Home Motion & Voice Lighting System

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1. Abstract

This study proposes an automated home lighting system based on the **NUC140** M0 microcontroller, integrated with a **PIR** infrared human sensor and a **light-dependent resistor (LDR)**. The system automatically **turns on the light when a person is detected in low-light conditions**, and turns it off when the environment is bright or no one is present. Additionally, a 8-second delay and a **"turn off" voice interruption** mechanism are implemented to enhance energy efficiency and user convenience. Experimental results show that the system **achieved a 100% success rate in both automatic lighting and voice interruption tests**, demonstrating that low-cost sensing components can provide stable smart lighting control. This confirms the system's potential for applications in general households and IoT-based energy-saving environments.

Keywords— Smart lighting system, NUC140 microcontroller, PIR sensor, light-dependent resistor (LDR), voice interruption, home automation, energy saving

2. Introduction

With the rise of smart home technologies and energy-saving concerns, traditional manual switches can no longer meet users' expectations for convenience and energy management. Infrared motion detection and ambient light sensing are widely used in public areas such as building corridors and parking lots.

However, the cost of commercial modules and wiring remains a barrier for general households. To address this, the study focuses on a low-power, easy-to-install, and cost-effective single-point lighting solution, aiming to ensure that lights are **"only on when needed"** — achieving energy savings without compromising daily convenience.

3. Material and Method

3.1 System hardware

(1) M0 Development Board (NUC140): Responsible for sensor data acquisition and output control.

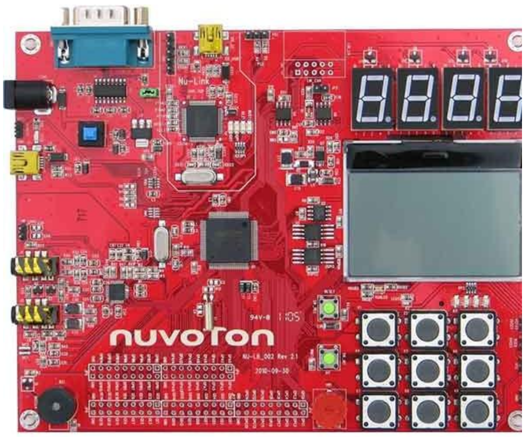

Figure 1. M0 Development Board (NUC140)

(2) PIR Sensor (BM22S4023-1): Detects changes in infrared radiation caused by human presence.

Figure 2. PIR Sensor (BM22S4023-1)

(3) Photoresistor (GL5528): Detects ambient light intensity.

Figure 3. Photoresistor (GL5528)

(4) LCD Panel (on NUC140 board): Indicates lighting status and system state.

(5) Computer: Serves as the power supply source.

3.2 Architecture

(1) **Sensor Decision Logic:**

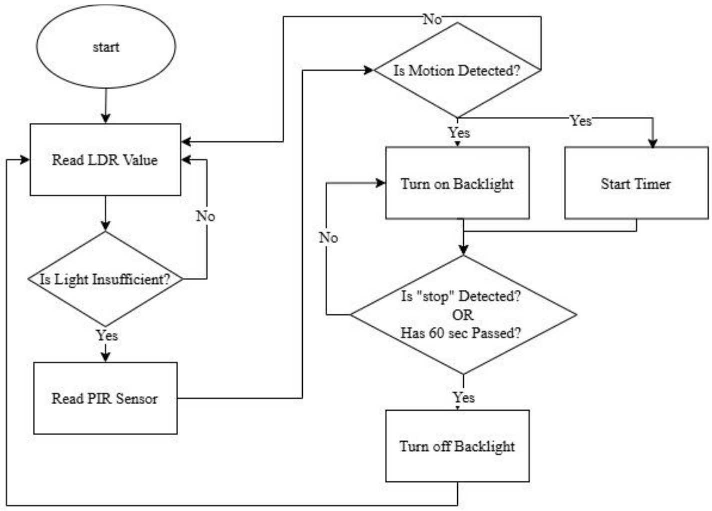

Figure 4. program flow chart

(2) **Light Intensity Threshold:**
Based on experimental results, an LDR ADC value below **1000** is defined as the threshold for a "dark" environment.
(3) **Voice Interrupt:**
During the delay period, the system continuously listens for audio input. If the keyword “turn off” is detected, the light turns off immediately and the timer is reset.

3.3 Methodology

This study adopts a combination of implementation and experimentation to design and validate a **home motion-sensing lighting system with ambient light detection functionality**. The overall methodology consists of four main stages: system design, module integration, program development, and real-world testing.

In the system design phase, the NUC140 microcontroller serves as the core processing unit, integrated with a **PIR sensor for human presence detection** and a **photoresistor (LDR) for measuring ambient light levels**. The system obtains environmental brightness data via an analog-to-digital converter (ADC), and when the measured light level falls below a predefined threshold while human motion is detected, it activates an LED light through PWM control to simulate home lighting. In addition, a delay mechanism and a **voice interruption feature** — triggered by the **keyword “tuen off”** — are incorporated to enhance usability and control.

The module integration is divided into the following three parts:

(1) Voice Recognition

In the early stage of this study, a speech command recognition model was initially developed using the PyTorch deep learning framework. The model was trained on the Google Speech Commands dataset using a convolutional neural network for voice classification. However, after evaluating the time required for data collection, labeling, model training, and the computational demands of real-time deployment, this approach was deemed less suitable for lightweight, embedded applications.

To improve development efficiency and ensure high recognition accuracy, this study ultimately adopted the Google Speech Recognition API in combination with the Python speech_recognition library to implement the speech control functionality. This solution offers several advantages, including high recognition accuracy, fast development, and seamless system integration, making it ideal for voice-activated applications such as light control in this system.

In the speech processing workflow, the speech_recognition library accesses the local microphone to capture real-time audio input, which is then transmitted to Google's cloud-based speech recognition service for analysis and transcription. The default recognition language is English (en-US), but the system can be extended to support multilingual command recognition as needed.
Compared to conventional approaches that require dataset collection and model training, the adopted solution eliminates the need for local model development, enabling immediate deployment and cross-platform compatibility. The resulting speech recognition module is lightweight, responsive, and reliable, successfully enabling voice-triggered system control and interruption functionalities.

(2) Ambient light and LCD backlight

In this study, the NUC140 microcontroller serves as the core processing unit, paired with a **light-dependent resistor (LDR)** in a voltage divider configuration. The output voltage from this circuit is **connected to the seventh ADC channel (GPA7/ADC7)**. The ADC input is configured to produce a 12-bit integer value, which is used to determine lighting conditions. When the brightness falls below a preset threshold (**ADC < 1000**), the system **triggers a PWM output** to activate the simulated lighting via the LCD panel. Simultaneously, the LCD display module shows the current ADC value and its corresponding status (e.g., “dark” or “ok”) to provide real-time feedback. Modules such as **GPIO, ADC, PWM, and LCD** are configured according to datasheet specifications and integrated through embedded programming.

During the experimental phase, after completing the circuit wiring, the control program was written and flashed using IAR Embedded Workbench. Repeated tests were conducted to simulate various brightness conditions (e.g., covering or exposing the LDR to light). Each test involved observing whether the ADC value displayed on the LCD responded accurately to changes in brightness and whether the LCD backlight toggled correctly—thereby validating system logic. Initially, an issue arose with abnormally high ADC values. This was resolved by adjusting the ADC channel setting (consistently using ADC7 and masking upper bits), correcting the pin mapping (to GPA7), and avoiding redundant data reads. Through these debugging efforts, a stable and responsive light-sensing control system was successfully achieved.

(3) PIR search

This study utilizes the BM22S4023-1 passive infrared (PIR) sensor, which receives environmental signals using passive infrared technology and communicates with the host device via a UART interface.

The BM22S4023-1 offers two operating modes: **Auto mode** and **Command mode**. In Auto mode, the sensor continuously outputs PIR detection results without requiring commands from the host. In this project, **Command mode** is adopted, meaning the host must send a specific command to the BM22S4023-1 in order to trigger a detection response.

No.	Command Type	Command Code	Functional Description	Data (Byte)
1	READ	0x01	Request to read PIR original signal	—
			Respond with PIR original signal	2
2	READ	0x02	Request to read PIR filtering signal	—
			Respond with PIR filtering signal	2
3	READ	0x03	Request to read device module name	—
			Respond with device module name	10
4	READ	0x04	Request to read PIR configuration register	—
			Respond with PIR configuration register	1
5	WRITE	0x05	Setup PIR configuration register	1
			Respond with WRITE information	1
6	READ	0x06	Request to read sensitivity register	—
			Respond with sensitivity register	1
7	WRITE	0x07	Setup sensitivity register	1
			Respond with WRITE information	1
8	READ	0x08	Request to read PIR time delay interval	—
			Respond with PIR ON time interval	2
9	WRITE	0x09	Setup PIR ON time interval	2
			Respond with WRITE information	2
10	READ	0x0A	Request to read PIR block time interval	—
			Respond with PIR block time interval	1
11	WRITE	0x0B	Setup PIR block time interval	1
			Respond with WRITE information	1
12	READ	0x0C	Request to read PIR STATUS register	—
			Respond with PIR STATUS register	1
13	SETUP	0x0D	Request device to enter Sleep mode	—
			Respond with SETUP information	1
14	SETUP	0x0F	Reset the device	—
			Respond with SETUP information	1
15	READ	0x10	Request to read temperature data (Unit: 0.1°C)	—
			Respond with temperature data (Unit: 0.1°C)	2

Figure 6. Command table of the BM22S4023-1, excerpted from the datasheet.

By pre-programming the NUC140 microcontroller, a command is sent to the sensor only when data needs to be retrieved. During development, the onboard keypad was used as an input interface to trigger the sensor to output parameters or retrieve data.

The sensor primarily provides two key pieces of data that are used to determine whether a person is present within the detection range, original signal and filtered signal, but since the original signal are quite unstable, the filtered signal was used, the typical signal value for a person to walk by is between 200 to 1000 depends on how far the person is from the PIR sensor.

Sleep mode was also implemented, when the lighting value is over the threshold, PIR sensor will be set to sleep mode until the lighting value is lesser than the threshold.

3.4 Experimental Design and Procedure

(1) Hardware program design

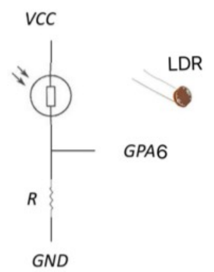

Figure 7.

【Table 1.】 Light Sensor Trigger Test Record

(5 Trials per Environment)

components	NUC140 Pin number	Note
ADC	GPA6	
LCD backlight	GPA12	Both are connected to each other
PWM	GPD14	
PIR motion sensor	RX : PB5 TX : PB4	
UART transmission	RX: PB1 TX: PB0	

After connecting the circuit on the NUC140 board and breadboard, the program was written and executed using the IAR software.

(2) **Software Program Design**

As illustrated in Fig. 7, the overall system workflow consists of several stages: audio acquisition, noise filtering, automatic speech recognition (ASR), keyword matching, and result transmission. If the recognized result contains the command "turn off," a corresponding control signal is sent via UART to the NUC140 microcontroller to interrupt the lighting system.

Voice input is captured via microphone, processed through the Google Speech Recognition API for transcription, matched against predefined commands, and finally transmitted to the NUC140 microcontroller via UART.

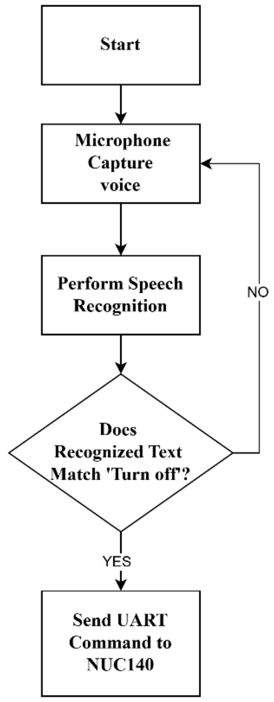

Figure 7. The flowchart of the voice detecting.

3.5 Verification Design and Procedure

(1) System Verification

I. Test Items

- Accuracy of light sensing trigger (auto lighting)
- Response delay of voice interruption function

II. Test Environment

An indoor space with natural lighting is selected. The following setups are used to simulate different lighting conditions across times of day:

- **Morning / Bright condition**: Flashlight applied to the sensor
- **Night / Dark condition**: No flashlight applied

(2) Verification Procedures

I. Brightness-Based Trigger Test

[1] Place the system in a fixed environment
[2] After the ambient light stabilizes, perform **5 simulated pass-by actions** (person walking past)
[3] For each test, record: Whether the light was successfully triggered

II. Voice Interruption Function Test

[1] Under a condition where the LCD backlight is already on (choose a successful lighting case from each scene)

[2] Speak the voice command keyword (e.g., **"Turn off"**) to the system

[3] Repeat 5 times; for each test, record: Whether the light turned off successfully

4. Results

【Table 2.】 Light Sensor Trigger Test Record (5 Trials per Environment)

environment	motion detected	no.	ADC value	light on/off
Bright (ADC > 1000)	Yes	1	1238	off
		2	1375	off
		3	1645	off
		4	1802	off
		5	1459	off
	No	1	1475	off
		2	1460	off
		3	1498	off
		4	1508	off
		5	1460	off
Dark (ADC < 1000)	Yes	1	915	on
		2	866	on
		3	938	on
		4	756	on
		5	827	on
	No	1	932	off
		2	833	off
		3	739	off
		4	918	off
		5	812	off

【Table 3.】 Voice Interruption Test Record

environment	No.	light on/off
When the environment is dark and motion detected, **someone said "turn off."**	1	off
	2	off
	3	off
	4	off
	5	off

5. Discussion

Based on the results of the light sensor trigger test (Table 2), when the ambient brightness was above 1000 (Bright), the system correctly refrained from turning on the light, regardless of whether motion was detected. This indicates that **the system can effectively suppress unnecessary lighting in well-lit environment**s. In contrast, under low-light conditions (ADC < 1000), **the system successfully turned on the light in all five motion-detected trials**, demonstrating a **100% activation accuracy**. Additionally, the light remained off in all trials where no motion was present, further confirming the system's low false trigger rate and the reliability of the dual-condition logic combining brightness and motion detection.

In the voice interruption test (Table 3), when the light was on due to dark environment and motion detection, users issued **the voice command "turn off." The system successfully responded and turned off the light in all five trials**, achieving a **100% voice-triggered interruption success rate**. This suggests that the voice control module is capable of recognizing commands clearly and interrupting the existing delay logic in real time. Overall, the system demonstrated fast and accurate collaboration between brightness sensing, motion detection, and voice control, meeting the expected behavior in practical scenarios.

6. Conclusion

This system integrates a photoresistor and PIR sensor to realize an intelligent lighting control mechanism based on **"ambient brightness + motion detection."** Additionally, a voice interruption function is included to provide user-initiated control. Experimental results show that the system performs with high stability and accuracy, achieving **100% success in both auto-light triggering and voice interruption tests**.

In conclusion, the system offers **a combination of environmental awareness, responsive motion detection, and voice control**, delivering a well-rounded and practical **smart home lighting solution**. Future improvements may include enhanced noise resistance for the voice recognition module and the integration of contextual learning features to adapt to individual user preferences and daily routines.

7. References

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