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Voice Controlled Smart Home Lighting for User Centric Control and Energy Efficiency

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ABSTRACT

Conventionally, lighting control has been manual, requiring physical, local manipulation, which can be challenging, especially in the dark or with multiple lights and switches. This paper introduces an innovative voice-controlled smart home lighting system designed to enhance user control and energy efficiency. It allows users to create custom lighting scenes and schedules, automating settings for efficient lighting based on specific needs. Voice-controlled smart lights improve energy efficiency by enabling users to control lighting with voice commands, adjust brightness, and create schedules for various activities. Timers also prevent unnecessary usage, making them a valuable addition to energy-efficient smart homes. This approach successfully contributes to energy efficiency in smart homes, representing a significant advancement in the field. By combining personalized lighting control with seamless automation, the system not only provides convenience but also promotes sustainable and efficient energy usage in modern smart homes.

Keywords:

Voice controller; Smart home; Smart lighting

1. Introduction

With the rapid development of economy, science, and technology, people have higher and higher requirements for the quality of home life, and smart home systems are required to have higher convenience and comfort [1]. As the number of IoT devices continues to rise within these smart homes, it becomes essential to find effective and sustainable ways to power them [2]. The rise in people's desire for enhanced living standards has played a pivotal role in driving the evolution of smart homes. Smart homes realize the interconnection of smart devices in the home, register each device on the cloud, and implement remote control through mobile terminals [3]. Smart home not only has the functions of traditional home but also has the characteristics of automatic and intelligent and can even save energy and money [4]. A smart home provides comfort, safety, energy-saving potential for the house at any time [5], which gives a better quality of life for

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the people [6]. Smart lighting systems allow to "Light-up smart," to a sustainable and affordable way, where it is needed, when it is necessary, and as best as possible [7].

Driven by population expansion, urban transport infrastructure evolution, industrial process innovation, and rapid urbanization, including the proliferation of structures and novel ecosystems due to human activities, there has been an alarming surge in energy consumption [8]. The high level of energy consumption is one of the largest contributors to climate change, accounting for about 60% of global greenhouse gas emissions. On the other hand, studies show that improving energy efficiency standards could reduce the overall electricity consumption of buildings and industry by 14% [9,10]. The main direction of smart lighting research is energy saving. The cause is the large proportion of energy consumption coming from lighting systems [11]. Three key factors identified in relation to building energy consumption are natural elements, social influences, and human behaviour [12,13]. The lighting system can occupy up to 40% of electricity consumption, so it is important to have strategies and energy management systems (EMSs) to optimise this consumption [14,15].

Using voice recognition technology in smart homes, people can communicate and control in natural language with devices, which greatly improves experience and meets people's consumer needs [1,16]. The demand for human-level linguistic understanding in voice-operated devices has the power to significantly transform lifestyles and work methodologies. It is the needs of social life that have promoted the rapid development of technologies such as speech recognition [14]. Voice control system provides people with a more user friendly, more convenient control method, especially when people are in a closed place or dark environment, speech recognition control is necessary [17].

Conventionally, lighting control has been manual, which requires physical, local control manipulation and is commonly used in the widest scope of applications [18]. It is difficult when it is in a dark, people can only blindly search for the switch before turning on the light. Sometime, people might have an injury due to unseen obstacles while trying to approach the switch in the dark [19]. The task becomes more complicated when there are multiple lights with multiple switches. With the evolution of technology, people try to replace the traditional physical lighting switch with remote control. But the small and portable size increases the probability of missing the device. Thus, some of them change to control using an application. With the increased use of smartphone, there is a rise in demand for mobile applications. People pursuing devices that have better user experience, accessibility and ability to ease their daily lifestyle.

There is a need for a comprehensive and cost-effective smart home control system that can be controlled through voice commands [1]. Therefore, a voice controller is introduced to make the light more accessible compared with the current touch panel controller. It could reduce the number of steps to control the light, with just giving specific keyword commands the light can be trigger without having multiple clicks.

2. Related works

Legrand Lighting Control is a free application that introduced by Legrand to provide a quick and easier way to access and control the RF lighting control system. It connects to the lighting system via a Wi-Fi connection. This application consists of a variety of switches, dimmers and scene controllers [20]. This application allows the user to group available light into a scene and allows to set automated lighting rules for each scene. User allows to customize, schedule and automate the group, set the suitable lighting for the scene. The date and time can be set for each scene, specify the recurrence of the scene, can be either daily or weekly. This makes user life easier as the light

that has the same behaviour is grouped and will be self-activated when it reaches the time set. Users can manage the list of scenes created easily as there is a function to add, edit and remove. Changes can be made on the scene to update the recurrence, date or fade rate [21].

Hao *et al.,* approach [17] utilizes components such as ARM microprocessor, speech recognition chip, voice broadcast module, and NRF24L01 wireless transceiver module. The voice control system of smart home, which is composed of sensor detection and other main modules, is different from the mainstream smart home control products in the market (Xiaomi Intelligent Audio. A portable wearable functions as the input device. To activate the recognition mode, simply touch the button to turn it on. Most importantly, it includes the function of voice broadcast so that it can let users achieve simple interaction.

Isyanto *et al.,* approach [6] utilizes components of Microcontroller of NodeMCU, relay, lights, power supply unit and google assistant. They used voice commands of Google Assistant on smartphones. Users do not need to move to turn on or turn off electrical equipment. The Google Assistant application will accept voice commands when the pronunciation is correct. Voice commands are simpler to apply, without typing text messages. Users get convenience compared to using text. Users only send voice commands to the Google Assistant Application, and the system will automatically display the text messages that we said before, without typing text messages.

Swamy *et al.,* approach [22] proposed the voice-controlled home automation using Raspberry Pi for the benefit of easy use and control of devices. It provides a basic home automation which can be easily implemented and used effectively for a real time application of voice-controlled home automation. Thus, the Raspberry Pi is used to be smart, economic and efficient platform for implementing the home automation system. It implemented the operation of lights through the voice-controlled home automation system by giving voice commands as an input for use to turn ON and FOFF the lights at home.

ZigBee-based smart voice home appliance [1] control system that uses wireless voice sensors to control household electrical appliances. The system can be connected to the light switches and light bulbs in the house, and the user can control the lights using voice commands. The system uses voice recognition technology to recognize the user's voice commands and sends signals to the light switches to turn on or off the lights. the system provides a convenient and hands-free way for the user to control the lights using voice commands. This eliminates the need for the user to physically interact with the light switches, which can be especially useful for people with mobility or accessibility issues.

In Elakkiya *et al.,* approach [23], the lights are automated based on the inputs from a motion detector. The web application developed used to control the light from a remote area using natural language. The voice recognition feature is used to take input to control lights. Therefore, the user can control the lights either by using the motion detector or by giving voice commands through the web application.

The reviewed approaches [6,20-23] trigger the light indirectly. Light is trigger using audio command through a third-party service such as Google Assistant and Alexa. An account needs to be created in order to use this function. By proposing light control application whereas the application itself has the platform specified for audio command, light can be triggered directly through audio command and no third party will involve in the process. This, in turn, reducing the number of clicks to reach the desired audio controller page compare with an existing application with an audio controller. Besides, using this voice controller it’s able to satisfy the user satisfaction and also for energy saving.

3. Proposed Solution

The proposed design consists of a light controller application, a controller hub, and a dimmable light bulb. Three of this hardware need to be connected to perform the function of this proposed light controller application. The connection between the light controller application and the control hub is via Bluetooth which having a more convenient configuration of the light even the location that is Wi-Fi unavailable.

Under the light controller application, it consists of an application interface to have an interaction with the user. Besides a database is required to store all the lighting device details and status. One of the special features of this application has the ability to trigger the light device using voice command. Thus, users able to interact with the application via touch panel and voice panel. The architecture design of the proposed smart light with voice controller application is shown in Figure 1.

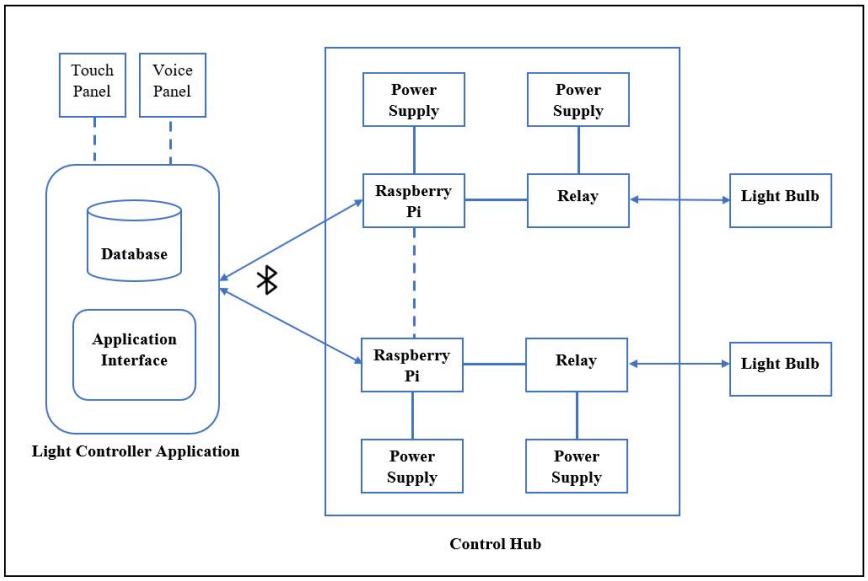

Fig. 1. Architecture design of the proposed Smart Light with Voice Controller Application

There is a control hub in this architecture. The main function of the control hub is to trigger the light when receiving a command from the user application. In this project, raspberry pi is used as the control hub of this application. Besides, a power supply is required to enable raspberry pi to perform its task. Furthermore, an AC light dimmer that acts as a switch to control the current flow and brightness of bulb. A wire that connected to the AC current is then connect to the dimmable light bulb and AC light dimmer to make the system complete. The hardware setup for voice controlled smart home lighting is show in Figure 2

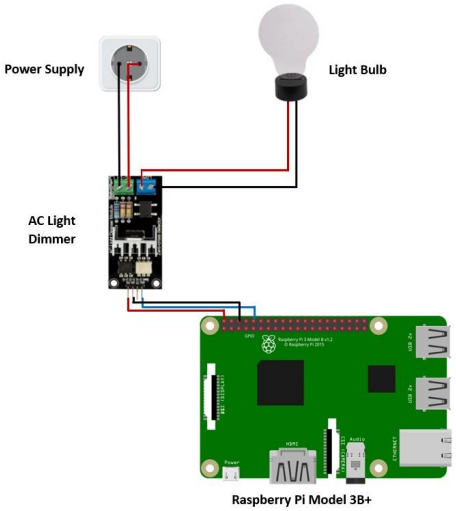

Fig. 2. Hardware setup for voice controlled smart lighting

3.1 Register and Manage Light Device

The user needs to register the light with Bluetooth connection as shown in Figure 3. A list of Bluetooth devices scanned by the application will be displayed below the button area, as depicted in Figure 4. The user must select the desired light device for registration. Following this, the user will be prompted to rename the light device, thereby finalizing the registration process. Figure 5 showcases a page displaying details of a registered light device. Users have the capability to manage the light device by either deleting it or updating its name.

Fig. 3. Register page of voice controller application

Fig. 4. Register page with list of device scan of voice controller application

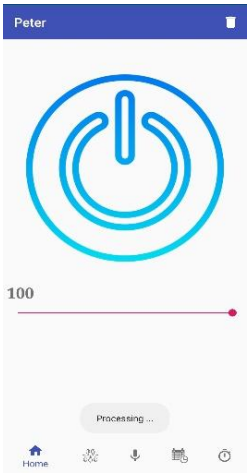

Fig. 5. Desired lighting page of voice controller application

3.2 Control Light Device

Users can control the light device through the voice panel, as shown in Figure 6. By holding the microphone icon, the application will commence accepting and listening to commands, as depicted in Figure 7. Upon the user's release of the button, the application processes the received command,

displays it on the page, and delivers a specific reply to the user's audio command. To initiate light control, a particular keyword must be included in the audio command. For instance, to turn on the light, the user needs to specify the light's name along with the action keyword "on". After command verification, the message will be sent to the hub, triggering the corresponding light action.

Fig. 6. Audio control page of voice controller application

Fig. 7. While listening to user command in Audio control page

3.3 Group Light Device

A list of the available registered light devices enables the user to group them under a specific name, as depicted in Figure 8. This function simplifies light control, requiring just one click to manage lights that share similar behaviour. The chosen name undergoes verification to ensure the absence of special characters or identical names in the database. Users need to create a group name that is not already present in the database; otherwise, they won't be able to successfully create the new group.

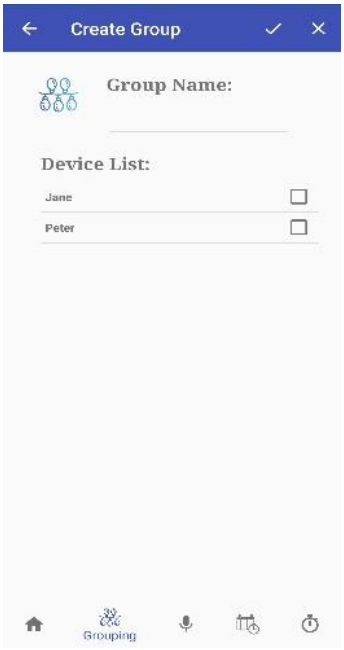

Fig. 8. Create group page voice controller application

3.4 Manage Lighting Group

Similar to individual lighting, users able to manage the lighting group either to update group details or remove the particular lighting group from the database. As shown in Figure 9, the user able to edit the group name and the desired individual light device to be group under the selected group. As shown in Figure 10, there exists a button beside each group, the user able to control the light either to switch on or off by clicking on the button. By swiping the lighting group to the left, the user able to delete the selected lighting group.

Fig. 9. Desired group page of voice controller application

Fig. 10. Group listing page of voice controller application

3.5 Manage Light Automation Scheduling

Users can select the desired automation time, repeat day, light action, and the desired light for the automation. The scheduling page and the automation listing page is shown in Figure 11 and Figure 12 respectively. The selected light will be trigger with the automation action when the automation time has reach. Besides, the user can manage the automation by editing or deleting the automation. Users can either swipe to delete or delete in the edit automation page. Users can manage by turning the automation either on or off in the automation page. This function is mainly eased user life, as this could reduce a routine step in their daily life. The light will trigger automatically based on the automation set.

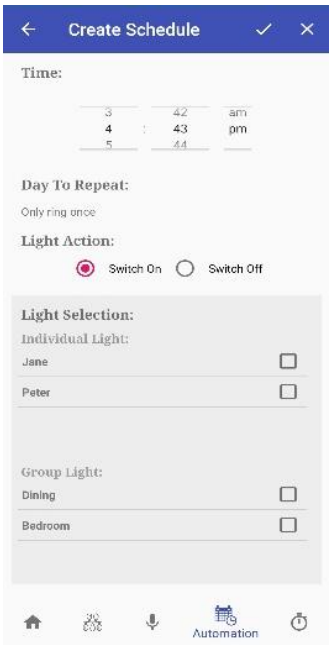

Fig. 11. Scheduling page of voice controller application

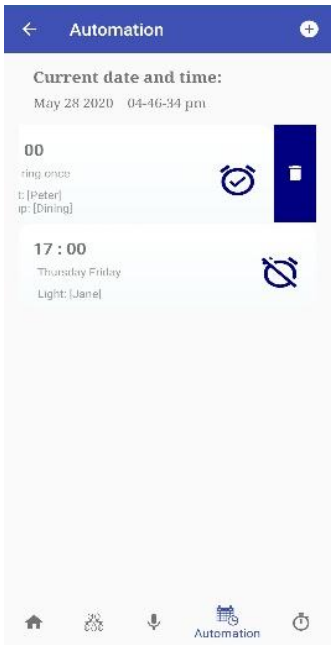

Fig. 12. Automation listing page of voice controller application

3.6 Set Delay Timer

Users are allowed to select a desired individual light or group to either switch on or switch off after a specified time, as illustrated in Figure 13. The timer is activated only when all the required parameters are filled in by the user, as depicted in Figure 14. Once the timer reaches its end, the command is sent to the hub, triggering the light according to the user's action.

Additionally, users can delay light actions through the voice panel by using the specific keyword "delay," which activates the delay control feature in the application. Moreover, users need to specify the trigger time in either minutes or seconds. The audio command is then processed, and the application responds accordingly based on the user's command.

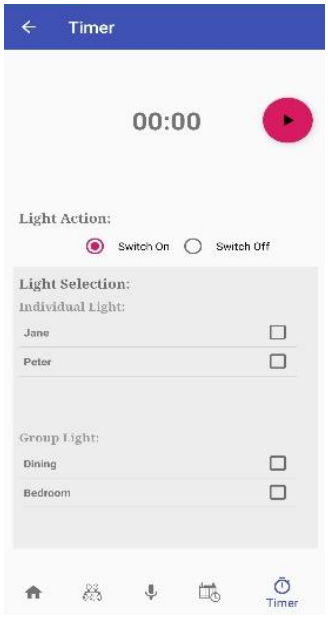

Fig. 13. Timer page of voice controller application

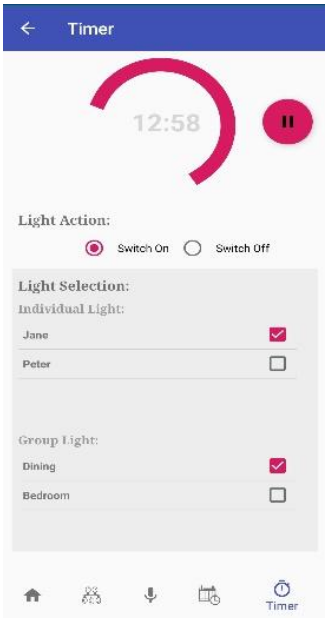

Fig. 14. Running timer page of voice controller application

3.7 Project Set Up

The prototype of the smart lights with voice control is show in Figure 15.

Fig. 15. The prototype of the electrical equipment control system

By using this light controller application, the user able to group multiple lights that have the same behaviour. Users able to manage and control the lighting group, a list of light in a group can be triggered by just turning one toggle switch or by using audio command. Besides, the user able to schedule the light automation, the light will be trigger on the scheduled time with the action set. Lastly, the user able to set a delay timer for the light using touch or voice panel. It is a “countdown” function in this application, which emulates a timer, the light will be trigger when the delay time set reaches

4. Testing and Results

After the design of the device is complete, the next step is to check, test and measure the device. This stage aims to check the overall function and performance of the device and also user satisfaction.

4.1 Unit Testing

The main purpose of unit testing is to segregate the application into a smaller part of the function. Each of the functions is tested separately to ensure each of it is performed as its designs. Test case for device registration, management of light, light control, group light management, light automation scheduling, voice panel control and delay timer setting has been carried out with 30 respondents. All test cases were passed.

4.2 Performance Testing

Voice control Panel is carried out by 40 respondents to complete the task given based on their voice. This system test aims to test the performance of the voice control panel with the light control. With this testing, the performance of the device is achieved 97% of successful rate by the expected design.

4.3 Usability Testing

The main purpose of usability testing is to have a better understanding of how real users interact with the application created and improve the design based on the given set of test tasks. The User Satisfaction rate is shown in Table 1.

Table 1
User Satisfaction rate

	User satisfaction (1-5) 5-highly Agreed.				
	1	2	3	4	5
Device registration	0	0	0	5%	95%
Management of Light	0	0	0	10%	90%
Light control	0	0	0	8%	92%
Group light management	0	0	0	10%	90%
Light automation Scheduling	0	0	0	7	93%
Voice panel control	0	0	0	6	94%
Delay timer setting	0	0	0	5	95%

The summary of the result is show in Figure 16.

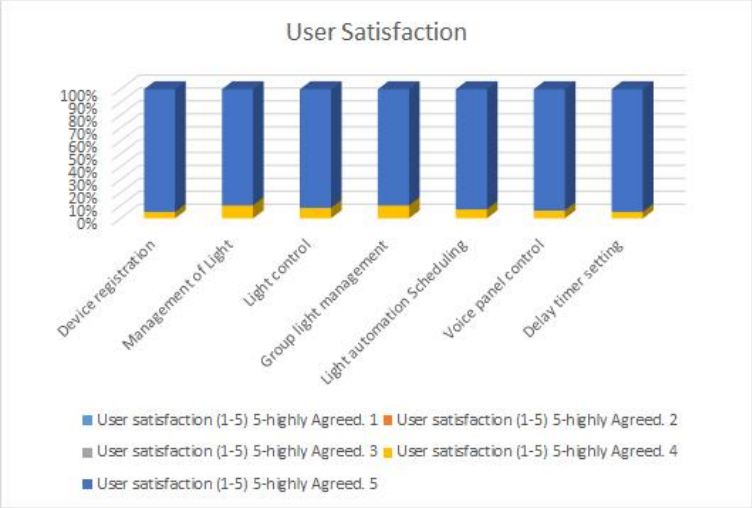

Fig. 16. User Satisfaction

Most of users are highly satisfied with the use of device registration (95%), management of light (90%), light control (92%), group light management (90%), light automation scheduling (93%), voice panel control (94%) and delay timer setting (95%).

4.4 Energy Saving and Efficiency

This Voice-controlled smart lights enable users to turn lights on and off, adjust brightness levels without physically interacting with switches. This capability encourages users to easily turn off lights when not needed, reducing unnecessary energy consumption. Besides, Smart lights often offer the ability to create customized lighting scenes and schedules. Users can optimize lighting levels for different activities (e.g., reading, working, relaxing) and automate these settings, ensuring that lights are used efficiently based on specific needs. Users also can set timers to automatically off it. This feature helps prevent instances of lights being left on unintentionally when users are away from home. This voice-controlled smart lights have successfully contributed to energy efficiency for smart home.

5. Conclusions

In conclusion, the paper introduces an innovative voice-controlled smart home lighting system that prioritizes user control and energy efficiency. Through customizable lighting scenes, automated schedules, and intuitive voice integration, the system optimizes lighting based on individual needs. This approach not only enhances convenience but also contributes to sustainable energy use in contemporary smart homes. By harmonizing personalized control with efficient automation, this system represents a significant leap forward in the field, paving the way for smarter and more environmentally conscious living spaces.

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