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Intelligent control and reduce energy consumption of smart street lighting system

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ABSTRACT

Public lighting is one of the criteria for the development of society, in addition to which it is important in human life, as it ensures safety and security during the night, but this may lead to an increase in energy consumption and therefore there is a deficit in energy bills. This research offers a smart street lighting system that has been implemented and tested at pilot site consists of 9 LED lights in order to reduce energy consumption without compromising the security and safety of street users. The developed system control solution relied on combining the effectiveness of the system with reduced installation costs, As soon as the user enters the street, his movement is detected using a motion sensor, so the controller processes this information and raises the intensity of the lighting around the street user's area, then sends a message via a wireless network to the next controller, which in turn raises the intensity of the lighting, thus increasing the intensity of lighting in front of the user rather than behind. Through experimental results obtained, the system has proven its effectiveness in achieving energy savings up to 50% depending on the use of the smart control scenario.

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1. INTRODUCTION

Energy prices have recently risen considerably, posing a major challenge to the countries and governments of the world to provide this vital material adequately to the functioning of the country and to meet citizens' needs. Street lighting contributes to improving citizens' lives by providing them with safety and safety during the night, but this results in significant energy consumption, estimated at about 2.3% to the global electricity consumption [1], [2], and increased carbon dioxide emission (CO_2) [3]. Traditional street lighting control systems, whether with simple on/off systems, on/off systems including timers or the systems based on GPS systems, share a single concept of non-energy saving on-demand, which results in reduced efficiency of these systems [4]. Increasing the efficiency of the street lighting system is one of the solutions on which to rely for saving energy and increase its efficiency by controlling the power supply according to street users. Governments around the world have enlisted their experts and frameworks through the provision of substantial financial resources and research laboratories to find solutions and opportunities to increase the efficiency of street lighting and management. This has allowed many smart street lighting (SSL) systems to emerge that have contributed to improving energy efficiency and management and many of them allow reductions in electricity consumption of more than 50% [2]. The most common solution for increasing energy efficiency in street lighting is to replace common lamps with LEDs, which allows for environmental sustainability and increased energy conservation by an estimated 40% [5] to 80% [6]. Furthermore, the LED lamp can give an optimal brightness [7].

There are many research papers dealing with the problem of energy consumption in street lighting systems. Lau *et al.* [8] suggested an intelligent lighting system adapted by speed and traffic intensity, this system proved capable of maintaining energy savings of up to 30% compared to the latest smart lighting systems and 90% compared to traditional lighting systems. The research in [9] proved this system is capable of maintaining energy savings of up to 30% by combining the movement of passers-by and light intensity around the user's area. Jagadeesh *et al.* [10] implemented a low-cost intelligent lighting system capable of reducing energy waste by 60% and CO_2 emissions. This system characterizing by collecting information from road users through PIR sensors and IR sensors. This allowed for controlling the intensity of lighting around the user's area without lessing his comfort and his security. Attia *et al.* [11] proposed a system that increases the efficiency of street lighting through the multi-level dimming of LED lamps instead of the two-level dimming, which will allow lighting to be provided according to the traffic density. The [12], [13] proved that the application of internet of things (IoT) technologies to street lighting systems contributes to the acceptable saving of energy as the IoT allows to connection control units of lighting units with each other and thus allows to effective monitoring and management of energy. Abdullah *et al.* [14] suggested reducing energy waste and carbon emissions and preserving the environment by replacing high-pressure sodium (HPS) lamps with light-emitting diodes (LED). Prasad [15] presented a remarkable study to reduce carbon emissions by obtaining energy savings of up to 55% per month for a street lighting system in an urban city by replacing old lamps with LED lamps and controlling their intensity through sensors. A smart network based on the IoT was used to monitor and control this system. Gagliardi *et al.* [16] introduced a smart, low-cost 80% power-saving system compared with traditional lighting systems based on the IoT through ZigBee connections and video processing algorithms for motion detection. Tukymbekov *et al.* [17] proposed an intelligent, adaptive and autonomous lighting system powered by solar panels. The results show that the system works to increase energy efficiency and sustainability and also operates in good and stable conditions. Gordic *et al.* [18] presented an analytical and economic study through the installation of LED corn lamps in street lighting high-density discharge lamps, which would allow for lower costs and increased energy efficiency. Sutil and Ortega [19] developed an algorithm called street lights regulation (SLR) for raising and increasing the energy sustainability, in order to control the level of illumination. This algorithm is based on the artificial bee colony (ABC) optimization algorithm, and the LoRa LPWAN network was used to monitor the system and collect data on energy variables. The large energy savings obtained were demonstrable benefits of the system.

The goal of the study was to develop and test a smart street lighting system capable of providing adequate lighting for the safety and security of street users while reducing energy consumption by implementing an adaptive lighting system that keeps lighting at a low level when no one is present, then lights up around the user and then conceals it after passing., Road user information is processed by the controller ESP32. The movement of road users is also tracked and detected by a motion sensor passive infrared (PIR). The bright region should come in front of the user rather than behind him or her. A system capable of sensing the movement of passers-by is required for this purpose. The system should also be able to handle a large number of road users at once. We sought to reduce the installation costs of the lighting poles by relying on a low-cost, fast wireless communication protocol called ESP-NOW, that allows the control units of poles lighting to connect with each other, which allows minimizing costs and keeping the infrastructure.

2. SMART STREET LIGHTING DESIGN AND CONTROL

The control was conducted at a realistic pedestrian testing site on the campus of Bechar in Algeria, consisting of 9 LED_s Street lights set on a wall, and the street is utilized by students or security agents. During the night, a weak traffic density characterizes this street during the night. Moreover, there is no such way to a side outlet. Figure 1 shows a picture of the pilot site.

An intelligent lighting control system with the ability to detect route user movement was tested in our pilot installation. As a result of this information, the lighting control was adjusted to illuminate the area ahead of a walker rather than behind them. The current lighting control system in the region was centralized. During the day's bright periods, lights were switched off, and during the night, all luminaires were turned on at a 30% control level. The goal was to create and evaluate an optimal lighting behavior that saves significant amounts of energy while maintaining traffic and safety, as well as route users' sense of security in the dark. When there are no road users, the minimum illumination level is 30%, and when there is movement around the user, the lighting level is 100%.

This research suggests a system designed for the pedestrian area so that users have a comfortable level of lighting with minimal necessary lighting. Figure 2 shows the design of the system. The system is controlled by three controller nodes each node consisting of a motion sensor passive infrared (PIR), ESP32 board and power supply unit. The proteus program was used for developing the control unit Figure 3(a) shows the block diagram and Figure 3(b) shows real picture of the control unit. In our work the first control unit was installed under the first street light (SL#1), the second control unit was installed under the fourth street light (SL#4), the third control unit was installed under the seventh street light (SL#7), each control unit controls three street lights, the first control unit SL#1, SL#2and SL#3, the second control unit SL#4, SL#5 and SL#6, the third control unit SL#7, SL#8 and SL#9.

Wireless solutions are in great demand in situations where high-speed data transmission is not required but tiny, low-cost, and autonomous (low-power) terminals with secure and reliable connections are required. Many of these applications need large-scale topologies with the lowest potential cost per node [12]. In our work, in order to reduce installation costs and optimal control of the system, a secure and fast wireless communication protocol called ESP-NOW was used to exchange street users' information between the control units to provide suitable lighting for the used area and this is what we considered a solution to ensure pedestrian comfort and energy saving.

Figure 1. Picture of the pilot site

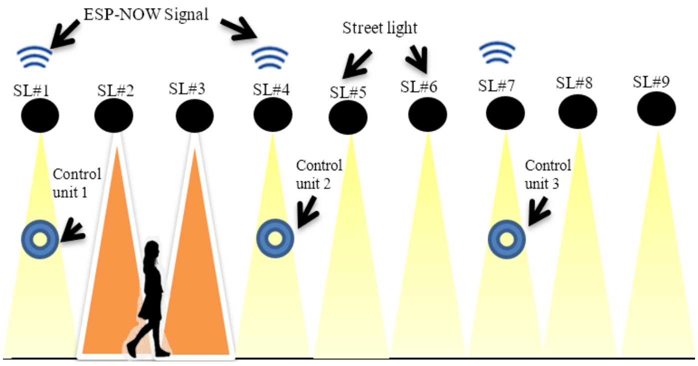
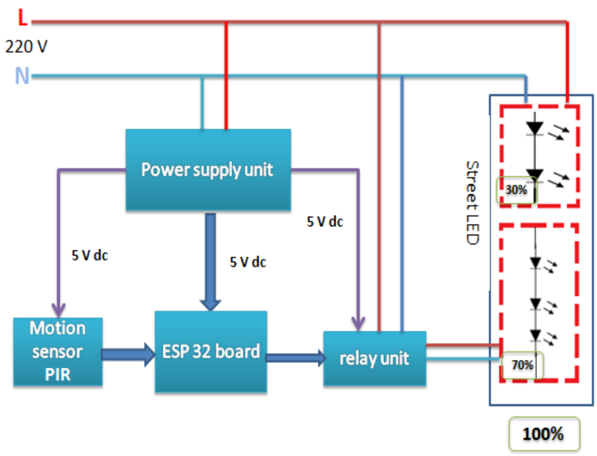
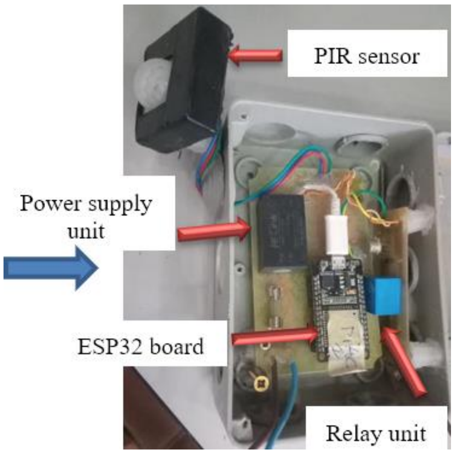


Figure 2. The design of the system



(a)



(b)

Figure 3. Design of control unit for (a) the block diagram of system and (b) real picture of the control unit

2.1. ESP32 board

ESP32 board is similar to an Arduino board; the ESP32 was built by Espressif Systems and is a system on a chip (SoC) microcontroller dual core [20]. The ESP32 has a low power consumption and low cost intended for internet of things (IoT) and embedded applications and is the successor to the ESP8266.furthermore, ESP32 board can interface with other systems to provide Wi-Fi and Bluetooth functionality through its SPI/SDIO or I2C/UART interfaces. In addition, it is often programmed by an Arduino IDE which allows loading of a program whose language is a set of C/C++ functions into the board by USB cable [21], [22]. In our work we used ESP32 DEVKIT V1-DOIT version with 30 $GPIO_S$. Figure 4 shows a summary of the hardware of the ESP32 board.

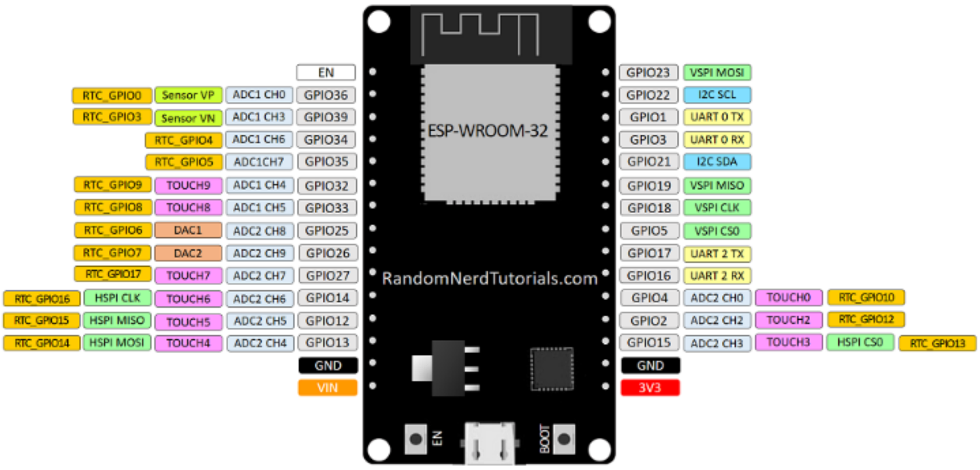


Figure 4. Summary of the hardware of the ESP32 board

2.2. PIR motion sensor

We provide a passive infrared (PIR) sensor system for movement tracking in this paper. PIR sensor is passive sensor. The main goal of using the PIR sensor is that it can detect moving objects by detecting the difference in infrared radiation between the “segments “in its range of vision [23]. The disadvantage of PIR sensing is that it can be disrupted by other sources of thermal energy, such as engines and temperature fluctuations in the environment. Furthermore, because the detection is reliant on temperature changes, the target must move or additional procedures, such as infrared radiation chopping or sensor rotation, must be utilized [24]. When movement is detected at distances of up to 7 meters in a 120-cone field of view, this sensor provides a logic high signal. PIR sensors are widely integrated into many applications due to their great reliability in object detection as well as their small size, low power consumption and low price. In our work, a HC-SR501 PIR sensor is used. Figure 5 shows a picture of HC-SR501 PIR sensor.

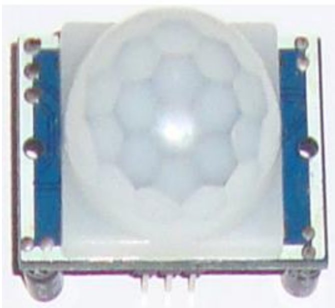


Figure 5. Picture of HC-SR501 PIR sensor

2.3. ESP-NOW protocol

ESP-NOW is a protocol developed by Espressif, ESP-NOW is a communication protocol with brief packet transfer. This protocol makes it simple for several devices to communicate with one another [25]. By using the Wi-Fi protocol, ESP-NOW can connect, transmit, and receive up to a 250-byte payload. This protocol allows for unencrypted peers; however, the total number of unencrypted peers should be 20 or less, including encrypted peers. This protocol enables information exchange without the need for a Wi-Fi station or router. Furthermore, if one of the boards unexpectedly loses power or resets, it will immediately reconnect to its peer to continue communicating when it resumes [26]. EPN-NOW works just with devices was developed by Espressif, although its range is 2.4 GHz, this type of communication, it can send information to the most distance through a bridge, for example by using ESP32 board where each board sends the data to its peer until the data reaches its purpose, there are some experiments that have been formed a bridge more than 700 meters using this protocol. To interact through ESP-NOW, you must first determine the MAC address of the ESP32 receiver. That is how you determine which device will get the data. Each ESP32 has a unique MAC Address, which we use to identify each board when sending data to it using ESP-NOW.

3. CONTROL SCENARIO

A lighting scenario is designed in line with the specificities of the installation site equipped with surveillance cameras so this designed scenario is capable of providing lighting conditions in which the lit area extends six times more in front of the user than behind allowing surveillance cameras to capture clear images of pedestrians. Moreover, the road user cannot detect lighting changes. Figure 6 shows the algorithm adapted to street lighting proposed.

The Figure 7 shows the changes in lighting along the route of the street user from the moment he enters the system until his exit When no user is along the street, the light intensity of all LEDs is 30%, referring to the design of the lighting system shown in Figure 2 and using the control scenario shown in Figure 7, the system works as follows: using PIR sensor, the detection of any movement of a street user by any control unit. The control unit raises the brightness of the LED lights that it controls to 100%, then sends a message by ESP-NOW to the next control unit, which in turn raises the intensity of the LED lights it controls to 100%, and thus there will be six LED lights with intensity 100% on the street user area and the LED lights that behind the user will decrease to 30%, and this will ensure his comfort and safe.

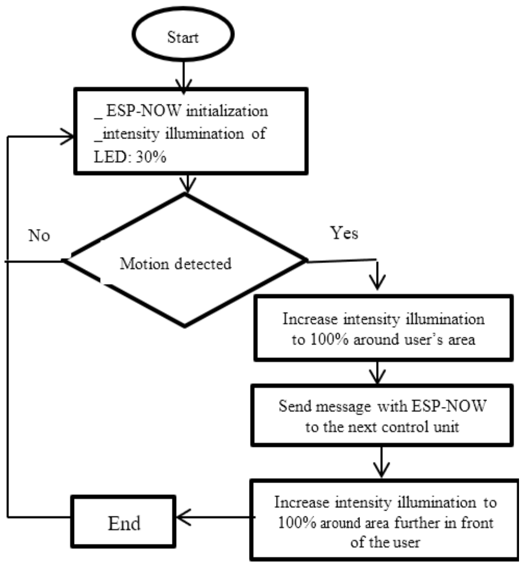


Figure 6. The algorithm adapted to street lighting proposed

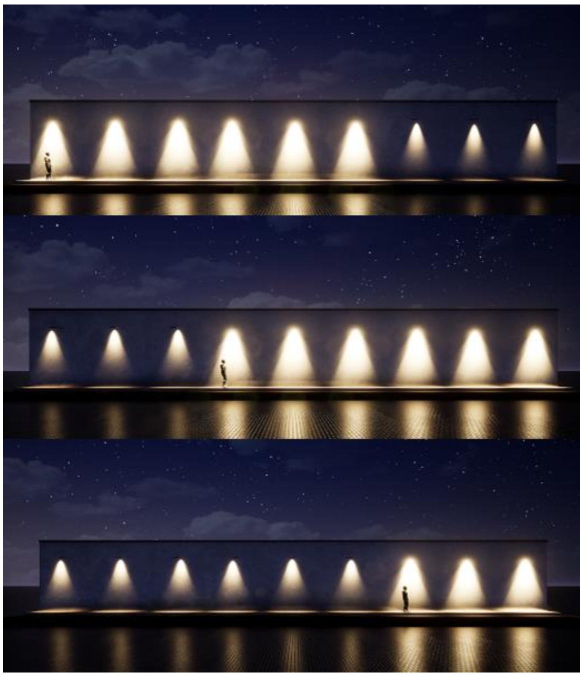


Figure 7. Control scenario

4. RESULTS AND DISCUSSION

To order to know the energy efficiency of the proposed system we compared and analyzed the energy consumption results of the street lighting system before and after the installation of the proposed system, we used two methods to calculate the energy consumption: the first method, a dSPACE controller board was employed as the central control platform. It allows MATLAB/Simulink/control desk to communicate with the actual hardware platform. To do this, the dSPACE 1104 with its RTI environment and interfaces is connected with current sensor LV25-P and the voltage sensor LA25-NP for calculates the energy was consumed by system. The second method we used an energy counter. Figure 8 shows experimental block diagram of calculating energy consumption. The energy consumed was calculated in an hour was calculated using the dSPACE 1104 controller bored before and after installing the developed smart system at installation pilot site.

The Figures 9(a)-(c) and the Figures 10(a)-(c) show the experimental results obtained for the variations of voltage, current and power during an hour before and after installing the proposed system in the pilot installation site on campus street, which consists of 9 LED lamps. From Figure 9, it is observed that the current, voltage and active power remain constant throughout the study time (I_{MAX}=20 A, V_{MAX}=315 V, P=1900 W) and the energy consumption by the lighting system is estimated at about E=1.8956 KW/h. From

Figure 10, it is observed that the variations of current and power were constant during the period 0 to 1400 s at I_{MAX}=10 A and P=770 W because movement was absent during this period, in addition to that, the intensity of illumination for all LEDs was 30%. At the time of 1400s, we observed an increase in the value of the current and the active power; this indicates the presence of movement in the street. From the current and active power data, it is clear that the system was able to detect the movement of pedestrians along the street. The energy consumed by the lighting system is estimated at about E=0.905 KW/h. Therefore, the energy savings obtained in one hour reached 52.25%. Using the energy counter, and before installing the proposed smart system, we calculated the energy consumed by the lighting system located in the pilot site during the night (7:30 pm - 7 am) after the proposed smart system was installed; we calculated the energy consumed by a lighting system during five consecutive days using the scenario shown in the document. The Figure 11 shows the results obtained for the energy consumption before and after the installation of the proposed system.

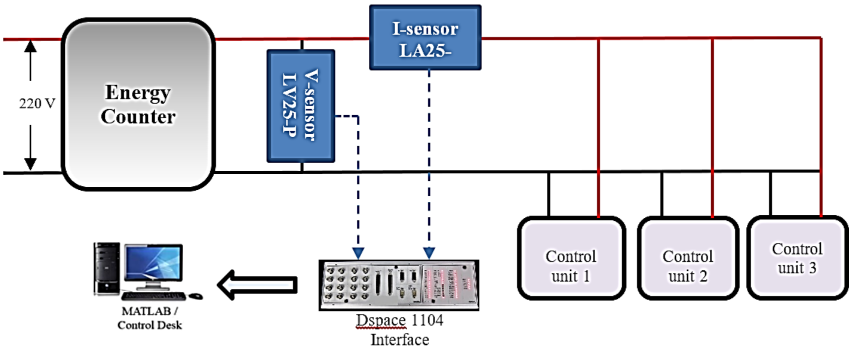
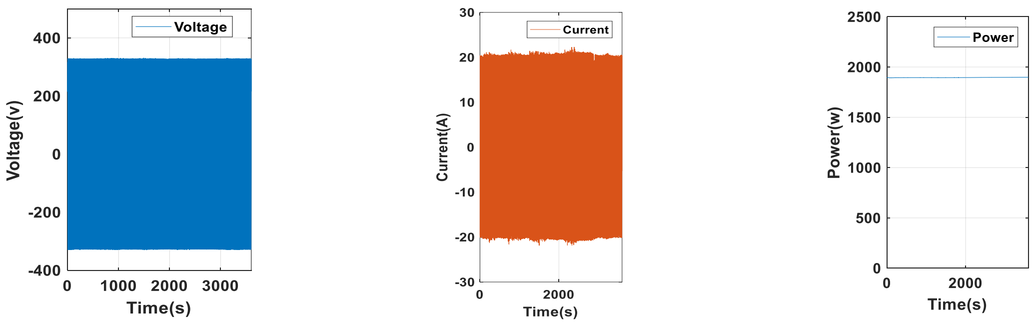
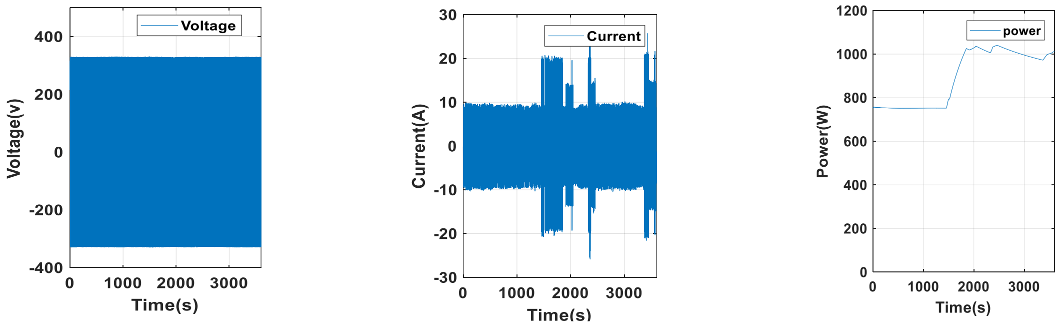


Figure 8. Experimental block diagram of calculating energy consumption



(a) (b) (c)

Figure 9. The experimental results obtained before installing the developed smart system for (a) voltage, (b) current, and (c) active power active



(a) (b) (c)

Figure 10. The experimental results obtained after installing the developed smart system for (a) voltage, (b) current, and (c) active power

Through the experimental results obtained shown in the Figure 11, we note that after installing the developed system, there is a decrease in the energy consumed by the system by about 47.1% to 60% but we noticed that the system is affected by the wind and this is because the sensor is only installed in an experimental box, it is affected in a way It is directly affected by natural factors, especially the winds that move it, which results in false discoveries, which will inevitably increase energy consumption, and this is what we noticed during the experiments, especially in the two days 18/04/2022, 22/04/2022. The developed system, which was piloted in a real campus use environment, demonstrated its ability to implement adaptive lighting as planned in the proposed scenario. The experiences gained by calculating the energy consumption before and after the developed system proved that the system proved effective in improving energy efficiency in addition to that it was effective in the outdoor environment.

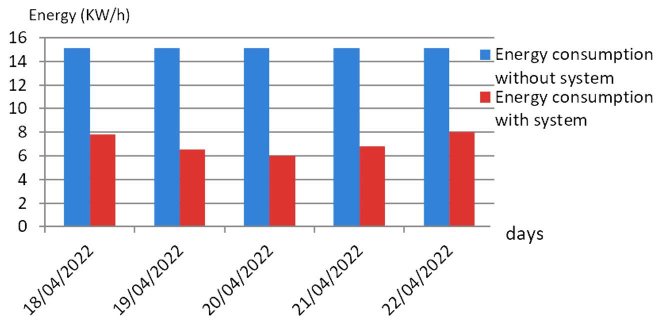


Figure 11. The energy consumption before and after the installation of the proposed system.

The motion sensor (PIR) was used in the developed system was effective in detecting pedestrian movement once a street user entered a sensitive field of view. One of the features demonstrated by this sensitivity is that even if the user's movement was weak or the user was immobile, this sensitive device was able to detect it allowing the user's area and the area in front of him/her to remain 100% lit, allowing the user's security and safety. False detections in inclement weather can lead to an increased level of illumination on occasions when no one is already present. This will increase energy consumption [24]. By relying on cheap devices and sensors, the cost of installing the developed system in the experimental site was inexpensive, in addition to that, relying on a low-power wireless communications ESP-NOW protocol was very important because it helped make the system more flexible by transferring data between control units quickly and at the lowest costs. Relying on LED lights has contributed to increasing energy efficiency and sustainability, in addition to LED lights providing practical solutions for decreasing the detrimental impacts of light pollution [27].

5. CONCLUSION

This paper presents an intelligent, adaptive and effective control system to improve the performance of street lighting systems, which was implemented in a real experimental site inside the campus. This system relies on cheap and effective devices and sensors; in addition to that, it relies on fast and low-power wireless communications, which made the entire system low-cost. In terms of installation, the system has become more flexible and can manage the movement of more than one user on the street at the same time.

Through the experimental results obtained, the system proved its utility in decreasing the energy consumption overall, and this is by obtaining energy savings of more than 50%; these have a large economic impact and have an influence on environmental sustainability. For future work, we aim to provide our system with different sensors and algorithms that are more dynamic. We also plan to transfer and implement our system in places outside the campus, which will allow more study than will allow it to be developed and adapted to different environments.

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