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Microcontroller based Housing Automation Control System through Li-Fi Technology

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Abstract: Low electromagnetic interference (EMI) and develop safer and faster communication is one of the all-times challenges. Data transmission through LED lamps, better known as Light Fidelity (Li-Fi), is an efficient and accurate solution for it. This work presents a novel method to control the domotic for private housing. Integrating a small device behind car headlights controlled by a UI inside the car, the system is able to control lights, doors, watering system, and some other devices inside the house. The complete system has been tested in a demo implementation simulating controlled devices, such as motor and lights, in Proteus software. The physical implementation was tested with a maximum functional range of 1.2-meter distance in Arduino MEGA 2650 board.
Keywords: Arduino, automation, automotive, DSP, domotic, LED transmission, Light Fidelity (LiFi), microcontrollers, wireless communication.

I. INTRODUCTION

Light Fidelity (Li-Fi), is the data transmission through LED bulbs that varies in intensity faster than human perception. Li-Fi is the term that some have used to label the fast and cheap wireless communication system, which is the optical version of Wi-Fi. The term was first used in this context by Harald Haas in his TED Global talk on Visible Light Communication [1]. The principle of high brightness light-emitting diodes is very simply, when the LED is set, transmission is performed as a digital 1, if the LED is low, data transmission stops as a logic 0. LED bulbs can be switched on and off very quickly, which provide nice opportunities for data transmission. It is possible to encode data in the light by varying the rate at which the LED flicks on and off to give different strings of 1's and 0's. The LED intensity is modulated so rapidly that human eye cannot notice it, so the output (lighting) appears constant. More sophisticated techniques could dramatically increase visible light communications (VLC) data rate. Nowadays researchers are focusing on parallel data transmission using array of LEDs, where each LED transmits a different data stream [2]- [5]. Another technique is using mixtures of RGB-LED to alter the light frequency encoding a different data channel. Li-Fi, as it has been dubbed, has already achieved blisteringly high speed in the lab. Researchers at the Heinrich Hertz Institute in Berlin, Germany, have reached data rates of over 500 megabytes per second using a standard white-light LED. The technology was demonstrated at the 2012 Consumer Electronics Show in Las Vegas using a pair of Casio smart phones to exchange data using light of varying intensity given off from their screens, detectable at a distance of up to ten meters [6].

Over the years, a large number of projects have been developed focusing the work with less invasive technologies, cleaner technologies, avoiding EMI. In the pursuit of design, a novel technique to improve domotic control and access control systems, a microcontroller based housing automation control system through Li-Fi technology is proposed. Encompassing the domotic field, an idea about how to integrate cleaner technologies, as Li-Fi is, and a new challenge with this idea became. Compact modules, high efficiency and fast speed must be achieved. The aim of this work is to develop a control module to be adapted in the headlights for applying different data stream, a command dataset transmitted to execute a variety of functionalities, such as opening/closing access, light manipulation, watering system configuration, alarm enable/disable.

II. MATERIAL AND METHOD

In this project, two data transmission techniques were applied. Firstly, a methodology for data transmission by UART protocol were implemented. Secondly, data transmission by toggling GPIO pins in the microcontroller was tested. For the implementation an open source electronics prototyping platform was employed. The Arduino Mega 2560, which is a board based microcontroller on the ATmega 2560. It includes 54 digital input/output pins, 16 analogical inputs, 4 UARTs channels, a 16 MHz crystal oscillator, and a rest button. The Mega 2560 board can be programmed with the Arduino Software (IDE). The environment of the open-source Arduino Software is written in Java and based on Processing and other open-source software. This software can be used with any Arduino board. The Mega 2560 board has a number of facilities for communicating with a computer, another board, or other microcontrollers. Table 1 shows a summary of the prototyping board.

TABLE I. Summary - Prototyping platform ATmega 2560

Microcontroller	ATmega 2560
Operating voltage	5V
Input voltage (recommended)	7-12V
Input voltage (limits)	6-20V
Digital I/O pins	54 (of which 14 provide PWM output)
Analog Input pins	16
DC current per I/O pin	40 mA
DC current for 3.3V pin	50 mA
Flash memory	256 Kb of which 8 Kb used by bootloader
SRAM	8 Kb
EEPROM	4 Kb
Clock speed	16 MHz

A. Transmitting and receiving UART data

The Universal Asynchronous Receiver/Transmitter (UART) takes bytes of data and transmits the individual bits in a sequential mood. At the destination (receiver), a second UART re-assembles the bits into complete bytes. Each UART contains a shift register, which is the fundamental method of conversion between serial and parallel forms [7]. The UART usually does not directly generate or receive the external signals used between different items of equipment. Separate interface devices are used to convert the logic level signals of the UART and from the external signalling levels.

Transmission operation is simpler since it is under the control of the transmitting system. As soon as data is deposited in the shift register after completion of the previous character, the UART hardware generates a start bit, shifts the required number of data bits out to the line, generates and appends the parity bit (if used), and appends the stop bits. Since transmission of a single character may take a long time relative to CPU speeds, the UART will maintain a flag showing busy status so that the host system does not deposit a new character for transmission until the previous one has been completed; this may also be done with an interrupt. Since full-duplex operation requires characters to be sent and received at the same time, UART use two different shift registers for transmitted and received characters.

All operations of the UART hardware are controlled by a clock signal which runs at a multiple of the data rate, typically 8 times the bit rate. The receiver tests the state of the incoming signal on each clock pulse, looking for the beginning of the start bit. If the apparent start bit lasts at least one-half of the bit time, it is valid and signals the start of a new character. If not, it is considered a spurious pulse and is ignored. After waiting a further bit time, the state of the line is again sampled and the resulting level clocked into a shift register. After the required number of bit periods for the character length (5 to 8 bits, typically) have elapsed, the contents of the shift register are made available (in parallel fashion) to the receiving system. The UART will set a flag indicating new data is available, and may also generate a processor interrupt to request that the host processor transfers the received data. In this way, a command previously defined in a LUT which contains all necessary commands, is sent to the receiver to execute a designed task. Specific commands, including security encryption are defined in the LUT shown in table 2.

Table II. LUT – Defined commands

Label	Command
0x00	Open main entrance
0x01	Close main entrance
0x02	Alarm enable
0x03	Alarm disable
0x04	Front lights
0x05	Backyard lights
0x06	Watering garden system enable
0x07	Watering garden system disable

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As an illustrative example, a transmitter based on UART protocol is shown in Fig. 1. As mentioned before, the prototyping board ATmega 2560 includes 4 UART ports. For this work, the system was implemented through serial port 1.

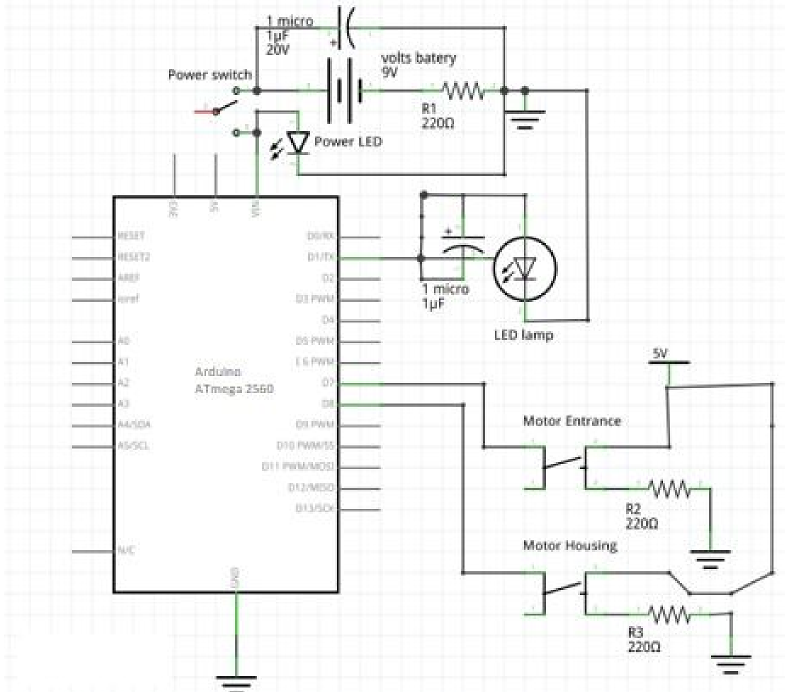

Fig. 1 Prototyping board ATmega 2560 by UART protocol.

Before sending the command an encryption method is called to protect the data transmission. Therefore, the security for the data transmission is increased and makes the system more robust and not easy to decipher it by external receivers, avoiding as well interference generation for surrounding systems. Fig. 2 shows a brief description of the source code with the encryption method.

```
string alphabet {"[ abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789.,:;-_*+/'"};
    string key {" [*+'-/;:_,.7532486910QZWXECRVTBYNUMIKLPOJFHDGSAzqxwcevrbtnymukpilodgshajf"};
    string secret_command {};

    cout << "Label + Command: ";
    getline(cin,secret_command);

    string encrypted_message {};
    cout << "\nEncrypting message ..." << endl;

    for(char c: secret_command){
        size_t position = alphabet.find(c);
        if(position != string::npos){
            char new_char {key.at(position)};
            encrypted_message += new_char;
        }else{
            encrypted_message += c;
        }
    }

    cout << "\nEncrypted message: " << encrypted_message << endl;
```

Fig. 2 Encryption methodology for command protection.

B. Transmitting and Receiving Toggling GPIO

As it was previously mentioned and presented, it is possible data transmission by UART protocol. Another technique for data transmission, is to send information by frequencies [8]-[10]. Frequency transmission is relatively easy to develop to make it work with smartphones and tablets, as well as personal computers, microcontrollers and PCs. This technique allows a wide range of possibilities to send a dataset of several instructions. In this project, the microcontroller was programmed with an algorithm to generate different frequencies, each one dedicated to activate certain function in the receiver side. More than one frequency could be sent by the transmitter to generate an encrypted set of data. Fig. 3 shows the transmitter design by frequency spectrum implementation. Pin D2 is the transmission signal.

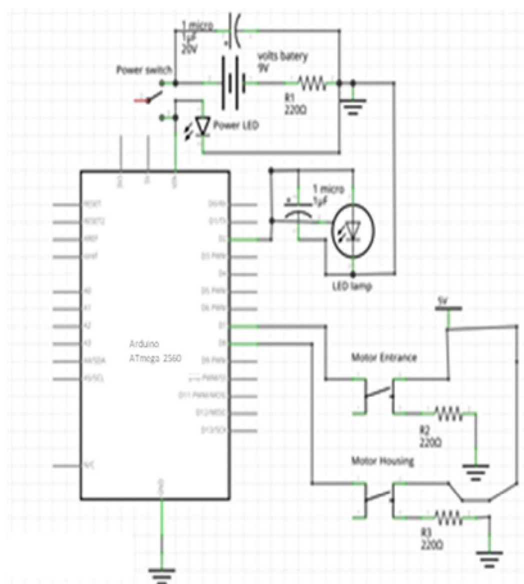

Fig. 3 Prototyping board ATmega 2560 by frequency spectrum protocol.

By the other side, in the receiver, an algorithm implemented specially to analyse and decipher the dataset, identifies the correct frequency to execute a specific task. The receiver is designed to be activate transmitter identification, when a "wake-up" signal is sent. Once the wake-up signal is detected, a sampling process starts to identify commands by applying Fast Fourier Transform (FFT) [11]-[13]. The receiver was programmed with an algorithm to identify the dominant frequency. Once the dominant frequency is detected, a specific task is done. Fig. 4 shows an overview of the Tx/Rx process.

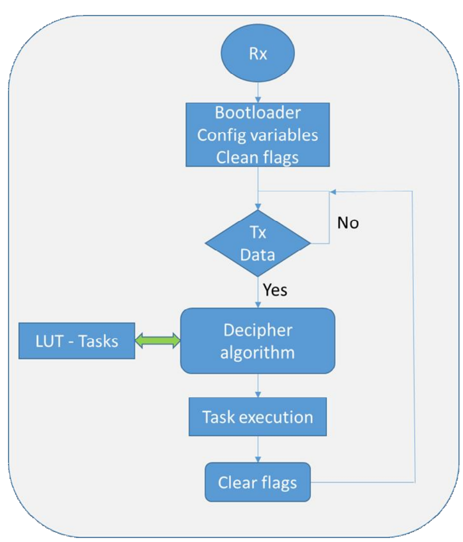

Fig. 4 Overview of the general transmission/reception process.

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For receiver, frequency spectrum and UART protocol, the final design is shown in Fig. 5. It consists in an array of a photo-diode (by Vishay Semiconductors), a filtering stage (OPAM) and a Schmitt trigger CI. The photo-diode will receive data transmission by the LED bulb. The photo-diode provides voltage and current in very low levels, therefore, is necessary to amplify those values to obtain a better signal from the sensor. To amplify the signal, it is applied a Schmitt trigger, and a module for noise reduction. With the signal in a correct way now it is possible to connect to the corresponding pin on the ARDUINO prototyping board.

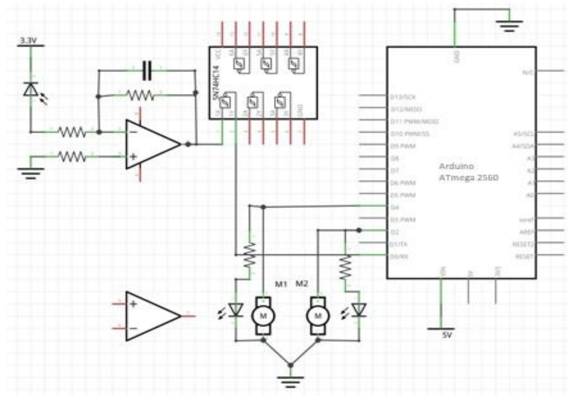

Fig. 5 Receiver implemented in the prototyping ATmega 2560 board.

III.RESULTS

In a first stage, the system was simulated in Proteus 8 software. Data transmitter/receiver were monitored by a virtual instrument (virtual terminal and oscilloscope). The encrypted data were successfully received and deciphered. After the simulation, a test with oscilloscope were performed in order to verify the data transmission. This test was performed for the frequency spectrum transmission; Fig. 6 shows the frequency corresponding to a 5 KH transmitted signal (alarm enable command). The value identified after applying FFT method was 4,826 Hz. According to the LUT previously defined, this task corresponds to the alarm enable command.

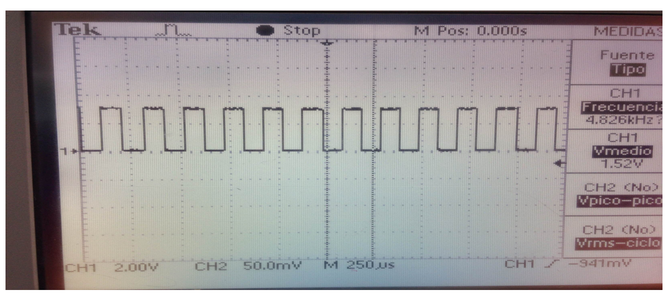

Fig. 6 The oscilloscope shows that a frequency of 4,826 Hz was detected by the receiver.

Fig. 7 shows a second test, corresponding to a transmitted frequency of 10 KHz (alarm disable command). The oscilloscope shows a received frequency of 9,902 Hz. According to the LUT, this task corresponds to the alarm disable command.

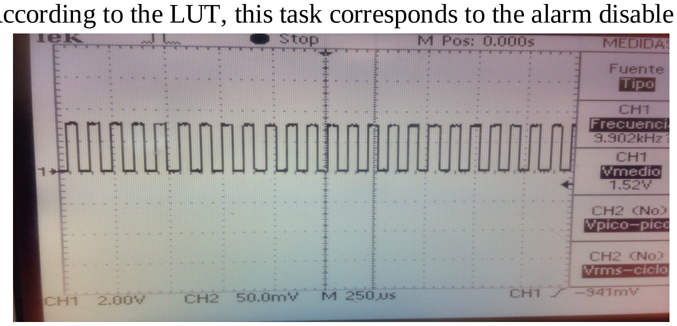

Fig. 6 The oscilloscope shows that a frequency of 9,902 Hz was detected by the receiver.

To corroborate with another tool, the correct impulse response transmitted/received, an App called Spectral View Analyzer was employed. This App allows the analysis of real-time audio signals, and it can display audio signals as coloured spectrogram. To achieve this goal, the received signal was connected through the audio Jack connector. Fig. 7 to Fig. 9 show the identification of the previously tested commands with the oscilloscope.

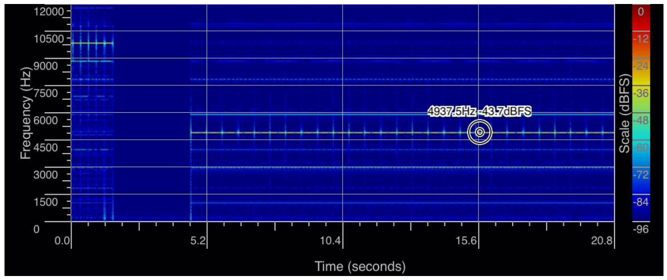

Fig. 7 The original transmitted frequency was 5 KHz, Spectral Audio Analyzer identified 4,937 Hz.

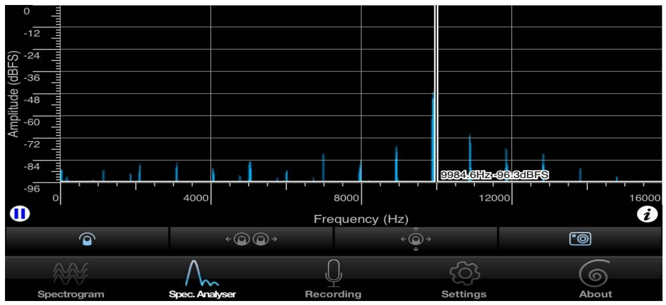

Fig. 8 Every quote shown in the graphic has a value of 500 Hz. The received frequency was 9,984 Hz. The real value of the transmitted frequency was 10 KHz. This test was made two meters away the receiver.

IV. CONCLUSIONS

According to the new tendencies for these technologies, the field to apply it is too extensive. The established goals since the beginning were successfully achieved, and other new potential applications were identified as well. The system works under controlled circumstances, such as low EMI interference, maximum distance between receiver-transmitter about 2 meters. The implementation with the prototyping board showed a fast response (nearly real-time), low operational current demand (less than 500 mA), and enough accuracy. Further work includes a better filtering of the transmitted data, improving receptor polarization, test including headlights and bidirectional communication.

V. ACKNOWLEDGMENT

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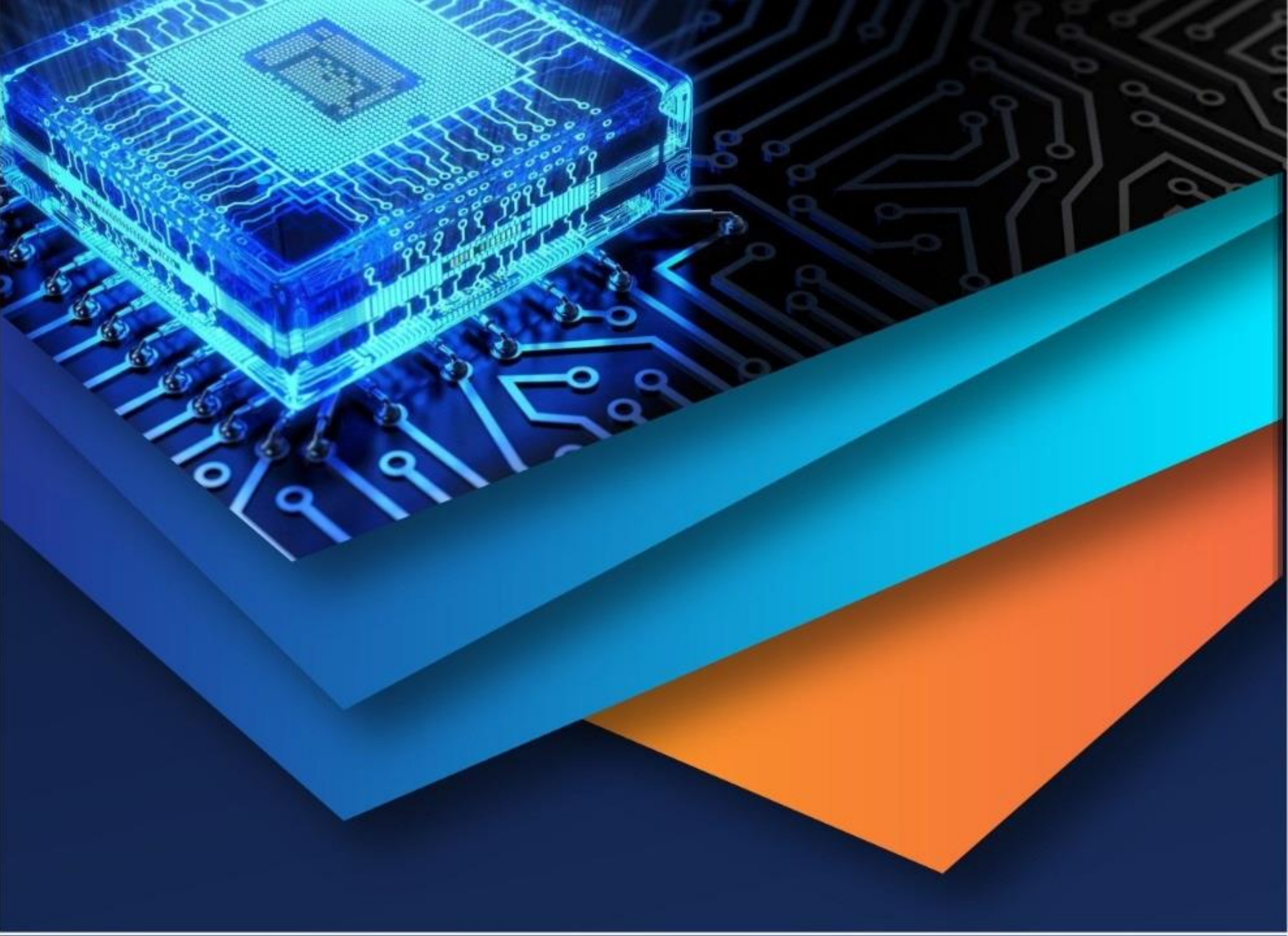

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