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Implementation of Embedded System for Energy Efficient Office using Image Processing

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***Abstract*—Due to the continuous increase in energy consumption in the world, there is an urgent need to reduce it and to implement a smart system for control energy consumption. Particularly in large offices, schools, and institutions, inefficient lighting usage persists, contributing to unnecessary energy consumption. The purpose of this research is to leverage image processing and sensor technology to address this issue effectively. In this research, image processing and sensor technology were used to reduce the aforementioned inefficient lighting consumption for intelligent energy management. Our previous research has demonstrated that through the implementation of appropriate algorithms, inefficient lighting use can be effectively controlled. The implementation of the embedded devices required for the developed algorithm of the energy control has been successfully completed. In this paper, realtime controlling lights by using image processing is explained. In the system implementation, "Jetson Nano" microcomputer, "Maix Bit" microcontroller, Siemens S7-1200 programmable logic controller and sensor (camera) have been used as part of the embedded development system.**

Keywords—smart grid, energy control, microcontroller usage, energy efficient algorithm, remote sensing

I. Introduction

Energy consumption in buildings represents a significant portion of total energy usage. Globally, buildings account for 30% to 45% of energy demand. In the United States, for example, buildings use approximately 40% of total primary energy, with lighting alone accounting for 20% to 35% of their operational energy consumption. Also in the UK, lighting systems constitute 11% of energy consumption in residential buildings, whereas lighting accounts for about 21% of energy used in office spaces [1-2].

Many countries' governments are actively promoting energy efficiency campaigns. Studies indicate that motion by combining sensors, microprocessors, and wireless communication technologies. In those indicated studies, lighting control input data were gathered using sensors like heat sensors, piezoelectric sensors, PIR sensors, microwave Doppler sensors, ultrasound sensors, WIFI sensors, motion sensors, light sensors, and infrared sensors.

In addition, lighting contributes significantly to global electricity consumption, with a notable impact in Europe, where lighting accounts for 40% of electrical energy use in buildings and 35% of carbon dioxide emissions. The other previous researches introduce the potential of LED lights as an efficient alternative to traditional lighting due to their lower power consumption and longer lifespan. While LED technology has been adopted, there is still a gap in widespread implementation of advanced control systems, such as dimming or motion-based adjustments, primarily because of high costs, installation challenges, and maintenance issues. The papers propose solutions by integrating a low-cost, wireless sensor network (WSN) that automates lighting control, adjusts intensity based on occupancy and ambient light, and can be retrofitted into existing systems.

The use of Zigbee communication protocols ensures scalability, making the system suitable for both small-scale and large buildings. The main contributions of the introduced works include the design and deployment of a low-power, adaptable LED control system and its validation through long-term real-world experiments, where the system achieved up to 55% energy savings. And the related works provide an overview of existing research and systems in the field of lighting control, distinguishing between wired and wireless solutions. Wired systems, while effective, are costly due to extensive cabling and difficult to retrofit in existing buildings. This makes wireless systems, such as those based on WSN, more attractive for energy management in smart buildings.

Previous studies, including those cited in this paper, have explored various control strategies using occupancy sensors and daylight monitoring. However, many existing systems focus on wired networks, which are less flexible and more expensive than wireless solutions. Research has also been done on using wireless sensors to adjust lighting levels based on user preferences and environmental conditions. However, the papers highlights that prior work has generally lacked long-term, real-world deployment and evaluation, or has used proprietary systems that are expensive and difficult to integrate. The previous proposed systems differentiates itself by offering a low-cost, scalable solution with distributed intelligence, which can control LED drivers directly without needing an expensive central controller. Additionally, the use of Zigbee technology allows for scalability and flexibility, supporting large-scale deployments while maintaining low power consumption. The authors also point out gaps in previous systems, such as the absence of comprehensive power consumption data and issues with cost and practicality. The some introduced works aim was to address these gaps with their innovative solution, providing detailed experimental validation and focusing on both user satisfaction and energy savings [3-9]. But, they also lack object classification capabilities; they can sense the movement of objects but cannot discern between types of objects human or non-human.

Our previous research paper presented an approach to lighting control system in office environments, employing a human detection algorithm that analyzes camera system data through image processing techniques. The experimental setup utilized advanced hardware configurations such as the "Raspberry Pi 4 Model B" microcomputer and "Maix Dock" for embedded development. Also for privacy, the image processing algorithms applied techniques like blurring images during analysis [10]. The execution time of the trained algorithm in the previous study was a maximum of 63.98 ms and a minimum of 10.8 ms for the Raspberry Pi 4 Model B microcomputer, while for the MaixBit microcontroller, it was 103.6 ms and 53.2 ms, respectively.

This paper introduces the implement of the smart lighting control system, based on our previous research work. It includes following headings: Research method, introduction for proposed system, experimental results, conclusion and references.

II. RESEARCH METHOD

A. Machine Learning Method for the Smart Lighting System

The research work introduced a simple and smart lighting control system for large and regular offices, schools, and institutions. The method operates by lighting control based on human presence in the environment, utilizing a camera for accurate human recognition [10]. Previous other methods typically divided into two categories: traditional image processing approaches and artificial intelligence algorithms and machine learning techniques [11]. For the artificial intelligence algorithms implementation Jetson Nano microcomputer is mostly used. The Jetson Nano is a small, powerful AI computer that allows you to run multiple neural networks in parallel.

In this research, machine learning methods were used, such as supervised learning methods and Deep Neural Network. The Python programming language, TensorFlow Lite, HaarCascade, OpenCV, numpy, imutils, and argparse libraries were used in the training process. Node-RED server and TIA Portal software were used in the implementation process for controlling algorithm.

Initially, a machine learning method is employed to train a model specifically designed for human recognition using MaixDock microcontroller. This model continuously reads real-time camera data, uploading it in to the trained model. When a person is detected within the environment, the system activates the lighting by sending a control signal. Conversely, if no human presence is detected, the system initiates another signal to deactivate the lighting. This systematic approach not only ensures efficient lighting control, also can energy savings by eliminating unnecessary energy consumption [10].

B. Proposed System

In this system, a trained human recognition model is uploaded onto the “Maix Bit” microcontroller. This microcontroller interfaces cameras to capture input data. Once person detected in the camera, a signal will transmitted via serial communication to the “Jetson Nano” embedded microcomputer. Subsequently, the “Jetson Nano” processes the signal and sends a control signal to a programmable logic device that control the end-device, in this case, the lighting system.

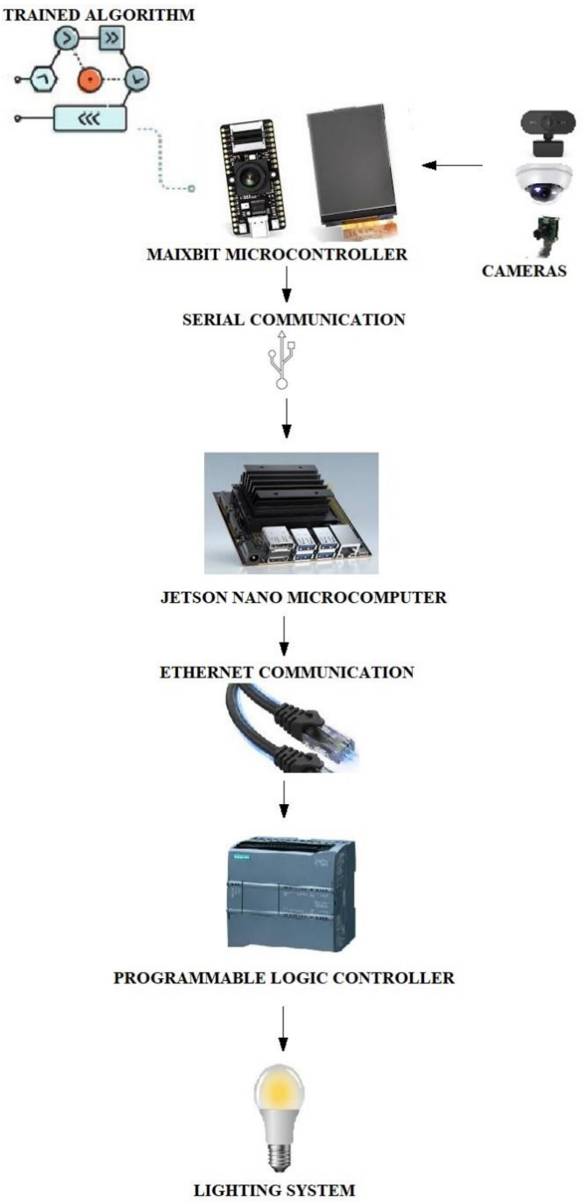

Fig. 1. Proposed smart lighting system

This integrated approach ensures efficient person detection and responsive control of lighting, enhancing energy conservation efforts within the environment. The proposed smart lighting system is illustrated in Fig. 1. Then, our proposed algorithm is shown in Fig. 2.

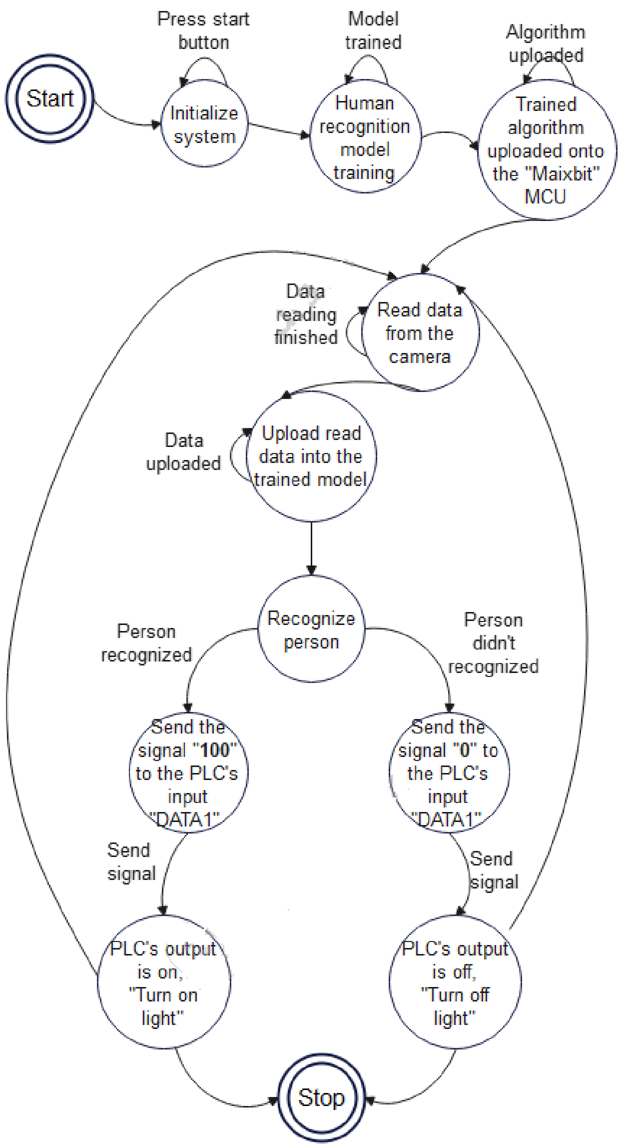

Fig. 2. Proposed algorithm

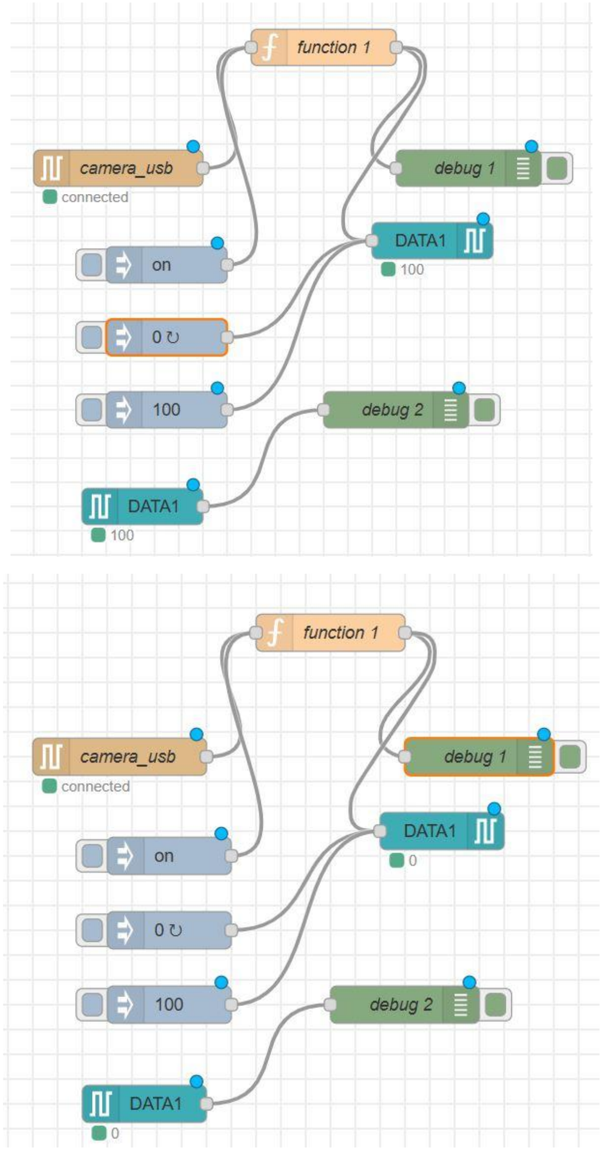

Fig. 3. Smart lighting system on the NodeRED server

III. Experimental Results

In the experiment of this proposed system, the "Maix Bit" microcontroller used to a person recognition process by using a trained model from camera information. If a person is recognized on the camera, a signal will be sent to the "NodeRED" server on the "Jetson nano" using serial protocol, it is presented in Fig. 3. Then, the ethernet protocol is used to transmit control signal to tags of programmable logic controller (PLC). Зураг 3 тайлбар

On the NodeRED server, a control node for sensors and actuators that will work according to the proposed algorithms has been created. The system will work following queues:

- The *'camera_usb'* node has been created to transmit information through the serial interface using a configuration of 115200 Baud Rate, 8 Data Bits, No Parity, and 1 Stop Bit. When a person is detected using the embedded microcontroller, it sends the signal "on". This image process using AI model is executed on the Maix Bit microcontroller.
- The "debug 1" node in Node-RED is used to monitor the data flow and ensure that the data is correctly sent to the PLC.

Fig. 4. Debugging window

- Fig. 4 shows the result, when a person is detected in the image processing, the signal "100" is being sent to the PLC's data block named 'DATA1'. Otherwise, the signal "0" is being sent to the PLC's data block named 'DATA1', respectively.

According to the debugging window illustrated in Fig. 4, it can be seen that when a person is detected by the camera, a signal of '100' is sent via the Node-RED server, and it takes 1 sec for the signal to reach the PLC. However, when there is no signal indicating a detected person, a signal of '0' is sent after 1 minute to the PLC's data block named 'DATA1'.

From this, it can be observed that the total operating time of the system, compared to the results discussed in our previous study, depends on whether the Raspberry Pi or MaixBit microcontroller is chosen. The maximum time is 163.98 ms and 203.6 ms, while the minimum time is 110.8 ms and 153.2 ms, respectively.

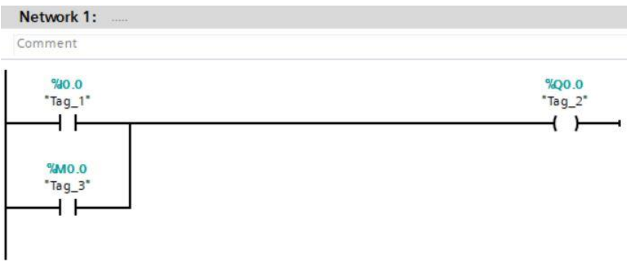

Fig. 5. Ladder diagram for PLC to control lights

- "iot_data" Data block is created by DATA1 tag to get input signal for control output tags on TIA Portal software of Siemens. Output tags can be connected controlling actuators, in this case it will be lights. Ladder diagram is presented in Fig. 5.

Fig. 6. Image processing and controlling of end-device's experimental results

The image processing and output tag's results are successfully carried out and it is illustrated in Fig. 6.

It is possible to calculate energy savings based on the lighting power in the sector where the camera is located.

IV. CONCLUSION

In this research paper, the development of an energy-efficient consumption control system and the comparison of the hardware and software of the development devices were considered. From the experimental result of the developed system, it was seen that the combination of PLC and AI-based embedded system can perform office lighting control system.

In the future work, there is planned to expand this experiment to execute the image processing system with high speed, to obtain a more reliable recognition artificial intelligence model, and to reduce the size of the model file and deploy it on a real embedded system.

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