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Smart Li-Fi Door Lock System

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Abstract:
Smart door lock systems are widely used to enhance security in residential and commercial environments. However, most existing systems rely on radio frequency (RF) communication technologies such as Wi-Fi, Bluetooth, and RFID, which are susceptible to signal interference, signal leakage beyond physical boundaries, and dependence on network connectivity. To address these limitations, this paper presents the design and implementation of a Smart Li-Fi Door Lock System based on Visible Light Communication (VLC) using Morse code for secure indoor access control. The system transmits authentication data through light pulses generated by a smartphone flashlight, detected by a Light Dependent Resistor (LDR) and processed by an Arduino Nano microcontroller to control a relay-driven solenoid door lock. Experimental testing demonstrated approximately 95% password recognition accuracy within a 30 cm operating range, with an average response time of 2–3 seconds. The prototype demonstrates that Li-Fi technology is a cost-effective and secure alternative to conventional RF-based smart door lock systems.

Key Word: *Li-Fi, Smart Door Lock, Visible Light Communication (VLC), Access Control System, Arduino Nano, Morse Code, Embedded System.*

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I. Introduction

Security and access control systems play a critical role in protecting residential and commercial environments from unauthorized entry. Traditional mechanical door locks offer only basic protection and depend entirely on manual operation. To overcome these limitations, smart door lock systems have been developed using wireless technologies such as Wi-Fi, Bluetooth, and RFID. Although these systems offer automation and remote accessibility, they suffer from significant limitations including security vulnerabilities, signal interference, high power consumption, and dependence on continuous network connectivity [1,2].

Radio frequency (RF)-based communication signals can easily extend beyond the physical boundary of a door or wall, increasing the risk of unauthorized access through signal interception [2]. Furthermore, network-based smart lock systems require a stable internet connection to function, which can reduce system reliability and increase overall complexity. These challenges highlight the need for a localized, interference-free, and inherently secure access control mechanism suitable for indoor applications.

Light Fidelity (Li-Fi) is an emerging wireless communication technology that uses visible light for data transmission. Unlike radio waves, visible light cannot penetrate walls and remains confined within a line-of-sight region, making Li-Fi inherently more secure for indoor applications [3,7] . Professor Harald Haas introduced the concept of Li-Fi during a 2011 TED Global talk, demonstrating high-speed data transmission through LED light [5] . The visible light spectrum used by Li-Fi is approximately 10,000 times broader than the radio frequency spectrum [7] , offering significant bandwidth advantages.

This paper presents the design and implementation of a Smart Li-Fi Door Lock System using Morse code transmitted via a smartphone flashlight for authentication. The main contributions of this work are: 1. a complete hardware prototype integrating LDR sensing, Arduino Nano processing, and relay-driven solenoid actuation; 2. a network-independent, line-of-sight-restricted authentication mechanism using Morse code over visible light[3] ; 3. real-time user feedback via LED indicators and a buzzer [4,5] ; and 4. Quantitative performance evaluation including accuracy, response time, and operating range.

II. Literature Survey

Several researchers have explored smart door lock and wireless communication systems using various technologies, forming the foundation for the proposed Li-Fi based approach.

Asman et al. [1] designed a prototype smart lock based on IoT using an ESP8266-equipped Wemos D1 R1 board, controlled via a smartphone through the Blynk application. The system used the ADDIE development model and a PIR sensor for motion detection, with a solenoid lock operating at 12V DC. Testing confirmed the

PIR sensor functioned within a 90 cm radius at 120°. However, the system was entirely dependent on Wi-Fi and internet connectivity, and RF signals could extend beyond the door boundary, reducing security confinement.

Shinde et al. [2] presented an Android-based smart door locking system using Arduino UNO and a BOLT IoT device (ESP8266). A cloud-based Android application enabled remote unlocking via the BOLT IoT cloud platform. While accessible from anywhere, the system required continuous internet connectivity and displayed offline errors when the network was unavailable, limiting its reliability and introducing potential signal leakage vulnerabilities common to Wi-Fi systems.

Lee et al. [3] proposed a novel optical Morse code-based electronic lock using a smartphone LED as the transmitter and a photoresistor as the receiver, processed by a LinkIt ONE microcontroller. A fuzzy controller with a digital potentiometer (MCP41010) was introduced to compensate for ambient light variation. Mathematical models including $V_u = 3.3 \times R /(3.3 + R)$ were derived for the LDR voltage divider, and recognition accuracy improved from ~65% to 100% across illuminance levels of 150 to 900 Lux. While this work directly employed visible light communication, it focused on signal decoding without full mechanical lock actuation.

Shilpa K.C. et al. [4] implemented a Li-Fi door lock system using an LDR module, Arduino Uno, MOSFET-driven lock mechanism, and a GSM module (SIM800C) for SMS alerts upon successful access. The system transmitted a key via smartphone flashlight and verified it against a stored password. However, the paper lacked quantitative performance evaluation and detailed analysis of ambient light interference effects on system reliability.

Kirange et al. [5] presented a Li-Fi enabled smart door lock with tamper detection using an accelerometer. The system triggered buzzer alerts on unauthorized physical manipulation and reported a success rate exceeding 95% under ideal line-of-sight conditions. Key challenges identified included signal interference, environmental LDR sensitivity, latency in Morse code pattern recognition, and limited communication range.

Nayana R. and Shashidhar R. [6] developed a smart door lock combining fingerprint recognition with OTP authentication via GSM. Users entered their registered mobile number, received an OTP by SMS, and completed fingerprint verification before access was granted. While this offered dual-factor authentication, it required biometric hardware and GSM network availability, significantly increasing cost and complexity compared to light-based approaches.

Ismail et al. [7] implemented a Li-Fi based home automation system and studied the effect of LED color on VLC transmission distance. Results showed that a red LED (660 nm wavelength) achieved a maximum transmission distance of 165 cm at 5V, outperforming warm white (97 cm) and blue LEDs (86 cm) at the same voltage. This finding is directly relevant to optimizing LDR receiver sensitivity and the operating range of the proposed system.

Based on the above review, existing RF-based systems [1,2] suffer from signal leakage and internet dependency, while prior Li-Fi approaches [3,4,5] either lack complete lock actuation or quantitative performance data. The proposed system addresses these gaps by delivering a complete, network-independent Li-Fi door lock with measured accuracy, response time, and operating range.

Table no 1: Comparative Analysis of Related Works

Author / Reference	Technology	Authentication Method	Key Limitation
Asman et al. [1]	IoT / Wi-Fi	Blynk Smartphone App	Internet dependency, signal leakage
Shinde et al. [2]	Cloud / Wi-Fi	Android + BOLT IoT Cloud	Offline failure, internet required
Lee et al. [3]	VLC / Morse Code	Flashlight + Fuzzy Controller	No mechanical lock actuation
Shilpa K.C. et al. [4]	Li-Fi / LDR	Smartphone Flashlight App	No quantitative results
Kirange et al. [5]	Li-Fi + Tamper Detect	Flashlight + Accelerometer	Ambient light sensitivity
Nayana & Shashidhar [6]	GSM + Biometric	OTP + Fingerprint	High cost, GSM dependency
Ismail et al. [7]	Li-Fi / VLC	LED + LDR Home Automation	No password authentication
Proposed System	Li-Fi / Morse Code	Smartphone Flashlight + Arduino Nano	Line-of-sight required

III. Methodology

A. System Overview

The proposed Smart Li-Fi Door Lock System consists of two main sections: the transmitter and the receiver. The transmitter is a smartphone running a Morse code generator application that converts a pre-defined alphanumeric password into light pulses using the built-in flashlight. The receiver unit comprises an LDR sensor, an Arduino Nano microcontroller, a relay module, a solenoid door lock, LED indicators, and a buzzer. Unlike the Wi-Fi-based systems of [1,2] , the proposed system operates without any internet connectivity, making it fully autonomous and immune to network failures.

B. Li-Fi Technology: Working Principle

Light Fidelity (Li-Fi) is a bidirectional, high-speed wireless communication technology that employs visible light as the transmission medium, operating within the 400–700 nm wavelength band of the electromagnetic spectrum. Unlike Radio Frequency (RF)-based systems, Li-Fi exploits the intensity modulation capability of Light Emitting Diodes (LEDs) to encode and transmit data. The fundamental mechanism involves switching the LED output at frequencies imperceptible to the human eye—typically in the range of tens of kilohertz to several megahertz—such that the modulated light signal carries binary data. A photo detector or photosensitive element at the receiver end converts the incident light intensity variations back into electrical signals, which are subsequently demodulated to recover the transmitted data.

In the proposed system, the smartphone's built-in LED flashlight serves as the Li-Fi transmitter. The Morse code generator application controls the flashlight via the Android camera API, toggling the LED on and off at precisely defined intervals to produce timed light pulses corresponding to Morse code symbols. The LDR sensor functions as the optical receiver, with its resistance varying inversely with the intensity of incident light. This resistance variation is transduced into a measurable voltage at the Arduino Nano's analog input through a voltage divider network.

Li-Fi offers three principal advantages pertinent to the proposed application. First, visible light cannot penetrate opaque barriers such as walls and doors, inherently confining the communication channel to the immediate line-of-sight region and thereby preventing external signal interception. Second, the technology operates entirely within the optical spectrum and generates no radio frequency emissions, rendering it immune to RF interference and compatible with electromagnetically sensitive environments. Third, the simplicity of LED-based modulation permits cost-effective implementation without the need for dedicated RF transceivers or network infrastructure.

C. Morse Code: Encoding Scheme

Morse code is a standardized encoding scheme that represents alphanumeric characters as sequences of two discrete signal elements: a short element (dot, ·) and a long element (dash, –). Each character in the Latin alphabet and the decimal digit set is uniquely mapped to a specific dot-dash combination; for example, the letter 'A' is represented as ·– and the letter 'S' as ···. The temporal structure of the code is governed by a base unit interval (T), with a dot defined as one unit in duration and a dash as three units. Gaps between consecutive symbols within a character occupy one unit, gaps between characters occupy three units, and gaps between words occupy seven units.

In the context of optical communication, each dot and dash is mapped to a corresponding duration of LED illumination. The discrete, time-bounded nature of Morse code symbols makes the encoding scheme well-suited for pulse-based optical transmission, as the receiver need only distinguish between two states—light ON and light OFF—and measure the duration of each state relative to a predefined threshold. This binary classification is computationally efficient for microcontroller-based decoding and introduces an inherent layer of security, since the specific timing parameters of the encoding remain configurable and undisclosed to unauthorized users. Table 2 presents the complete International Morse Code encoding table for alphabetic characters, provided in both capital and lowercase designations. It is noted that standard Morse code is case-insensitive; however, the dual-column representation is retained herein for documentary completeness and visual reference.

Table no 2: Morse Code Encoding

Letter	Corresponding Morse Code	Letter	Corresponding Morse Code	Letter	Corresponding Morse Code
A	·–	J	·——	S	···
B	–···	K	–·–	T	–
C	–·–·	L	·–··	U	··–
D	–··	M	—	V	···–
E	·	N	–·	W	·—
F	··–·	O	——	X	–··–
G	—·	P	·—·	Y	–·—
H	····	Q	—·–	Z	—··
I	··	R	·–·		

D. Block Diagram

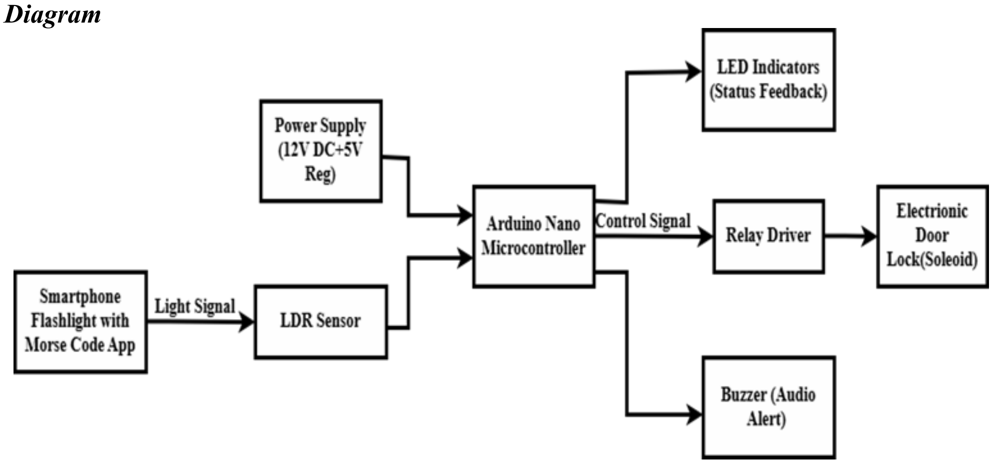

Figure no 1: Block diagram

E. System Operation and Signal Processing

The end-to-end operation of the system is described through the following sequence of processing stages, which collectively constitute the Li-Fi-based Morse code authentication pipeline.

Step 1: Password Input and Morse Code Encoding:

The user enters an alphanumeric password through the Morse code generator application installed on a smartphone. The application encodes each character of the password into its corresponding Morse code symbol using the standard International Morse Code table. The encoding maps each character to a unique dot-dash sequence; for instance, the character 'P' is encoded as ·—· and 'V' as ···–. The complete password is thus transformed into a sequential binary signal pattern prior to transmission.

Step 2: Optical Transmission via Li-Fi:

The encoded Morse code sequence is transmitted optically using the smartphone's built-in LED flashlight, which serves as the Li-Fi transmitter. The application controls the flashlight via the Android camera API, toggling the LED on and off at precisely defined intervals. In the implemented system, a dot is represented by a 150 ms LED flash, a dash by a 450 ms flash, following the Morse code encoding approach of [3]. An inter-character gap of 500 ms and an inter-word gap of 1000 ms are enforced to delimit symbol boundaries. The resulting sequence of timed light pulses constitutes the Li-Fi optical signal carrying the encoded authentication data.

Step 3: Optical Reception and Signal Transduction:

The LDR sensor positioned at the receiver unit detects the incident light pulses generated by the smartphone flashlight and converts the light intensity variations into proportional electrical voltage changes. The LDR operates on the principle of photoconductivity: its resistance (R_{LDR}) decreases nonlinearly with increasing irradiance (E_v) in accordance with the empirical power-law relationship $R_{LDR} = k \cdot E_v^{-\gamma}$, where k and γ are material-dependent constants. This resistance variation is transduced into a measurable voltage at the Arduino Nano's analog input pin through a series resistor voltage divider network. The transduction is governed by the voltage divider equation:

where R_{LDR} decreases from approximately 1 MΩ under dark conditions to approximately 1 kΩ under direct illumination, yielding a dynamic voltage swing at the Arduino Nano's analog input (A0) from near 0 V (light absent) to near Vcc (light present). The 10-bit ADC of the Arduino Nano resolves this swing into 1024 discrete quantization levels, providing a voltage resolution of approximately 4.9 mV per LSB (for Vcc = 5 V). A software-defined threshold, empirically determined as ADC $\geq$ 512 (corresponding to Vout $\geq$ 2.5 V), is applied to classify each instantaneous sample as a logic HIGH (flashlight ON) or logic LOW (flashlight OFF). This transduction and thresholding principle is consistent with methodologies reported in [3,7].

Step 4: Morse Code Decoding by Microcontroller:

The Arduino Nano continuously samples the analog voltage from the LDR circuit and applies the software-defined threshold (ADC ≥ 512) to classify each sample as either a logic HIGH state (flashlight ON: encoding a dot or dash) or a logic LOW state (flashlight OFF: encoding a gap). Upon each HIGH-to-LOW transition, the firmware records the elapsed HIGH-pulse duration (tpulse) and applies the following decision rule to classify it as a Morse symbol: if tpulse < 300 ms, the symbol is decoded as a dot (·); if tpulse ≥ 300 ms, the symbol is decoded as a dash (–). The midpoint threshold of 300 ms is derived as the arithmetic mean of the nominal dot duration (150 ms) and the nominal dash duration (450 ms), thereby providing equidistant decision boundaries and maximizing classification robustness against minor timing jitter. Similarly, upon each LOW-to-HIGH transition, the elapsed LOW-gap duration (tgap) is evaluated: tgap < 500 ms denotes an intra-character (inter-element) gap; 500 ms ≤ tgap < 1000 ms triggers decoding of the accumulated dot-dash buffer as a complete character using the embedded International Morse Code lookup table; and tgap ≥ 1000 ms identifies an inter-word boundary, appending a space delimiter. The successive decoded characters are concatenated into a string buffer, which accumulates the complete received password for subsequent authentication comparison.

Step 5: Authentication and Actuation:

The decoded password string is compared against the pre-stored reference password in the Arduino Nano's program memory. If the strings match, the microcontroller asserts a HIGH digital output signal to the gate of the IRF730 MOSFET, which in turn energizes the 12V relay coil and connects power to the solenoid door lock, causing it to retract and unlock the door. Simultaneously, the green LED is activated and the buzzer emits a confirmation tone. In the event of a mismatch, the relay remains de-energized, the door lock remains engaged, the red LED is activated, and an error tone is generated — consistent with the feedback indicator designs documented in[4,5]. The complete relay switching logic, solenoid activation timing, and LED/buzzer signaling sequence are formally codified in the pseudo-code presented in subsection G below.

F. Algorithm and Pseudo-code

The following structured pseudo-code formally specifies the complete control logic embedded in the Arduino Nano firmware. The algorithm governs peripheral initialization, continuous LDR sampling, Morse code symbol classification based on pulse-width thresholding, password string reconstruction, and conditional actuation of the relay-driven solenoid lock together with the associated LED and buzzer feedback signals.

ALGORITHM: Li-Fi Morse Code Door Lock Authentication

SECTION 1: INITIALIZATION

```
SET LDR_PIN        ← Analog Input (Arduino A0)
SET RELAY_PIN      ← Digital Output (Arduino D12)
SET GREEN_LED_PIN  ← Digital Output (Arduino D6)
SET RED_LED_PIN    ← Digital Output (Arduino D11)
SET BUZZER_PIN     ← Digital Output (Arduino D4)
SET STORED_PASSWORD ← "PVPIT"
SET DOT_THRESHOLD  ← 300 ms  // midpoint of 150 ms and 450 ms
SET CHAR_GAP       ← 500 ms
SET WORD_GAP       ← 1000 ms
SET ADC_THRESHOLD  ← 512     // corresponds to ~2.5 V
INITIALISE RED_LED = ON; GREEN_LED = OFF; RELAY = OFF; BUZZER = OFF
DECLARE symbolBuffer ← ""// accumulates dots and dashes for one letter
DECLARE passwordBuffer ← "" // accumulates decoded characters
```

SECTION 2: MAIN SAMPLING AND DECODING LOOP

```
LOOP forever:
    adcValue ← READ_ANALOG(LDR_PIN)      // sample 10-bit ADC (0–1023)
    lightState ← (adcValue ≥ ADC_THRESHOLD) ? HIGH : LOW
    IF (RISING_EDGE detected: LOW → HIGH) THEN
        pulseStart ← TIMESTAMP()          // record flash onset time
    END IF
    IF (FALLING_EDGE detected: HIGH → LOW) THEN
        t_pulse ← TIMESTAMP() − pulseStart
        IF (t_pulse < DOT_THRESHOLD) THEN
            APPEND "." TO symbolBuffer    // classify as DOT
        ELSE
            APPEND "-" TO symbolBuffer    // classify as DASH
        END IF
        gapStart ← TIMESTAMP()            // record gap onset time
    END IF
    IF (lightState = LOW AND gapStart IS VALID) THEN
        t_gap ← TIMESTAMP() − gapStart
        IF (t_gap ≥ CHAR_GAP AND t_gap < WORD_GAP) THEN
```

```
letter ← MORSE_LOOKUP(symbolBuffer) // decode dot-dash string
APPEND letter TO passwordBuffer
CLEAR symbolBuffer
END IF
END IF
```

SECTION 3: AUTHENTICATION AND ACTUATION

```
IF (passwordBuffer = STORED_PASSWORD) THEN     // PASSWORD MATCH
SET  RELAY      ← ON                 // energise 12 V relay coil
SET  GREEN_LED  ← ON                 // activate green indicator
SET  RED_LED    ← OFF
TONE(BUZZER, 1000 Hz)                // emit confirmation tone
WAIT  3000 ms                        // hold solenoid retracted (door open)
SET  RELAY      ← OFF                // de-energise relay; solenoid re-engages
SET  GREEN_LED  ← OFF
SET  RED_LED    ← ON                 // revert to locked state indicator
SILENCE BUZZER
ELSE                                   // PASSWORD MISMATCH
SET  RELAY      ← OFF                // relay remains de-energised
SET  RED_LED    ← ON                 // keep red indicator active
SET  GREEN_LED  ← OFF
TONE(BUZZER, 400 Hz)                 // emit error tone (low-frequency)
WAIT  1000 ms
SILENCE BUZZER
END IF
CLEAR passwordBuffer; CLEAR symbolBuffer   // reset for next attempt
END LOOP
```

G. System Flowchart

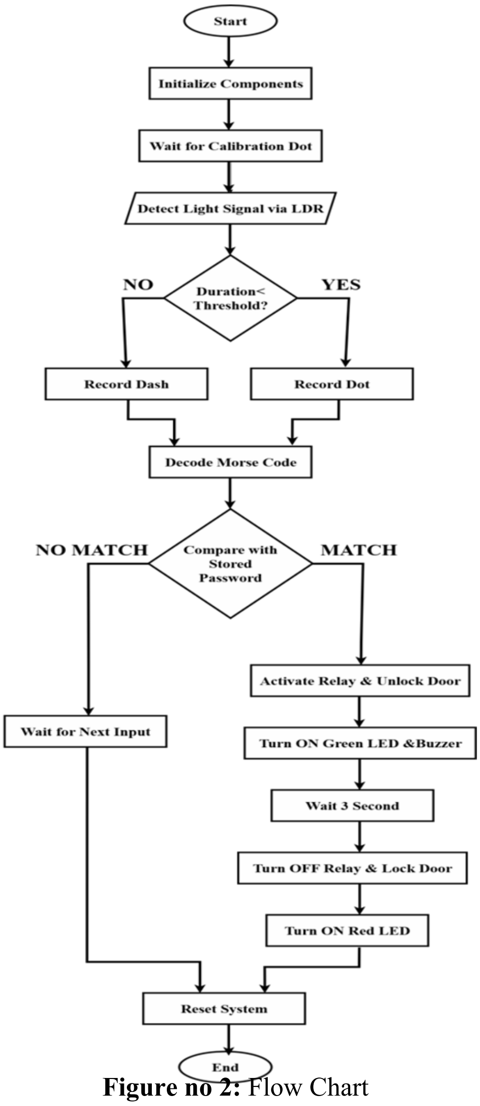

Figure no 2: Flow Chart

IV. Result

The proposed system was tested under controlled indoor lighting conditions. The password “PVPIT” was encoded in Morse code and transmitted via the smartphone flashlight at varying distances. These experimental conditions are comparable to those used in [3,5] , enabling meaningful performance comparison.

A. Accuracy Testing

The system was tested 20 times at each operating distance under standard indoor fluorescent lighting. The accuracy at 10–30 cm (95–100%) is comparable to the optimized performance reported by Lee et al. [3] using fuzzy control compensation, though without the need for additional signal conditioning circuitry. Table 3 summarizes the results.

Table no 3: Password Recognition Accuracy vs. Operating Distance

Distance (cm)	Tests Conducted	Correct Recognitions	Accuracy (%)
10	20	20	100%
20	20	19	95%
30	20	19	95%
50	20	14	70%

Results indicate that the system performs most reliably within a 30 cm range, achieving 95–100% accuracy. Beyond 30 cm, accuracy degrades due to reduced light intensity and increased susceptibility to ambient light interference — consistent with transmission distance findings of Ismail et al. [7] who showed VLC performance strongly depends on transmitter-to-receiver distance and LED wavelength.

B. Response Time

The response time was measured from completion of the last Morse code character to solenoid activation. Across 20 successful trials, average response time was approximately 2.1 seconds (range: 1.8–2.6 s), including signal decoding (~0.5 s), password comparison (~0.1 s), and relay switching (~0.05 s). The millisecond-precision timing of the Morse code pattern makes unauthorized replication highly difficult, as noted by Kirange et al. [5].

C. Power Consumption

In standby (locked) state, the Arduino Nano and LDR circuit draw approximately 45 mA at 5V (~225 mW). During unlock, the solenoid draws ~500 mA at 12V (~6 W) for the 3-second unlock period. This energy-efficient profile compares favorably with Wi-Fi-based systems [1,2] , which require continuous network connectivity and sustained power consumption.

D. Output Results

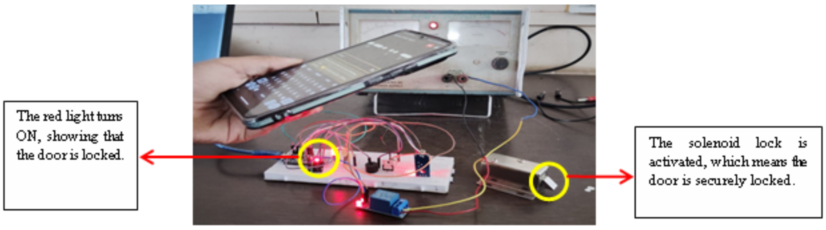

Figure no 3: Door locked condition (incorrect/no code)

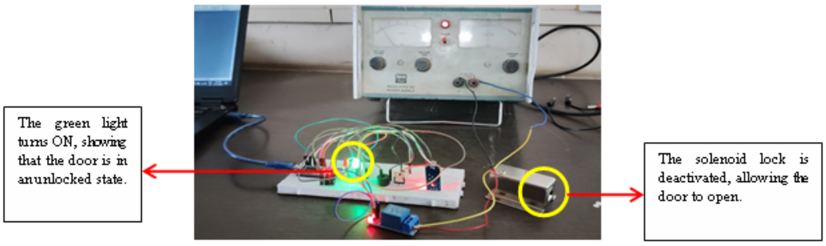

Figure no 4: Door unlocked condition (correct code)

V. Discussion

The proposed Li-Fi door lock system offers key advantages over RF-based alternatives [1,2]. The line-of-sight requirement of visible light inherently prevents remote signal interception. The system operates without internet connectivity, unlike [1,2] making it robust against network failures. The cost using Arduino Nano and off-the-shelf components is significantly lower than biometric systems [6] . However, effective operation is restricted to ~30 cm and performance degrades under high ambient light. Integrating ambient light compensation such as the fuzzy controller of Lee et al. [3] and using red LED transmitters as demonstrated by Ismail et al. [7] are key directions for future improvement.

VI. Conclusion

This paper presented the design and implementation of a Smart Li-Fi Door Lock System using visible light communication and Morse code for secure, network-independent access control. Experimental evaluation showed 95–100% password recognition accuracy within a 30 cm range, an average response time of ~2.1 seconds, and low standby power consumption of ~225 mW. The system demonstrates that Li-Fi is a viable, cost-effective, and inherently secure alternative to conventional RF-based smart lock systems for indoor applications.

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