is based on IoT technology and offers interactive ability, perception ability, processing feedback ability, environmental detection, and intelligent diagnosis and analysis. Smart home is an integrated control system[1-3] that uses communication network, security prevention and control, audio and video technologies, and other components to control various home devices and equipment. It provides humanized and diversified user interaction interfaces for lighting control, remote monitoring, burglar alarm, indoor and outdoor remote control, electrical timing regulation, and environmental monitoring. IoT[4-5] operates in an intelligent space through intelligent interfaces and connects physical or virtual objects using existing or evolving information technology. It can identify, acquire, and process data and provide communication services for various applications.

Developing smart homes in the Internet of Things (IoT) environment presents several challenges, includited intelligence and high costs, as well as insufficient standardization and equipment customization. However, there are ongoing efforts to address these challenges. For instance, enhancements are being made to the intelligence and cost-effectiveness of smart home bedding. Additionally, industry standards for smart homes are being established, and manufacturing costs are being reduced through collaborative partnerships among enterprises. Moreover, the product customization system is being expanded to cater to the diverse needs of consumersng.

In the future, smart home control centers will be based on artificial intelligence and cloud data, with mobile phones and other devices serving as the main entrance[6-9]. Control functions will be hidden in a database using big data and artificial intelligence. The Internet of Things will continue to decentralize and become more intelligent, potentially allowing for home robots or any Internet of Things-based smart home device to act as a gateway.

This paper aims to provide personalized, diversified, and customized home lifestyle to meet the needs of different user groups. It proposes a smart home system that connects multiple intelligent home services through a cloud platform to achieve collectivization, intelligence, and humanization. The paper utilizes digital twins[10-12], time series formulas[13], focal loss[14], and system optimizations[15] to accomplish its objectives.

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Figure 1: A typical scenario in smart homes

Smart homes, which are based on the Internet of Things technology, have gained popularity, and have become an important part of people's lives, as shown in Figure1. They provide various intelligent services such as home appliance control, environmental monitoring, and security monitoring, making home life comfortable and convenient. As a result, the smart home industry has received extensive attention from both academia and industry.

This paper presents the design of an intelligent lighting system that automatically operates the light based on the user's habits and infrared sensing to detect people in the house. The system's brightness and timing can be adjusted through a mobile app. The system also includes an alarm function that notifies the user through a special app if someone enters specific areas. The smart home system is based on IoT technology and Wi-Fi wireless communication, machine learning, and the Cloud Intelligence APP provided by the Alibaba Cloud IoT Platform. The machine learning part of the system uses the K nearest neighbor and random forest models. The system can be personalized for users and detects the user's return to mine data using network data mining technology and analyze it through Python.

2. System Framework

The smart home system is composed of a main control module and a collection module. The main control module is responsible for processing information inputs from different modules and making decisions, while the collection module collects information about the surrounding environment, such as temperature and human behavior, and sends it to the main control module for processing. Through the wireless communication module, the main control module can transmit collected information and control instructions to the cloud platform, which allows users to access real-time data and enables the system to record their behavioral habits for predictive actions. The cloud platform also provides a login interface for users to view relevant data.

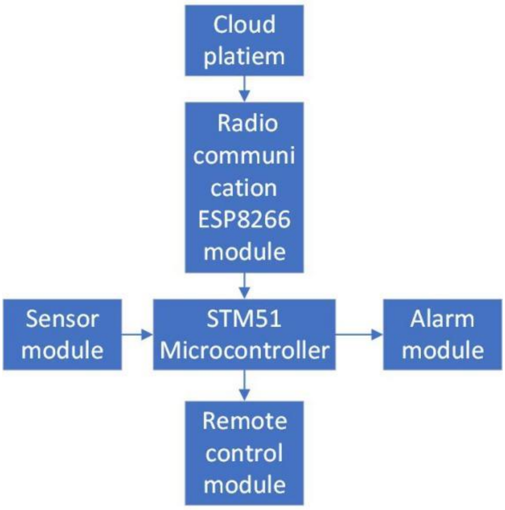

Figure 2: Smart Home Systems

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The main control module is the central component of the smart home system, serving as the overall commander. It is equipped with an STM51 microcontroller that receives signals from peripheral subsidiary modules and issues corresponding operation instructions to various operation modules. This enables coordination and cooperation among the system modules, ultimately achieving the various functions of the smart home system, as shown in Figure 2.

The wireless communication module of the system uses the ESP8266 module, which has WiFi transmission capability. It is able to convert the collected data and control instructions into digital signals and transmit them to the cloud platform. The RX pin is used to send data to the cloud platform, where the data is processed, and the processed data is then sent back to the microcontroller via the TX interface.

The sensor module includes ambient temperature acquisition, light information acquisition and spatial acquisition functions. The SHT30, an I2C protocol-based small temperature sensor, provides accurate and quick measurement of the current environment temperature. The light sensor monitors the ambient light status and sends it to the microcontroller via the DO pin, providing a reference for intelligent light control. When it detects darkness, the DO pin sends a signal to turn on the light, allowing remote control of the light. The alarm module analyzes information from the main control module and other subsidiary modules to determine whether there are preset problems in the environment. It reports the information to the cloud platform, which processes the data and provides feedback through the buzzer if it cannot be processed, realizing the system's alarm function.

This paper focuses on the simulation aspect of smart home systems and proposes the use of digital twin theory. Digital twin is a virtual model of a physical object that simulates its behavior in a realistic environment to better understand its state. This involves constructing a mathematical model and using IoT technology to capture, transmit, and synchronize meta-information about physical entities. The digital twin model construction mainly involves conceptual models and model implementation methods, where the conceptual model describes the system's architecture and the implementation methods involve modeling languages and development tools.

2.1. Digital Modeling

We utilized the Random Forest model for mathematical modeling, which is an algorithm that employs multiple decision trees to train, classify, and predict samples, specifically for time series forecasting. Suppose there are n samples $D = \{(x_1, y_1), (x_2, y_2), \cdots, (x_n, y_n)\}$,X is d-dimensional, representing d input features, and the j feature $x^{(j)}$ and its value s are selected as cut variables and cut points, thus defining two regions in the following.

$R_1(j, S) = \{x | x^{(j)} \le s\}$, $R_2(J, S) = \{x | x^{(j)} > s\}$. A random forest model is developed, with the expression:

$$R_1(j, S) = \frac{x}{x^{(j)}} \le s, R_2(J, S) = \frac{x}{x^{(j)}} > s \tag{1}$$

$$LF = \min_{J;\delta}[\min_{C_1} \sum_{x_1 \in R_1(j,s)} (y_i - c_1)^2 + \sum_{x_2 \in R_2(j,s)} (y_i - c_2)^2] \tag{2}$$

By dividing the input space into M parts, the final generated decision tree is that:

$$f(x) = \sum_{m=1}^{M} c_m I(x \in R_m) \tag{3}$$

To address sample imbalance in a dataset with missing samples, we can use Focal loss as a loss function:

$$L_{box} = \lambda coord \sum_{i=0}^{s^2} \sum_{j=0}^{B} 1_{1,j}^{obj} \, l_{i,l}^{box}$$

$$L_{cls} = \lambda class \sum_{i=0}^{s^2} \sum_{j=0}^{B} 1_{1,j}^{obj} \, l_{i,j}^{box} + L_{obj} = \lambda noobj \sum_{i=0}^{s^2} \sum_{j=0}^{B} 1_{1,j}^{obj} \, l_{i,j}^{box} + \lambda_{obj} \sum_{i=0}^{s^2} \sum_{j=0}^{B} 1_{1,j}^{obj} \, l_{i,j}^{box} \tag{4}$$

$$Loss = L_{box} + L_{cls} + L_{obj}$$

$$FL(P_t) = -(1 - P_t)^{\gamma} \log(P_t) \tag{5}$$

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2.2. Computation and Prediction

To analyze time-series prediction data and make remote predictions for furniture control, the smart home system employs various data analysis methods. These include performing average data analysis, error analysis, and collision detection to avoid individual object collisions in the smart home.

(1) Mean Absolute Error, MAE:

$$MAE(y,\hat{y}) = \frac{1}{m}\sum_{i=1}^{m}(|y_i - \hat{y}_i|) \tag{6}$$

(2) Mean Square Error, MSE:

$$MSE(y,\hat{y}) = \frac{1}{m}\sum_{i=1}^{m}(y_i - \hat{y}_i)^2 \tag{7}$$

(3) Root Mean Square Error, RMSE:

$$RMSE(y,\hat{y}) = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(y_i - \hat{y}_i)^2} \tag{8}$$

(4) Artificial Intelligence Algorithms:

$$Output = P\left[\frac{1}{t} + \left(1 - \frac{1}{t}\right)\right] + (\frac{1}{M})\int[\frac{1}{t} + (1 - \frac{1}{t})d] \tag{9}$$

P is used to adjust the magnitude of differentiation and scaling, M is used to adjust the magnitude of integration and differential integration.

We rely on AI to enable the cooperation and coordination among different components in the smart home system. Specifically, we use intelligent algorithms based on AI and retain the PID algorithm after making improvements.

(1) The conventional algorithm is as follows.

Output = proportional action (P) + integral action (I) + differential action (D)

(2) The PID algorithm is partially improved as follows.

Output = proportional action (P) + integral action (I) + differential action (D) + differential integral action ($\int I$)

(3) Relationship between proportional and differential action:

proportional action= K($\frac{1}{t}$)

differential action= K(1-$\frac{1}{t}$)d (t is the ratio of the lag time to the control period)

(4) Artificial intelligence algorithms:

$$\text{Output} = \text{P}\,[\frac{1}{t}+(1-\frac{1}{t})d] + (\frac{1}{M})\int[\frac{1}{t}+(1-\frac{1}{t})d]$$

2.3. System Optimization

The smart home system relies on various technologies such as the Internet, mobile terminals, cloud platforms, and radio frequency technology to achieve intelligent control. To improve the system's stability, it is essential to analyze the causes of smart home system faults. In the following section, we provide a detailed analysis of the occurrence of faults and their corresponding solutions.

(1) The system may become unresponsive and the home appliances may not function, indicating a failure of the main control unit or a network connection issue with the cloud platform. The system's appliance switch is located in the main distribution box and is controlled by the main control unit. A failure of the main control unit or a network issue can result in the above phenomenon.

(2) The system is functioning normally, but remote operation is not possible. This may be caused by a failure in the network layer, the ESP8266 module, or the failure to transmit data to the cloud platform, which prevents remote operation from being executed.

(3) The corresponding device cannot be controlled by the specific control element. The cause of the problem can be analyzed as follows: there may be interference with the sub-unit or defects in the

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hardware and software design.

The above-mentioned problems will affect the effectiveness of the use of smart home, the following specific solutions are discussed.

(1) The control units of different appliances involved in the sub-unit are decentralized to ensure that the system can still operate normally even if it fails. Each appliance has its own built-in independent drive and control circuit, enabling the user to operate the appliances individually.

(2) The main control switch is designed with a graded structure. The cloud platform controls the sub-unit data communication and monitors equipment operation, while the mobile phone application and the main control system are responsible for receiving and sending equipment status data via an RS232 serial port. Feedback information is sent to the control system if a single module fails, ensuring the system performance is strongly guaranteed.

(3) Each level of intelligent gateway is equipped with multiple communication methods, and the user network is configured with wireless network communication. The network control is configured with one level of wireless infrared communication, ensuring stable operation of the system even if one type of communication fails. The system sends feedback to the user in another way to check the failure of the sending unit.

3. The Design for A Typical Smart lighting System

Smart home lighting design requires a balance between practicality, aesthetics, and comfort. Here are some tips for designing smart home lighting:

(1) Users can choose the appropriate lighting equipment: Users can choose the lighting equipment suitable for home decorating style, the choice also needs to consider brightness, color temperature, color rendering index and other indicators to ensure that the lighting can meet the different needs of users.

(2) Use intelligent sensing lighting solutions: According to user needs, different types of lights are controlled with artificial intelligence, such as reading eye protection lights, soft lights at bedtime, and cooking function wall lights, to meet various lighting needs of users. Using different lighting schemes in different areas can also increase the variety and layering of spaces. Ergonomics should also be considered to improve the quality of life and physical health.

(3) Utilize intelligent voice-activated lighting control: Intelligent voice-activated lighting control makes it easier to control and more comfortable to use. For example, using smart home center equipment connected to the cloud platform, the cloud platform can process the user's needs and feedback to the required intelligent devices, allowing for more natural, intelligent, and comfortable lighting.

(4) Consider environmental protection: Choose eco-friendly lighting such as LED to reduce pollution. Additionally, intelligent lighting control can achieve the goal of energy-saving and environmental protection.

The ESP8266 module controls the WIFI transmission of the system to upload collected data to the cloud. The system is tested in two aspects: data collection and inferred user behavior functions. By passing various function tests, the system ensures the correctness of monitored data, stability, and reliability, achieving expected goals (see Table 1).

Table 1: Testing Standard

Test Objective	Test Range	Eligibility Criteria
(1)All indicators are operational accuracy>90%;	(1)Sensor test modules;	(1)Information detection
(2)The stability of the projections efficiency>90% made after data collection analysis module	(2)User behavior	(2)Information transfer

To ensure the accuracy of user behavior analysis in the system, it is crucial to measure the sensitivity of the infrared sensors, light sensors, and switches, and whether they can collect and transmit data to the cloud platform without any missing data. The mobile phone client should be able to supplement any missing data. The system should also detect whether the sensors in the lighting system and the various network nodes are functioning properly. This paper uses the STM51 microcontroller to send a hex code to the sensor's tx segment and obtain data from the sensor by receiving it from the rx segment of the sensor to the tx segment of the microcontroller. The test results are summarized in Table 2. The STM51 microcontroller is showed in Figure 3.

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Table 2: Test Result

TYPE	TEST NAME	TEST ITEMS	TIMES	EFFECTIVE	RATIO
sensor test	switch sensor	on and off	100	98	98%
sensor test	photosensitive sensor	illumation	100	95	95%
sensor test	infrared sensor	have person or not	100	97	97%
upload detection	supple date	phone upload	100	93	93%

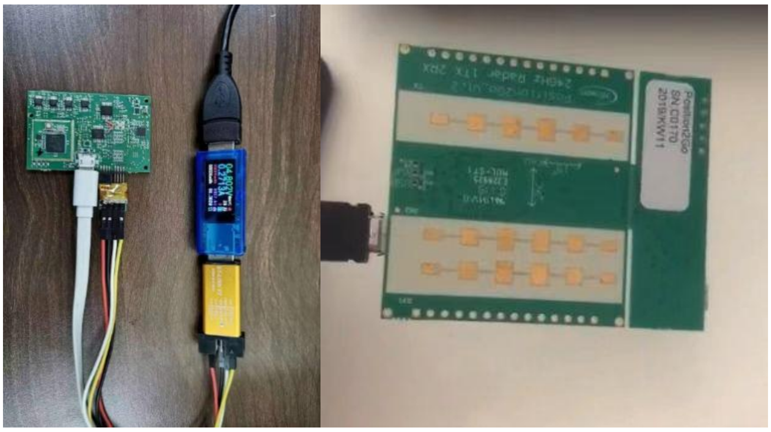

Figure 3: STM51Microcontrollor

In this study, we aim to test the effectiveness of digital twin theory in predicting user behavior for smart home lighting design. We begin by collecting data on the authors' light usage patterns throughout the day, which is then digitized and modeled using digital twin theory. We use Automation ML for conceptual modeling, followed by a microkernel digital twin platform architecture based on a simulation database.

The digital twin information model library includes an object model library with information on personnel, equipment and facilities, materials and materials, site environment and a rule model library with production information rule model library, product information rule model library, and technical knowledge rule model library as the main contents. We also incorporate the simulation and analysis layer of the digital twin and the simulation technology of the incident handling process, which allows us to dynamically predict the physical world and quickly locate and handle abnormal events through sensor data analysis.

Using the digitized data, we can simulate and predict future user behavior in different lighting scenarios. For instance, we can simulate the impact of weather on light usage patterns and predict how users will switch on and off their lights in the future. We can also use historical data and simulations to predict how many lights will be switched on at different times and in different locations.

By leveraging digital twin theory and simulation technology, we can achieve more accurate predictions of user behavior, which can inform the design of smart home lighting systems that are better suited to the needs and preferences of individual users.

4. Conclusions and Future Work

The purpose of this paper is to meet the demands of modern society, where people are increasingly living and working under pressure. The paper aims to design an intelligent lighting system that can be integrated with the Internet of Things (IoT) and deployed throughout a home, thereby reducing the stress of daily life. By creating private environmental data for each user, the system provides a more personalized smart home experience. To achieve this goal, an IoT-based smart home system is designed and built using the ESP8266 radio module for WiFi control, the STM51 microcontroller for testing, and digital twin technology for simulating data. The use of digital twin technology facilitates system design and testing, ultimately improving the reliability and stability of the system.

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