DALI Compatible Smart LED Driver Controller with Wi-Fi Communication

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Abstract— **DALI (Digital Addressable Lighting Interface) is one of the communication types commonly used in smart LED systems. Energy savings and user comfort can be achieved by making scenario definitions for LED drivers. In this study, the design of the LED driver controller, which is controlled via Wi-Fi communication with the user interface supporting the DALI protocol, will be mentioned. Communication of the developed controller with the user interface will be carried out wirelessly. Wi-Fi has been preferred. The hardware part of this developed system consists of a processor-supported control circuit, a communication unit circuit and DALI hardware circuit parts. The designed smart LED driver controller can fulfill the standard requirements of the DALI protocol. It converts the command information received over Wi-Fi to the DALI protocol and provides control of the LED driver. The control device will be controlled and monitored via smartphone, computer, tablet, and web. In conclusion, with the commands given from the user interface, the LED driver turns on/off the light, increases/decreases the light intensity and similar commands available in DALI standards are controlled.**

Index Terms— **DALI Protocol, LED Driver, Smart Lighting, Energy Saving, Wi-Fi Communication.**

I. Introduction

ENERGY SAVING is using less energy by changing behaviors or habits. Energy efficiency using new technologies without reducing quality and performance, better it is the provision of living conditions. Energy efficiency should be increased to use limited energy with better quality and to provide a more economical structure to enterprises. So, it is necessary to analyze the energy in every aspect. LED lamps consume 90% less energy and are produce lighter, compared to light bulbs. In this way, they help to achieve energy savings [1].

Many automation and smart technology solutions are used in the field of energy efficiency and saving. The most effective solution for the development of smart lighting systems is the use of universal protocols. One of these protocols is DALI.

DALI is a concept that stands for a smart lighting management system that provides increased energy savings, easier installation and maintenance, and maximum control and retrofit flexibility in a completely open standard. DALI is not a single product. It is an industry-standard protocol that allows the seamless mixing and matching of DALI-compatible components from different manufacturers (ballasts, control systems, sensors, controllers, switches, etc.) into complete systems [2]. Wireless technology has been identified as a promising wiring and communication alternative for building systems. Low cost and less complexity, as well as increased flexibility in wiring, are the main advantages of wireless-enabled systems over wired counterparts [2].

To control the LED drivers that support the DALI protocol, a master controller is needed, which is the requirement of each communication protocol [3]. Controllers serve to transfer the situations desired by the user to slave devices. Commands to controllers are usually sent via a user interface. Human interaction is also provided by the application tier via graphical user interfaces (GUI) [4]. For commands to be sent to the controllers via the user interface, communication is needed between the computer and the controller. This communication is divided into 2 groups, wired or wireless. In the study, the communication between the user interface and the controller is carried out wirelessly using Wi-Fi communication.

In this study, the product to be presented to the customer who provides remote control of the DALI communication protocol is aimed. The working output is the product, and it is planned to remotely control the LED drivers that support the DALI communication protocol. A DALI protocol controller with Wi-Fi support has been made. Thanks to this device, 64 DALI-supported LED drivers on the line were connected to the DALI controller, which is the output of this study, and the control was made. With these controls, it is possible to remotely control the device by connecting to any Wi-Fi line by making a DALI line connection in the environment where DALI-supported LED drivers are located.

The final output of the study is a product designed with hardware and software. The WEB page has been designed for

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testing this product. It is possible to access this WEB page from any platform with an internet and internet browser, such as a computer, tablet mobile phone and it is possible to control the LED lighting from anywhere desired.

II. Related Studies in the Literature

20% of the consumed electrical energy is spent in industrial enterprises, 30% in stores, and approximately 40% in offices for lighting purposes. The share of lighting in energy consumption and energy expenditure is the largest item after heating and cooling systems. Considering that the electrical energy spent on lighting in buildings created with a modern understanding is about 60%, the importance of energy saving in lighting is better understood. The next step is to check the lighting. Lighting control, which will be carried out using appropriate control techniques and systems, should create lighting that can be suitable for each element working in terms of the amount and quality of light. By automatically controlling the lighting, it is also possible to manage consumption and expenditure more effectively by actively saving energy.

Bellido-Outeirino F. J., Arc. [5] his work focuses on the integration of DALI devices into wireless sensor networks to use energy effectively. Since different manufacturers are usually interested in one aspect of building automation, the building automation system offered to the end user has an integrated building management system and different sub-communication systems. Their main purpose is to provide the end consumer with an economical, fully centralised system in which automation systems are managed by IEEE 802.15.4 based wireless sensor network [5].

In the study conducted by the Moeck M [6] et al., they focused on the development of a prototype in a WSN network (Wireless Sensor Network) that also integrates the DALI protocol. Since DALI is a communication protocol standard that has been used for many years and is highly preferred by manufacturers, it is quite easy to find DALI compatible devices. This is one of the biggest reasons why they prefer [6].

In Bellido-Outeirino, F. J Arc's [7] work, he uses IEEE 802.15.4 networks with WSN to control DALI devices. ZigBee for working directly on the PHY (Physical Layer) and MAC (Media Access Control) layer of IEEE 802.15.4 [7] instead of using it, they decided to implement a WSN based on IEEE 802.15.4. Due to the lack of an interoperable protocol between different manufacturers, they did not prefer to use ZigBee.

In the study of Man-Lin Wu [8] et al., they focused on software development of the DALI master and DALI slave equipment manufacturer, while general lighting manufacturers focused on purchasing commercially available options to reduce individual costs and business development time.

In a study conducted by Delvaeye et al. [9, 10] in Belgium, they stated that the electrical energy savings in the lighting system of a DALI-controlled open-loop system are 46%, based on a one-year measurement.

In the study conducted by George K. Man [11], they have made a low-cost, low-power, efficient DALI LED driver controller based on Raspberry, which is open source. The Pi3 microcontroller was developed as a prototyping platform, control software and Linux kernel.

In the study by Jingyu Liu et al., [12] they used the DALI protocol to communicate the controller with LED luminaires. The simulation results show that an uncontrolled lighting system can provide sufficient illumination. The lighting system has determined wider controllability in order to ensure that the lighting environment operates in the most energy-saving way. The experimental results show that significant lighting energy is obtained by using the designed controller.

In the study conducted by Niko Gentile et al., [13] lighting systems were also used in places where daylight was insufficient, thanks to the increased control capabilities with LED technology. The use of daylight in integrative lighting is currently very limited.

In the study by Zhong Chen et al., [14] they worked on the DALI protocol by adjusting the LED light in busy places.

In the study by Mary Ann George et al., [2] they designed a lighting system with two dependent microcontrollers using a temperature sensor and a motion sensor by creating a photo-sensor interface with wireless technology.

In the work done by Oscar Osvaldo et al., [15] a bridge is created between the DALI bus, providing the necessary timing for the hardware and MCU selection of the DALI protocol, bus bits, Manchester coding and frame formatting.

It was implemented by Francisco Bellido-Outeiriño et al. [16] by integrating the DALI protocol with the advanced control system on the lighting system. Although designed for lighting control, DALI has also been adapted to other applications, such as the following. HVAC, motor, or fan controllers etc., the automation system that allows monitoring and control, which is part of the system, has been used in applications for the end user and energy efficiency.

In the work by Gil-de-Castro A et al., [17] the term smart grid refers to a fully modernized electrical distribution system that monitors, protects and optimizes the operation of its interconnected elements end-to-end. Smart Grid is expected to affect all areas of electric power systems, productions, distributions, end consumers, citizens, electric vehicles, street lightings and other home devices. There is a great potential to renew existing old street lighting and save energy consumption.

In the study by Domingo-Perez F et al., [18] a new remote management system for street lighting is presented. The management system was implemented using a wireless communication system and a lighting control protocol. It focuses on developing a street lighting management system using wireless sensor networks and DALI ballasts, and experimental results obtained from various tests are presented. To test the network and obtain the results, they implemented a JAVA-based SCADA (Supervisory Control and Data Acquisition) interface. The user can send a command to the PAN coordinator using this interface; the coordinator sends the selected command to the selected node.

Nowadays, some smart lighting applications can be made on mobile phones. Samuel Tang et al., [19] developed an algorithm by using the smart lighting system application, the daylight on the smartphone, and enabled the lighting system to be controlled wirelessly.

The system designed by Tullio de Rubeis et al. [20] is based on a mountable smart control unit and lighting control devices. The installation is non-invasive and does not require any modifications. Communication Provides communication between each lamp and the control system via 2.4GHz wireless protocol.

T.W. Kruisselbrink et al., [21] on the other hand, tested using two alternative brightness-based lighting control algorithms. In algorithm 1, the goal is to maintain desktop lighting. If it is algorithm 2, the goal is to maintain the predefined stage lighting.

The study by Ivan Chew et al. [22] focuses on energy-efficient, commercial and advanced smart lighting systems in smart lighting technology. In addition, the review of smart lighting connection options and their potential are discussed.

Kim D. In the study by H et al., [23] the modern lighting control system heralds a radical change since the development of LED lighting and the universalization of the Internet. An advanced lighting system starts to be controlled anywhere at any time without time and space restrictions via the Internet, and the ambient light can be controlled automatically depending on the environment. In addition, lighting controls began to illuminate the room as a single unit, and wireless communication began to be used instead of the wired communication technologies described for individual lighting control. In the study, lighting control system using wireless technology and lighting elements that should be considered by applying ad hoc mode or infrastructure mode of wireless communication technology are summarized. In this study, performance factors for wireless lighting control networks are studied. Some factors, such as latency, packet loss and the number of nodes are also as important as the traditional wireless communication network. But it is not as important as others, such as power saving and mobility. Problems such as improving communication broadcasting remain a challenge that needs to be solved.

In the study by Han Zon et al., [24] a study was conducted with the aim of reducing energy consumption while maintaining the lighting comfort of the building occupants. Using WinLight by existing Wi-Fi infrastructure, a suitable dimming command is calculated for each lamp of a lighting system. For this, a control algorithm has been created. A centralized lighting control system assigns these commands to a regional gateway, and occupancy-oriented lighting control is achieved by locally activating the brightness adjustment.

In the study carried out by Qiu C and his colleagues, he presents a wireless control system for visible light communication (VLC). It is equipped with BLE (Bluetooth Low Energy) SoC (Security Operations Center) to support iBeacon. VLC data/frequency can be easily configured by smartphone. This combined beacon/lighting/VLC function helps to reduce the cost of beacon placement and improve indoor localization accuracy [25]. The underlying communication technology of iBeacon is Bluetooth Low Energy. It transmits a signal with only small bits of data, typically a unique identifier. This allows mobile apps (Applications) to Decouple between beacons and act when necessary.

In the work of Zheng Z. et al., [26] visible light communication (VLC) technology uses light-emitting diodes (LED) as a medium to enable high-speed communication. The information is transmitted in the form of binary data by modulating the intensity of the LED light. As a new type of highly effective location-based technology, it is currently receiving great attention. In these two studies, it was integrated into a single system based on Bluetooth SoC. This compact system provides accurate location inside spaces and provides a flexible configuration in system parameters.

In the study of George M. et al., [2] a photo sensor, temperature sensor and occupancy sensor interface were installed on the Master CC2531 USB Dongle. By sending control signals to two dependent microcontrollers (CC2531 USB Dongles) using these sensor inputs, it has been enabled to control the ballast in two different regions using ZigBee Communication.

Michael Kent et al., [27] for energy efficiency, processed real-time lighting data with sensors that transfer to a light control controller, and controlled whether daylight provides more illumination than required or desired.

A smart LED luminaire was designed by Ivan Chew et al. [28] in this fixture; the LED driver consists of LEDs, ZigBee module, microcontroller and sensors. By creating an interface with the wireless communication module, the ambient light level was controlled.

In the study by Michael Papinutto et al., [29] as a result of current research they mainly focused on energy saving and automation mostly does not allow customization. In this case, users have developed strategies themselves to bypass automation.

In the study by Nima Hafezparast Moadab et al., [30] advanced and integrated lighting technology control, including an internet-based network, can be made for data communication used by lighting systems. Different scenarios have been developed by conducting this light simulation study in Sweden. The result of the study shows that the appropriate use of smart lighting solutions, including optimized sensor applications, has the potential to generate savings. Electric lighting energy consumption compared to non-smart systems, energy savings of more than 50% have been achieved.

L.T. In the study by Doulos et al., [31] the energy efficiency of LED luminaires is much better than others. Although the power factor values of luminaires with T5 fluorescent lamps are lower, they are pale.

When the differences between the other studies in the literature and this study are examined, the studies in the literature are generally suitable for automation systems. It has been seen that multiple sensors are remotely managed systems with wireless communication protocols for large businesses. These large systems are quite costly. In this study, the main purpose is to make DALI communication protocol supported master device. With this study, an interface was developed, and master device control was provided. The simple structure of the interface provides ease of use and low cost for customers.

III. Material and Method

The modern lighting system is not thought out independently of the controls. It allows for ensuring the regulatory parameters of the light environment with minimal energy costs. Various solutions can be used to control the light current. The protocols used in these systems are analogue 0-10V control, DMX512 (Digital Multiplex) protocol, RDM protocol (Remote Device Management), KNX (Konnex) protocol, Modbus and one of the most common ones is the DALI protocol [32].

A. The DALI Protocol

DALI is a communication protocol developed for lighting systems in accordance with the IEC 62386 technical standard. Devices working with the DALI protocol send messages to each other over the DALI line in a wired way [33]. The DALI protocol is used for communication between the master device and the slave. DALI is compatible with LED drivers provides energy saving in lighting systems with high efficiency. The DALI communication system consists of at least one controls, one DALI-supported LED driver and one power supply to supply the DALI line. The master can send commands and control all the lighting hardware in the DALI line individually or in groups [34].

In this study, commands will be sent to the controller via a user interface. However, in DALI systems, the controls do not have to be a user interface. The intensity of the light falling on the sensor is measured according to the illumination level of the environment. The sensor connected to the DALI line sends commands directly, and the sensor can control a lighting device or a group in a slave state [35].

The address information of the DALI LED driver devices and grouping information are made with the commands that will be sent to the LED drivers via the DALI line. In the DALI communication system, each lighting device has an address between 0 and 63. In other words, a DALI control device can control up to 64 drive devices [36]. In the case of using more LED drivers, controls should be used once for every 64 groups and their controls should be performed separately.

If we look at the general automation system structure in Figure 1, communication is used between the DALI controller and the lighting hardware, while Wi-Fi communication is selected between the control device and the user interface software. Depending on the control device, a different method can also be selected instead of Wi-Fi [8].

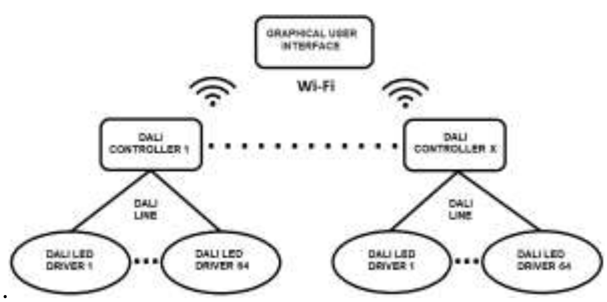


Fig.1. General Automation System Architecture.

Electrical characteristics of the DALI controller There is a double-wired connection between the DALI drives. A bridge diode is used at the input of the DALI circuit for protection purposes. The purpose of this is a precaution taken even though the team making the installation in the field environment makes the connections in reverse. There are no polarization restrictions due to this bridge diode. There is no positive or negative direction status for the cable that provides data communication [37]. A signal mark above 9.5 V is a sign of a high level. A signal less than 6.5 V is a low-level signal. The main control unit communicates with the DALI-supported LED drivers by setting the level to high or low according to the DALI protocol [34].

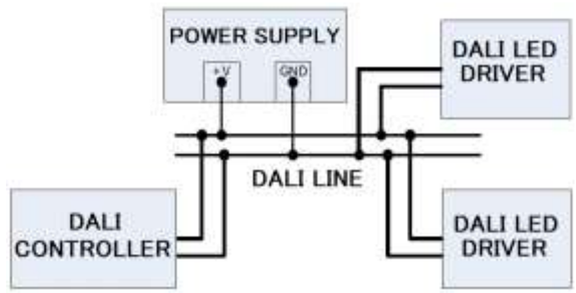


Fig.2. DALI Connection Diagram.

Logic 1 and logic 0 values are used when making DALI communication. For DALI communication to be successful, at least one control, at least one DALI-supported LED driver and power supply are needed on the connection line, as shown in Figure 2. Since the DALI devices do not supply the communication line, the DALI line must be short-circuited to set the voltage level on the line to logic 0. But since a short circuit during switching for communication will damage the DALI hardware, according to DALI standards, the power supply must allow a maximum current of 250 mA. In the DALI communication system, all lighting hardware communicates via the same communication line. The length of the cable line used should be a maximum of 300 meters.

According to DALI standards, each of the DALI devices in the communication system should be designed to consume a maximum current of 2mA. The cable used for the line must be 600V isolated. Communication is provided by the binary number system (0-1), the logic value graph used in DALI is given in Figure 3 [8].

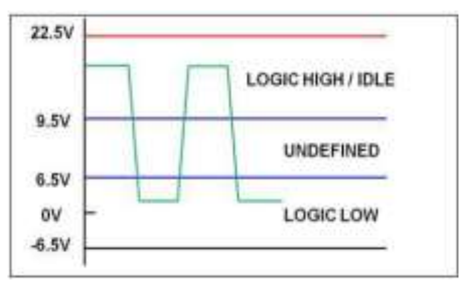


Fig.3. DALI Electrical Characteristics [8, 9].

B. Wireless Communication Protocols and Wi-Fi

Although it does not realize smart lighting systems, the most effective solution is to use universal protocols. Wireless communication protocols are one of the most important issues for IoT (Internet of Things). Communication protocols allow the devices in the system to communicate with each other.

These communication protocols are LoRa, Wi-Fi, Wi-SUN (Wireless Smart Utility Network), 4G/LTE (Long Term Evolution), LTE-M, Zigbee and Bluetooth [38]. Wi-Fi is the most recognized wireless network technology in the world. It is used to connect phones, computers, and tablets to the Internet. This study will also be used for controls and user interface communication on the computer using Wi-Fi communication [39]. It is compatible with IEEE 802.11 based standard. It communicates on 2.4GHz and 5GHz frequencies. It provides a usage environment for end users due to its advantages of fast and easy accessibility, sensitive security approach, high service quality and convenient usability [40]. In order for us to use Wi-Fi communication, it is necessary to add a Wi-Fi module to the card on which our DALI software is located. The hardware and software block connection diagram that should belong to the Wi-Fi connection area is given in Figure 4.

Fig.4. Wi-Fi Hardware and Software Block Diagram.

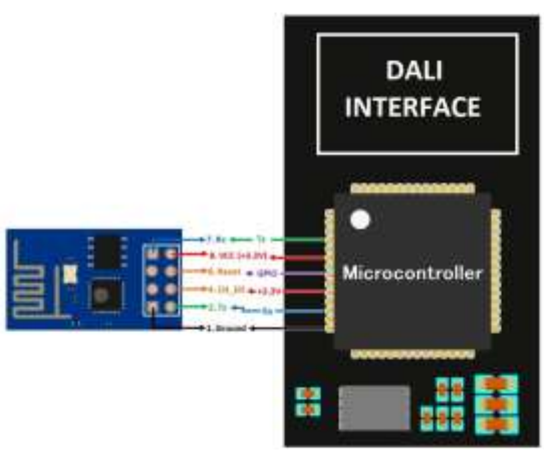


Fig.5. Connection of ESP8266 with Microcontrollers.

The ESP8266 module was also used in our project to work, so that we could only connect to the Internet and get the user's settings via the web-based interface. The ESP8266 is a WiFi chip with microcontroller capability and full TCP/IP (Internet Protocol-Internet Protocol) protocol stack that allows any microcontroller to access the WiFi network [41]. The ESP8266 module can host an application in itself or be controlled by another application processor [42]. Data exchange is provided via the main processor UART communication protocol with the ESP8266 module. An example illustration of the connection diagram is shown in Figure 5.

IV. Hardware and Software Operation

A. Hardware

The general hardware stages of our study have a main control unit, ESP8266 wireless communication module connected to the main control unit, DALI hardware circuit that will allow communication with DALI compatible LED drivers. The block diagram of the hardware made within the scope of the study is shown in Figure 6.

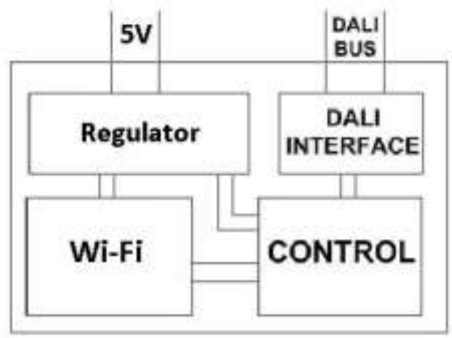


Fig.6. Hardware Block Diagram.

In the main control unit section, the data received via Wi-Fi communication is transferred to the LED drivers via the DALI hardware circuit with the DALI messaging software. The DALI control circuit is connected to our processor in the main control section via 2 GPIO pins. One of the pins is set as signal input (IN) and the other is set as signal output (OUT) pin. The reason we need the DALI hardware circuit is that the processor pins work with 3.3 V. But for the DALI protocol logic 1 signal, we need values between 9.5V and 22.5V, and for the logic 0 signal, between -6.5V and 6.5V. The remaining sections between 6.5V and 9.5V are Decoded as meaningless and are not processed.

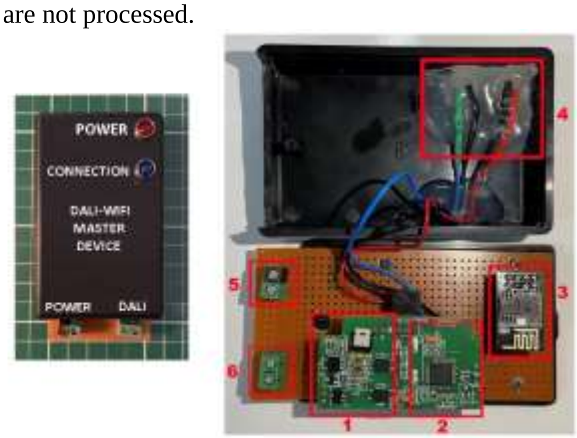


Fig.7. DALI Compatible Smart LED Driver Controller with Wİ-Fİ Communication.

There is a bridge diode at the place where the DALI hardware circuit is connected to the DALI line. Although DC is a voltage, the bridge diode must be present here for the requirement of the DALI protocol. Many devices can be connected to the DALI line at the same time. There are cable tangles in large automation systems. Polarization is eliminated in the DALI line thanks to the bridge diode. It is ensured that the cables in the DALI line are connected in 2 directions.

In this study, a device that transmits the data received from the web interface to the DALI control device via Wi-Fi and controls a DALI-compatible LED driver over the DALI line has been designed.

Figure 7 shows a visual of the control device.

As can be seen in Figure 7, the part indicated with 1 is the DALI hardware circuit. It transmits signals to the processor in isolation. The high-level signal between 9.5V and 22.5 V on the DALI line decelerates the signal level of the processor to 3.3 V. The low-level signal between -6.5V and 6.5V decays to the 0V level. In the same way, the signals sent from the processor reach the level of DALI standards. The part indicated with 2 is the hardware unit belonging to the processor and peripherals. The preparation of DALI messages with the analysis of data from Wi-Fi is carried out in this unit. the part indicated with 3 is the ESP8266 Wi-Fi module. The user interface data is received thanks to this module and transferred to the processor via UART. the part indicated with 4 has warning LEDs. One of these LEDs, the power LED, lights up if there is energy in the device, and the other is the LED that turns off if the connection LED is in communication with the user interface. The part specified with 5 is the power terminal. The part specified with 6 is the terminal used for DALI communication.

B. *Software Structure*

When the device made within the scope of the study is energized, the systemically necessary initial adjustments are made first. These are setting the processor frequency, setting the input-output pins used, the communication settings, and starting the timers. After these adjustments are made, the initial settings of the wireless communication unit are made first on our processor. Later Communication settings for the DALI protocol are made and the device is made ready. After the initial adjustments are completed, Wi-Fi messages are checked every second. The values taken from the interface are compared with the old values. In the beginning, the received message is checked. If there are no changes in the received parameters, the control is performed from the beginning. The DALI message is not created. If there are changes in the received values, the message content is assigned to the relevant variables in a meaningful way and the DALI message starts to be created. In Figure 8, the general software code flow structure is shared.

DALI uses Manchester encoding to send the start bit and information bits. The information rate is 1200 bps with a gap of ±10%. The duration of one bit is 833.33 μs, as shown in figure 9. The largest valence bit (MSB) is sent first. As shown in Figure 9, the 833.33us bit duration can be between 749.99 μs and 916.66 μs with a 10% margin of error. Likewise, 416.66 μs with a half-bit duration can be between 374.99 μs and 458.33 μs with a 10% margin of error.

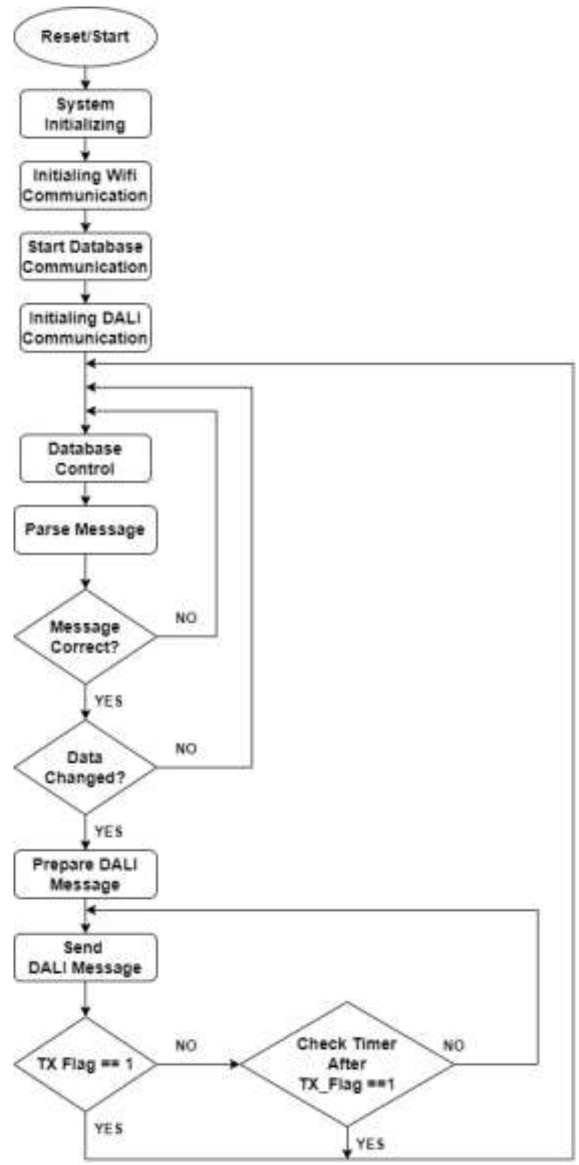


Fig.8. General Code Flow Chart.

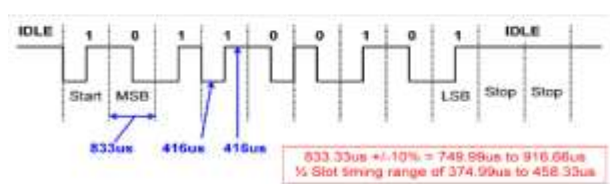


Fig.9. DALI Communication [8, 9].

In the forward direction, the message is the packet sent to the LED driver by the controller. The message in the reverse direction is the response packet sent back to the controller by the LED driver. It consists of a start bit, eight data bits and two stop bits.

The timing requirements for messages sent consecutively, as shown in Figure 10, are given below [43];

- The time Deciphered between two consecutive message data sent must be at least 9.17ms.
- The transition time between the message data received in the reverse direction and the message data sent in the

forward direction should be in the range of 2.97ms to 9.17ms.

- The control unit sends the message data in the forward direction and waits for 9.17ms. If the message data has not been sent in the reverse direction after 9.17ms has passed, the LED driver interprets this status as "no response has been received".
- There should be at least 9.17ms time gap between the two-message data in the backward and forward directions.

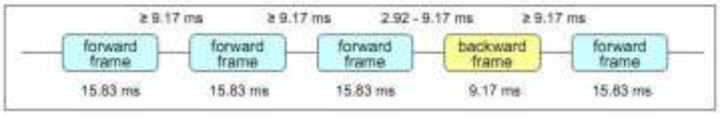
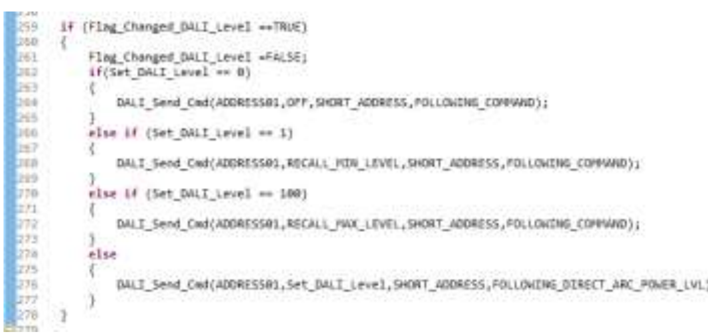


Fig.10. Message Data Sent Back to Back Duration Display [34] [39]

Manchester coding, in most cases, plays a critical role in binary data transmission, especially in analogue, radio frequency, optical, high-speed digital communication or long-distance digital communication. The package sent between the controller and the LED driver is a two-phase manchester package. Manchester coding is performed before the package is sent from the controller. Then the package is received by the LED driver, decoded, and the address and messages are processed accordingly.

The sample encoding in which a message is sent to the DALI line is shared in Figure 11. As can be understood from the visual, some commands are sent to the LED driver located at address 1 according to the Set_DALI_Level level. If the level to be sent is 0, the OFF signal, if the minimum level is equal to 1, the minimum level message, if the maximum level is equal to 100, the maximum level message has been sent. If there is an intermediate value LED brightness level other than these levels, that level is printed directly on the line with SET_ Decal_level.



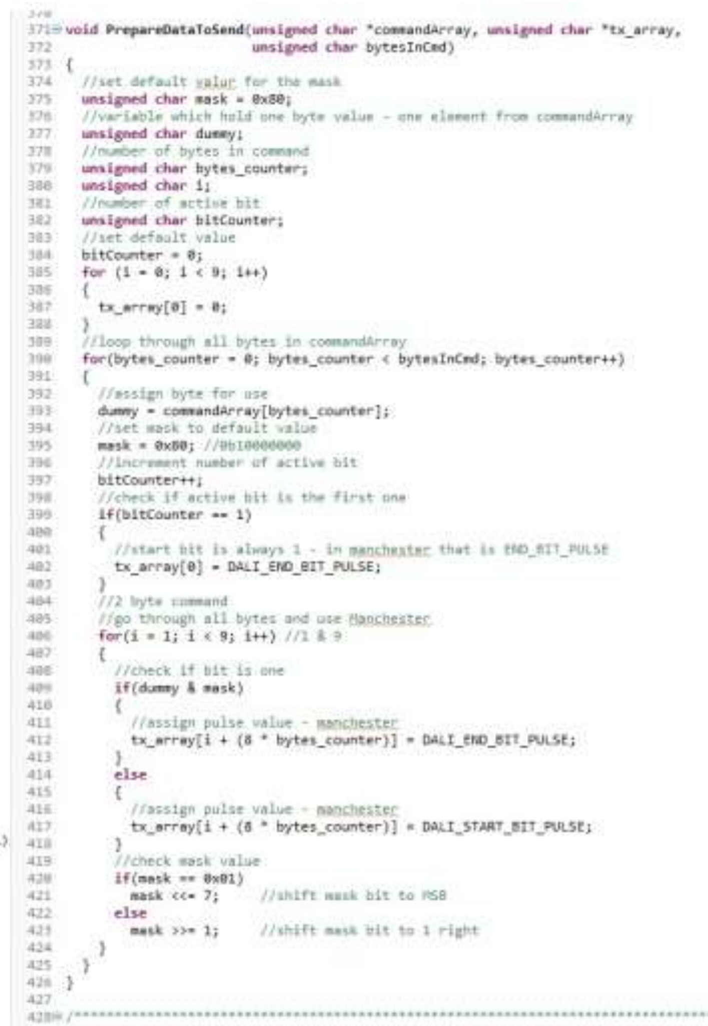
```
if (Flag_Changed_DALI_Level ==TRUE)
{
    Flag_Changed_DALI_Level =FALSE;
    if(Set_DALI_Level == 0)
    {
        DALI_Send_Cmd(ADDRESS01,OFF,SHORT_ADDRESS,FOLLOWING_COMMAND);
    }
    else if (Set_DALI_Level == 1)
    {
        DALI_Send_Cmd(ADDRESS01,RECALL_MIN_LEVEL,SHORT_ADDRESS,FOLLOWING_COMMAND);
    }
    else if (Set_DALI_Level == 100)
    {
        DALI_Send_Cmd(ADDRESS01,RECALL_MAX_LEVEL,SHORT_ADDRESS,FOLLOWING_COMMAND);
    }
    else
    {
        DALI_Send_Cmd(ADDRESS01,Set_DALI_Level,SHORT_ADDRESS,FOLLOWING_DIRECT_ARC_POWER_LVL)
    }
}
```

Fig.11. Sending a DALI Message Flow.

The DALI message to be sent in the DALI_Send_Cmd function is being prepared. As shown in Figure 12, the required address information for the message to be sent is set first. After that, our existing data is encoded in manchester, and the buffer encoded in manchester as dali_array_cmd is created. After that, the Timer_Start function is called and the manchester encoded data is sent to the processor pins here and DALI messaging starts.

```
unsigned char DALI_Send_Cmd(unsigned char ballastAddr, unsigned char cmd,
                            unsigned char typeOfCmd, unsigned char followingType)
{
  unsigned char data_array[2];
  unsigned char i;
 //set output pin to 0
  _OUT_LINE(1);

  tick_count = 0;
  bit_count  = 0;
  //set DALI state to send data
  dali_state = SENDING_DATA;
  //fetch ballast address and command
  data_array[0] = (char)ballastAddr;
  data_array[1] = (char)cmd;

  //reset dali_array_cmd values
  for (i = 0; i < 17; i++)
    dali_array_cmd[i] = 0;

  //Gonderilecek LED surucu bilgileri giriliyor
  PrepareAddressByte(data_array, typeOfCmd, 0, followingType);

  //encode data - Manchester encoding
  PrepareDataToSend(data_array, dali_array_cmd, 2);


  Timer_Start();

  return TRUE;
}
```

Fig.12. DALI Message Sending Function Software.



```
void PrepareDataToSend(unsigned char *commandArray, unsigned char *tx_array,
                       unsigned char bytesInCmd)
{
  //set default value for the mask
  unsigned char mask = 0x80;
  //variable which hold one byte value - one element from commandArray
  unsigned char dummy;
  //number of bytes in command
  unsigned char bytes_counter;
  unsigned char i;
  //number of active bit
  unsigned char bitCounter;
  //set default value
  bitCounter = 0;
  for (i = 0; i < 9; i++)
  {
    tx_array[0] = 0;
  }
  //loop through all bytes in commandArray
  for(bytes_counter = 0; bytes_counter < bytesInCmd; bytes_counter++)
  {
    //assign byte for use
    dummy = commandArray[bytes_counter];
    //set mask to default value
    mask = 0x80; //0b10000000
    //increment number of active bit
    bitCounter++;
    //check if active bit is the first one
    if(bitCounter == 1)
    {
      //start bit is always 1 - in manchester that is END_BIT_PULSE
      tx_array[0] = DALI_END_BIT_PULSE;
    }
    //2 byte command
    //go through all bytes and use Manchester
    for(i = 1; i < 9; i++) //1 & 9
    {
      //check if bit is one
      if(dummy & mask)
      {
        //assign pulse value - manchester
        tx_array[i + (8 * bytes_counter)] = DALI_END_BIT_PULSE;
      }
      else
      {
        //assign pulse value - manchester
        tx_array[i + (8 * bytes_counter)] = DALI_START_BIT_PULSE;
      }
      //check mask value
      if(mask == 0x01)
        mask <<= 7;      //shift mask bit to MSB
      else
        mask >>= 1;      //shift mask bit to 1 right
    }
  }
}
/*****************************************************************************
```

Fig.13. Manchester Coding of the Data.

The prepared hardware and software have been tested. The image taken at the DALI line exit is given in Figure 14. When the oscilloscope images were examined, the accuracy of the results obtained was seen in both communication signals.

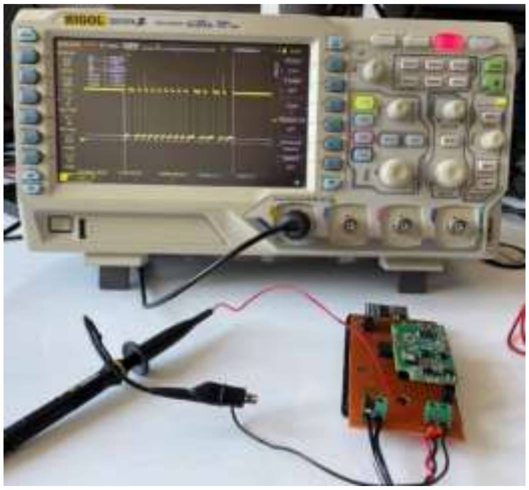


Fig.14. DALI Hardware Circuit Output Even the DALI Message Sent.

Tests were carried out with a Tridonic brand LED driver that has passed DALI standards tests and has a DALI certificate. Brightness reduction, brightness increase, minimum and maximum levels have been adjusted via the web interface. It was observed that the study fulfilled the required standards of DALI with the tests performed.

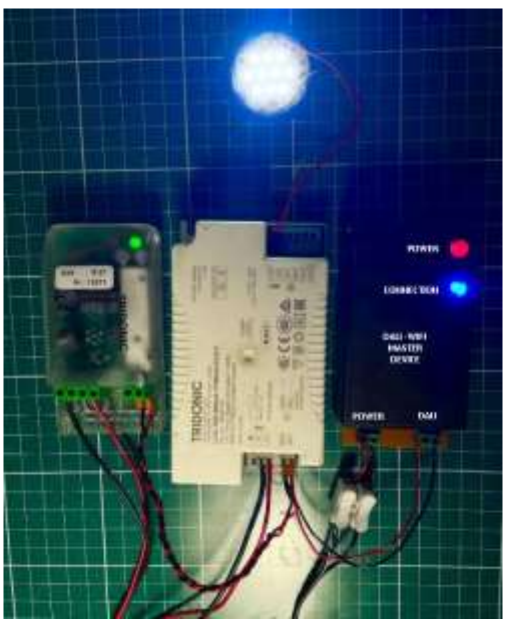


Fig.15. Experimental Setup.

Figure 15 shows the image of the experiments with the Tridonic brand LED driver. In the tests carried out, Tridonic brand power supply was used to supply the DALI line. As a result of the tests, it has been understood that the designed control device will be used safely in practical work due to the low cost of the materials used, easy to supply and the stability of the system.

It has been observed that the data entered via the user interface is transferred from the module to the processor via the UART protocol. The data were observed with the oscilloscope, and it was seen that the communication speed was within the tolerance gap determined. Live data tracking was performed via debug (debugging) via the processor. The data were examined, and the accuracy was observed.

With the Data assignment, it is known which command the user sent. The DALI command message is created. It was seen by debugging that the DALI message was created and sent after manchester encoding was performed. The DALI signals sent were examined with the help of an oscilloscope. The communication speed of the studied DALI signals is stated in the DALI technical document [5]. It was observed that it was in the specified gap. Peak signals at the highest and lowest levels also have electrical properties [9] it was seen that he was in it. After the accuracy of the tests was observed, it was observed that it communicated with the Tridonic brand LED driver. The desired LED brightness level has been checked.

As shown in Figure 16, there is a DALI signal at the output of our processor, the current high level of which is 3.24V, the low level of which is measured as 200mV. This signal is measured directly from the processor output. In the continuation of the circuit, this signal is transferred to the DALI hardware circuit. The signal level of the signal coming out of the processor will be printed on the DALI line so that the high level, which is the DALI standard, is between 9.5V and 22.5V, and the low level is between -6.5V and 6.5V.

In Figure 16, the same DALI signal at the processor output is zoomed in and the time of ½ bit of the signal is measured. This value, which is seen as the BX-AX (Cursor B, Axis X - Cursor A, Axis X) difference in the oscilloscope image, is seen as 420us. As mentioned earlier, there is a margin of error of 10%. Under normal conditions, this level should be 416us with a ±10 difference between 374.99us and 458.33us, which is sufficient for communication.

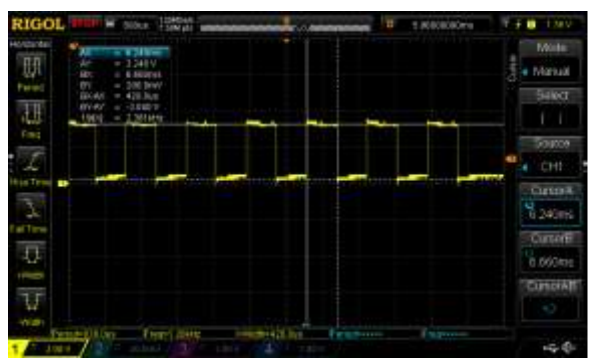


Fig.16. Measurement of Processor Output DALI Data Bit Time.

The 0V-3.3V signal at the processor output is sent to the line by passing through the DALI hardware circuit while pressing the DALI line. The reason for this is that we can print a signal even at the DALI signal level. If this circuit is not used, our high signal, which is 3.3V, will remain between -6.5 V and 6.5 V at the low level according to DALI standards. Therefore, it will be a meaningless message for other devices on the DALI line.

Figure 17 and figure 18 show the signal passing through the DALI hardware circuit. The maximum point of the signal AY (Cursor A, Axis Y) was measured at 17.40V. The high signal level, which is a requirement of the DALI standard, is between 9.5V and 22.5V. In the same way, the low signal level measured BY (Cursor B, Axis Y) 1.3V is between -6.5V and 6.5V, which is a requirement of the DALI standard.

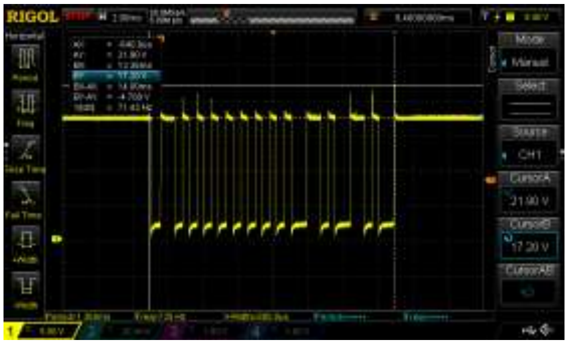


Fig.17. Observing Peaks at a High Level of the DALI Signal.

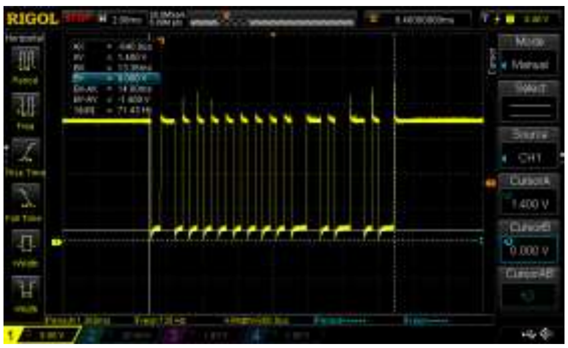


Fig.18. Observing Peaks at a Low Level of the DALI Signal.

Figure 17 shows the peak points in the transitions from 0 to 1 signal level due to the nature of communication signals at a high signal level. It is observed that the maximum point of this level is 21.90V, which is indicated by the AY. Since it is below 22.5V and is an instant value, it does not have a negative impact on our messaging. The same situation is shown in figure 18 for the low level. Here, the peak points in the transitions from 1 to 0 signal level are seen. The lowest signal level was measured as 0V shown in the BY. This situation is not a negative situation for our messaging.

```
void Usart_InitializeAp(void)
{
    USART_InitTypeDef USART_InitStruct;
    NVIC_InitTypeDef NVIC_InitStructure;

    // USART1 modülüne Clock verilir.
    RCC_APB2PeriphClockCmd(RCC_APB2Periph_USART1, ENABLE);

    USART_InitStruct.USART_BaudRate = 115200;                //Baudrate ayarl
    USART_InitStruct.USART_HardwareFlowControl = USART_HardwareFlowControl_None;
    //Usart Full-Duplex calisacak TX ve RX modu aktif edilir.
    USART_InitStruct.USART_Mode = USART_Mode_Tx | USART_Mode_Rx;
    USART_InitStruct.USART_Parity = USART_Parity_No;         //Parity Kullanmiyoruz.
    USART_InitStruct.USART_StopBits = USART_StopBits_1;      //Stop bit 1 ayarlaniyor
    USART_InitStruct.USART_WordLength = USART_WordLength_8b; //Data bit uzunlugumuz 8
    USART_Init(USART1, &USART_InitStruct);


    // USART1 Rx interrupt aktif ediliyor. USART'dan herhangi bir data geldiginde
    // USART1_IRQHandler() adiyla isimlendirdigimiz fonksiyona gider
    USART_ITConfig(USART1, USART_IT_RXNE, ENABLE); // USART1 Rx interrupt aktif ediliyor

    NVIC_InitStructure.NVIC_IRQChannel = USART1_IRQn;
    NVIC_InitStructure.NVIC_IRQChannelPriority = 0; //0 yazarak en öncelikli kaynak yapiyoruz
    NVIC_InitStructure.NVIC_IRQChannelCmd = ENABLE; //USART1 Interrupt kanali aktif edilir.
    NVIC_Init(&NVIC_InitStructure);

    USART_Cmd(USART1, ENABLE);  // USART1 aktif edilir.
}
```

Fig.19. Making UART Settings

The ESP8266 module is connected via UART with the processor. It is necessary to make software settings for the processor to recognize the ESP8266 module. The ESP8266 module is connected to the processor via GPIO pins PA9 (TX) and PA10 (RX). It is software-configured that the UART connections of the PA9 and PA10 pins will be used. After the pin settings are made, the UART settings of the ESP8266 module are set via the processor as shown in Figure 19. After these adjustments are completed, the module is ready for communication.

After the necessary adjustments have been made to recognize the ESP8266 module by the processor, some commands are available to communicate with the module. These commands are referred to as AT commands. For the adjustment of the ESP8266 module given in Figure 20, the settings written in the technical document are encoded and transferred to the module via UART communication. After each message is sent, a check is made to see if the "OK" response has been received. If "OK" has been received, it is understood that the message has successfully reached the module and the settings we have sent have been applied.

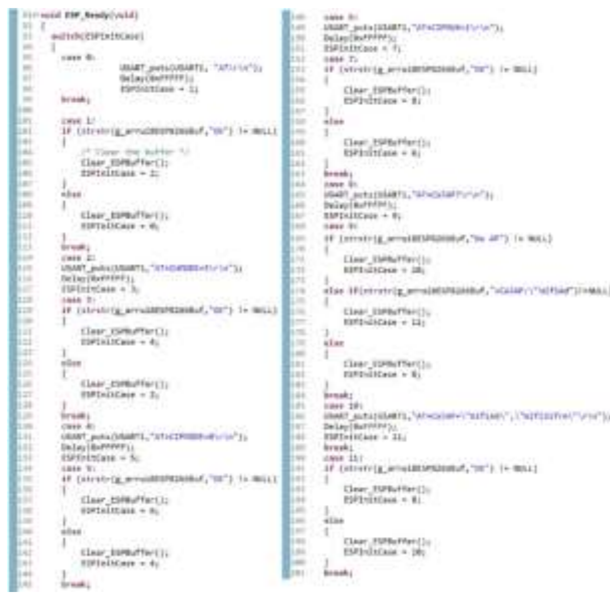


Fig.20. Setting Up the ESP8266 Module

With the help of the user interface page, users can control the brightness of Decelerated lighting system. The ESP8266 module checks the web service API, where the user interface stores data at intervals to check for changes. If there is a change in the received brightness value, the message content is assigned to the relevant variables and the DALI message starts to be created.

As can be seen in the image in Figure 21, with the AT+CIPSTART command, we first go to our site. We are establishing a TCP connection. If we get the answer "OK", the site connection is provided, if the answer "ALREADY" comes, it means that we are already connected to the site. In both cases, the next step is taken. We send length information before our query message with AT+CIPSEND command ">" when the answer comes, we query our brightness data to the site with "GET".

Fig.21. Providing a Connection to the Site by Establishing a TCP Connection with ESP8266.

After the query message is sent, a long message with brightness data is received via the site. For 50% brightness on the interface web service, the brightness data is kept as Wi-Fidata:050, which will be on the Wİ-Fİ at the beginning. As shown in Figure 22, the Wi-Fi data address is taken for the incoming message using the strstr function. Since the incoming data is ASCII (American Standard Code for Information Interchange), it is necessary to perform the decimal conversion. The conversion is performed with the Convert_ASCII_Buf_to_Dec function. Since Wi-Fi data's address was taken during the conversion, 8 is added to the address of Wi-Fi data to reach our main data, it reaches the address of the main data and transactions are made through it. The reason for adding 8 is that Wi-Fi data takes up 8 bytes of space in ASCII.

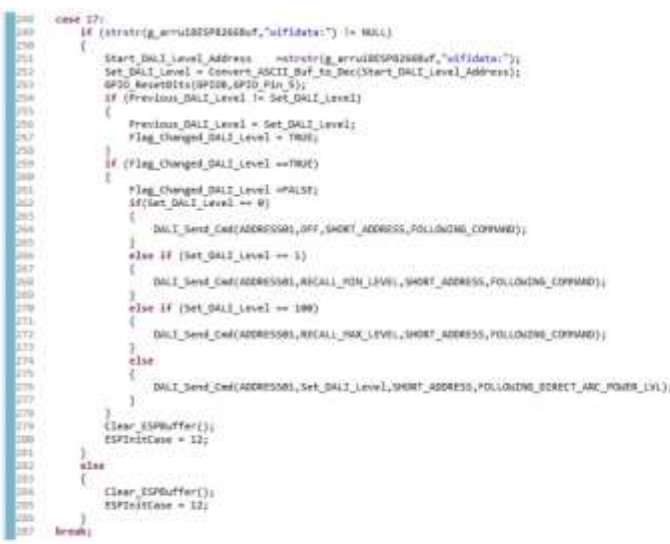


Fig.22. Getting the Brightness Data Starting the DALI Query.

254, seen in Figure 22. Whether the value read in the line is different or the same from the previous value is checked. If the value is different, a DALI message is generated according to the incoming value. If the incoming brightness level is 0, an OFF message is sent to our LED driver. If the brightness level is 1, the minimum level, and if the brightness level is 100, the maximum level message is sent. If a different value other than these values is received, the brightness data is sent directly to the LED driver.

The Web page developed within the scope of the project is shown in Figure 23. With the help of this interface, users are able to control the brightness of the selected lighting system [44]. The brightness can be increased or decreased at the desired level with the buttons on the page.

Fig.23. DALI Control Unit User Interface

The web application is formed with Asp.NET MVC (Model View Controller). HTML, CSS and Javascript languages were used on the front. On the server side, the C# programming language is used. When clicking on the buttons from the front, HTTP POST (Power on Self Testing) data is sent to the Controller class using the method. Then these data are recorded in the database. In the MVC project prepared in layered architecture, EntityFramework library was used for database operations. MSSQL as a database (Microsoft SQL Server) The server has been selected. The created tables and columns are shown in Figure 24.

EntityInfos

Column Name	Data Type	Allow Nulls
Id	int	☐
Brightness	int	☐
DaliNo	int	☐
MaxLevel	int	☐
MinLevel	int	☐
		☐

Fig.24. Database Table

Within the scope of the project, the current brightness of the DALI system of the embedded system, except for the website the Web service has been written so that it can read the data. For the service designed with REST architecture Asp.NET API is used. Thanks to this service, devices are prevented from connecting to the database and it is ensured that they can receive only the necessary data via the HTTP protocol.
The data is sent in string type for easy reading by the embedded system. The C# method, which retrieves the current brightness value from the database and works with HTTP GET, is given in Figure 25.

```
[HttpGet]
   public IActionResult GetBrightness()
   {
       Repository repository = new();
       var entity = repository.Get();
       var value = $"{entity?.Brightness:D3}";
       return Ok(value);
   }
```

Fig.25. Reading the Brightness Data

V. CONCLUSION

In this study, the construction of a smart LED driver control is presented. In the details of the study, the hardware features of the circuit made, the working principles were mentioned, the flow chart of the software and needs to work in the hardware for the system to work, the software details were mentioned. The DALI protocol, which is one of the most preferred communication protocols in lighting systems, has been preferred. In the communication via the interface, the most preferred Wi-Fi communication is used wirelessly. ESP8266 was preferred because it can be found quickly in the market for Wi-Fi communication and is inexpensive in cost.

When other studies in the literature are examined, it has been seen that more than one sensor for automation systems are generally large systems that require cost and are managed remotely with wireless communication protocols. In this study, the end product to be presented to the customer, which provides remote control of the DALI communication protocol, has been revealed. It provides a significant advantage to customers compared to other products in terms of cost. A DALI protocol controller with Wi-Fi support has been made. With this controller, it is possible to remotely control the device by connecting to any Wi-Fi line by making a communication line connection in the environment where DALI supported LED drivers are located. For control, use any device with an Internet connection (computer, tablet, mobile phone, etc.). The interface is accessible and LED lighting can be controlled from anywhere desired.

After the theoretical studies of the circuit were carried out, experimental studies were carried out, the oscilloscope images of the communication data of the results were examined and described in detail in the previous sections. The thesis study was verified by conducting tests with a Tridonic brand LED driver that has a DALI certificate.

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REFERENCES

[1] B. Söğüt, B. Fulin, and F. Parlak, "DALI Protokolü ile Kontrol Edilebilen Enerji Tasarruflu LED Sürücü," in *Elektrik Elektronik Mühendisliği Kongresi (EEMKON)*, Istanbul, TURKEY, 2017, p. 84.

[2] M. A. George, S. Choudhary, D. Sahay, T. Yerra, and C. P. Kurian, "Digitally Addressable Wireless Interface for Lighting Control System," in *2013 Texas Instruments India Educators' Conference*, 4-6 April 2013 2013, pp. 222-229, doi: 10.1109/TIIEC.2013.46.

[3] K. Lohia, Y. Jain, C. Patel, and N. Doshi, "Open Communication Protocols for Building Automation Systems," *Procedia Computer Science*, vol. 160, pp. 723-727, 01/01 2019, doi: 10.1016/j.procs.2019.11.020.

[4] M. K. Manyake and T. N. D. Mathaba, "An Internet of Things Framework for Control and Monitoring of Smart Public Lighting Systems: A Review," in *2022 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD)*, 4-5 Aug. 2022 2022, pp. 1-9, doi: 10.1109/icABCD54961.2022.9856268.

[5] F. J. Bellido-Outeirino, J. M. Flores-Arias, F. Domingo-Perez, A. Gil-de-Castro, and A. Moreno-Munoz, "Building lighting automation through the integration of DALI with wireless sensor networks," *IEEE Transactions on Consumer Electronics*, vol. 58, no. 1, pp. 47-52, 2012, doi: 10.1109/TCE.2012.6170054.

[6] M. Moeck, "Developments in Digital Addressable Lighting Control," *Journal of Light & Visual Environment*, vol. 28, pp. 104-106, 09/01 2004, doi: 10.2150/jlve.28.104.

[7] F. J. B. Outeiriño, F. Domingo-Perez, A. d. R. Gil-de-Castro, J. F. Arias, and A. Moreno-Munoz, "In-building lighting management system with wireless communications," in *2012 IEEE International Conference on Consumer Electronics (ICCE)*, 13-16 Jan. 2012 2012, pp. 83-85, doi: 10.1109/ICCE.2012.6161751.

[8] M. L. Wu, C. M. Kung, and Y. N. Lin, "DALI-2 Intelligent Lighting Control System," in *2020 International Symposium on Computer, Consumer and Control (IS3C)*, 13-16 Nov. 2020 2020, pp. 158-161, doi: 10.1109/IS3C50286.2020.00048.

[9] R. Delvaeye, W. Ryckaert, L. Stroobant, P. Hanselaer, R. Klein, and H. Breesch, "Analysis of energy savings of three daylight control systems in a school building by means of monitoring," *Energy and Buildings*, vol. 127, 06/01 2016, doi: 10.1016/j.enbuild.2016.06.033.

[10] S. Babu *et al.*, "Investigation of an integrated automated blinds and dimmable lighting system for tropical climate in a rotatable testbed facility," *Energy and Buildings*, vol. 183, pp. 356-376, 2019/01/15/ 2019, doi: https://doi.org/10.1016/j.enbuild.2018.11.007.

[11] G. Adam, "DALI LED Driver Control System for Lighting Operations Based on Raspberry Pi and Kernel Modules," *Electronics*, vol. 8, p. 1021, 09/12 2019, doi: 10.3390/electronics8091021.

[12] J. Liu, W. Zhang, X. Chu, and Y. Liu, "Fuzzy Logic Controller for Energy Savings in a Smart LED Lighting System Considering Lighting Comfort and Daylight," *Energy and Buildings*, vol. 127, 05/01 2016, doi: 10.1016/j.enbuild.2016.05.066.

[13] N. Gentile *et al.*, "Evaluation of integrated daylighting and electric lighting design projects: Lessons learned from international case studies," *Energy and Buildings*, vol. 268, p. 112191, 2022/08/01/ 2022, doi: https://doi.org/10.1016/j.enbuild.2022.112191.

[14] Z. Chen, C. B. Sivaparthipan, and B. Muthu, "IoT based smart and intelligent smart city energy optimization," *Sustainable Energy Technologies and Assessments*, vol. 49, p. 101724, 2022/02/01/ 2022, doi: https://doi.org/10.1016/j.seta.2021.101724.

[15] O. O. Ordaz-García, M. Ortiz-López, F. J. Quiles-Latorre, J. G. Arceo-Olague, R. Solís-Robles, and F. J. Bellido-Outeiriño, "DALI Bridge FPGA-Based Implementation in a Wireless Sensor Node for IoT Street Lighting Applications," *Electronics*, vol. 9, no. 11, doi: 10.3390/electronics9111803.

[16] F. J. Bellido-outeirino, J. M. Flores-arias, M. Linan-Reyes, E. J. Palacios-garcia, and J. J. Luna-rodriguez, "Wireless sensor network and stochastic models for household power management," *IEEE Transactions on Consumer Electronics*, vol. 59, no. 3, pp. 483-491, 2013, doi: 10.1109/TCE.2013.6626228.

[17] A. Gil-de-Castro, A. Moreno-Munoz, and J. J. de la Rosa, *Characterizing the harmonic attenuation effect of high-pressure sodium lamps*. 2010, pp. 1-6.

[18] F. Domingo-Perez, A. Gil-de-Castro, J. M. Flores-Arias, F. J. Bellido-Outeirino, and A. Moreno-Munoz, "Lighting control system based on DALI and wireless sensor networks," in *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, 16-20 Jan. 2012 2012, pp. 1-6, doi: 10.1109/ISGT.2012.6175666.

[19] S. Tang, V. Kalavally, K. Y. Ng, and J. Parkkinen, "Development of a prototype smart home intelligent lighting control architecture using sensors onboard a mobile computing system," *Energy and Buildings*, vol. 138, pp. 368-376, 2017/03/01/ 2017, doi: https://doi.org/10.1016/j.enbuild.2016.12.069.

[20] T. de Rubeis *et al.*, "A first approach to universal daylight and occupancy control system for any lamps: Simulated case in an academic classroom," *Energy and Buildings*, vol. 152, pp. 24-39, 2017/10/01/ 2017, doi: https://doi.org/10.1016/j.enbuild.2017.07.025.

[21] T. W. Kruisselbrink, R. Dangol, and E. J. van Loenen, "A comparative study between two algorithms for luminance-based lighting control,"

Energy and Buildings, vol. 228, p. 110429, 2020/12/01/ 2020, doi: https://doi.org/10.1016/j.enbuild.2020.110429.

[22] I. Chew, D. Karunatilaka, C. P. Tan, and V. Kalavally, "Smart lighting: The way forward? Reviewing the past to shape the future," *Energy and Buildings*, vol. 149, pp. 180-191, 2017/08/15/ 2017, doi: https://doi.org/10.1016/j.enbuild.2017.04.083.

[23] D. H. Kim, J. S. Sung, S. Park, and T. G. Kang, "A study on the performance factors for wireless lighting control networks," in *2016 International Conference on Information and Communication Technology Convergence (ICTC)*, 19-21 Oct. 2016 2016, pp. 906-908, doi: 10.1109/ICTC.2016.7763326.

[24] H. Zou, Y. Zhou, H. Jiang, S.-C. Chien, L. Xie, and C. J. Spanos, "WinLight: A WiFi-based occupancy-driven lighting control system for smart building," *Energy and Buildings*, vol. 158, pp. 924-938, 2018/01/01/ 2018, doi: https://doi.org/10.1016/j.enbuild.2017.09.001.

[25] C. Qiu, B. Hussain, and C. P. Yue, "Bluetooth Based Wireless Control for iBeacon and VLC Enabled Lighting," in *2019 IEEE 8th Global Conference on Consumer Electronics (GCCE)*, 15-18 Oct. 2019 2019, pp. 614-615, doi: 10.1109/GCCE46687.2019.9015330.

[26] Z. Zheng, L. Liu, and W. Hu, "Accuracy of Ranging Based on DMT Visible Light Communication for Indoor Positioning," *IEEE Photonics Technology Letters*, vol. 29, no. 8, pp. 679-682, 2017, doi: 10.1109/LPT.2017.2677424.

[27] M. Kent, N. K. Huynh, S. Schiavon, and S. Selkowitz, "Using support vector machine to detect desk illuminance sensor blockage for closed-loop daylight harvesting," *Energy and Buildings*, vol. 274, p. 112443, 2022/11/01/ 2022, doi: https://doi.org/10.1016/j.enbuild.2022.112443.

[28] I. Chew, V. Kalavally, N. W. Oo, and J. Parkkinen, "Design of an energy-saving controller for an intelligent LED lighting system," *Energy and Buildings*, vol. 120, pp. 1-9, 2016/05/15/ 2016, doi: https://doi.org/10.1016/j.enbuild.2016.03.041.

[29] M. Papinutto *et al.*, "Saving energy by maximising daylight and minimising the impact on occupants: An automatic lighting system approach," *Energy and Buildings*, vol. 268, p. 112176, 2022/08/01/ 2022, doi: https://doi.org/10.1016/j.enbuild.2022.112176.

[30] N. Hafezparast Moadab, T. Olsson, G. Fischl, and M. Aries, "Smart versus conventional lighting in apartments - Electric lighting energy consumption simulation for three different households," *Energy and Buildings*, vol. 244, p. 111009, 2021/08/01/ 2021, doi: https://doi.org/10.1016/j.enbuild.2021.111009.

[31] L. T. Doulos, A. Kontadakis, E. N. Madias, M. Sinou, and A. Tsangrassoulis, "Minimizing energy consumption for artificial lighting in a typical classroom of a Hellenic public school aiming for near Zero Energy Building using LED DC luminaires and daylight harvesting systems," *Energy and Buildings*, vol. 194, pp. 201-217, 2019/07/01/ 2019, doi: https://doi.org/10.1016/j.enbuild.2019.04.033.

[32] A. V. Kudryashov, E. S. Galishheva, and A. S. Kalinina, "Lighting Control Using DALI Interface," in *2018 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, 15-18 May 2018 2018, pp. 1-5, doi: 10.1109/ICIEAM.2018.8728728.

[33] S. G. Varghese, C. P. Kurian, and V. I. George, "A study of communication protocols and wireless networking systems for lighting control application," in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 22-25 Nov. 2015 2015, pp. 1301-1306, doi: 10.1109/ICRERA.2015.7418618.

[34] Z. Yuejun, Z. Ping, and W. Mingguang, "Research on DALI and Development of Master-Slave module," in *2006 IEEE International Conference on Networking, Sensing and Control*, 23-25 April 2006 2006, pp. 1106-1110, doi: 10.1109/ICNSC.2006.1673307.

[35] A. Kudryashov, "Lighting Control System for Premises with Display Screen Equipment," *IOP Conference Series: Materials Science and Engineering*, vol. 262, p. 012091, 11/01 2017, doi: 10.1088/1757-899X/262/1/012091.

[36] R. Sahu, "DALI Protocol and Interface with DALI Devices from External Master Controller," 07/25 2019.

[37] M. M. Rahman, E. J. Noor, M. O. Islam, and M. S. Salakin, "Arduino and GSM based smart energy meter for advanced metering and billing system," in *2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*, 21-23 May 2015 2015, pp. 1-6, doi: 10.1109/ICEEICT.2015.7307498.

[38] G. Gu and G. Peng, "The survey of GSM wireless communication system," in *2010 International Conference on Computer and Information Application*, 3-5 Dec. 2010 2010, pp. 121-124, doi: 10.1109/ICCIA.2010.6141552.

[39] Yoppy, R. H. Arjadi, H. Candra, H. D. Prananto, and T. A. W. Wijanarko, "RSSI Comparison of ESP8266 Modules," in *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, 9-11 Oct. 2018 2018, pp. 150-153, doi: 10.1109/EECCIS.2018.8692892.

[40] H. K. Lee, Y. Kim, and T. J. Lee, "Wi-fi boost protocol in a heterogeneous network with Wi-Fi and RFID," in *2016 Fifth International Conference on Future Generation Communication Technologies (FGCT)*, 17-19 Aug. 2016 2016, pp. 32-35, doi: 10.1109/FGCT.2016.7605064.

[41] S. Üstün Ercan and M. Mohammed, "IoT and XBee Based Central Car Parking Management System," *Balkan Journal of Electrical and Computer Engineering*, 01/30 2023, doi: 10.17694/bajece.1160300.

[42] A. R. Barai, M. R. K. Badhon, F. Zhora, and M. R. Rahman, "Comparison between Noninvasive Heart Rate Monitoring Systems using GSM Module and ESP8266 Wi-Fi Module," in *2019 3rd International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE)*, 26-28 Dec. 2019 2019, pp. 45-48, doi: 10.1109/ICECTE48615.2019.9303572.

[43] B. Güngör, "DALI Arabirimi Üzerinden Bir Acil Aydınlatma ve Yönlendirme Sistemi Yönetimi ve Uygulaması," Yüksek Lisans Tezi, Okan Üniversitesi, 2011.

[44] M. Şensoy, "Akıllı binalarda web teknolojilerinin kullanımı," Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü, Marmara Üniversitesi, 2022.

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