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Cloud and Sensor-based Automation using Field Programmable Gate Array (FPGA)

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***Abstract*—Cloud automation is one of the most promising and upcoming applications of IoT [1], as it allows users to control and monitor their environment remotely. Adopting the Internet of Things (IoT) in the automation industry has created an amazing opportunity to develop intelligent, automated systems. These systems can improve users' energy efficiency, security, and convenience. However, most automation systems based on microcontrollers may not be able to handle the complex and various tasks required in a modern environment. Field Programmable Gate Arrays (FPGAs) replace microcontrollers, providing a more powerful, flexible, and scalable solution for the latest automation systems [2]. FPGAs can perform multiple functions simultaneously, making them ideal for managing large amounts of sensor data and controlling signals in real-time. Moreover, FPGAs are reconfigurable, enabling custom application creation and new features catering to the user's specific needs. The ecosystem can also include voice assistants and AI-powered systems to learn user preferences and automate tasks. To create an effective ecosystem, devices must be compatible and communicate through a standard protocol like Bluetooth, Zigbee, Z-Wave, or Wi-Fi [13]. The ecosystem should also protect user privacy. A well-designed ecosystem can simplify daily tasks, increase comfort and convenience, and provide peace of mind by allowing users to monitor and control their systems remotely.**

***Index Terms*— Home automation, IoT, FPGA, PIR sensor, LM35, HC-SR04, LDR, ESP8266.**

I. INTRODUCTION

In the present era, the ubiquity of convenience has become indispensable for individuals. Automation represents an exemplary solution that provides convenience and fosters energy efficiency. By creating routines that enhance the quality of life, automation offers a multitude of benefits. To this end, we have introduced an FPGA-based home automation system designed to control specific appliances. An extensive literature review has been undertaken, revealing the lack of a system that eliminates the need for non-essential appliance control while enabling users to control them through a cloud-connected app that can be accessed remotely. The app provides users the ability to override the sensors and directly control the appliances. Conventionally, microcontrollers have been employed worldwide for IoT applications [3]. However, FPGAs are more flexible, scalable, powerful, and reprogrammable [2], allowing for the creation of custom applications and the implementation of new features along the way.

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A. Energy Conservation

Energy conservation is an important consideration for home appliances and energy efficiency [4]. Home appliances such as refrigerators, air conditioners, washing machines, and televisions are some of the biggest energy consumers in a household. Homeowners can significantly reduce their energy bills and carbon footprint by adopting energy-efficient appliances [5]. For instance, an energy-efficient refrigerator can save up to 40% on energy costs compared to a conventional model. [6] Similarly, a washing machine with an Energy Star rating can save up to 25% on energy and water consumption. Simple practices such as turning off appliances when not in use and using power strips can also help conserve energy and reduce electricity bills. By prioritizing energy conservation, homeowners can contribute to a sustainable future while benefiting from cost savings.

B. Ultrasonic Sensor

The HC-SR04 Ultrasonic Distance Sensor serves the purpose of detecting an object's distance through the usage of sonar. This sensor functions through the employment of non-contact ultrasound sonar technology consisting of two ultrasonic transmitters, a receiver, and a control circuit. The transmitters emit high-frequency ultrasonic sound waves that reflect off any adjacent solid objects, while the receiver listens for the return echo. The control circuit processes the echo received, enabling it to calculate the time differential between the transmitted and received signals. This duration is utilized to determine the distance between the sensor and the reflecting object.

C. Temperature sensor LM35

The LM-35 is a three-terminal device that produces an analog voltage that is linearly proportional to the ambient temperature. The voltage across a diode rises correspondingly with the surrounding temperature, and this voltage is then amplified and delivered through the output terminal. The LM-35 is conveniently obtainable in a TO-92 package and is easy to utilize. Furthermore, its operating voltage ranges from 4 to 20 volts, and it exhibits an accuracy of 0.5°C at 25°C.

D. Light-dependent resistor

This particular resistor operates based on the principle of photoconductivity, whereby the conductivity of the material is reduced upon the incidence of light on its surface. The photons present in the incident light must possess energy greater than the band gap of the semiconductor material, which causes the electrons to transition from the valence band to the conduction band. It is worth noting that these devices are reliant on light, and as such, when the LDR is exposed to light, its resistance is reduced, whereas when placed in darkness, its resistance is high.

E. Passive Infrared Sensor

The PIR sensor does not radiate energy in space. Passive infrared (PIR) sensors use pyroelectric sensors to detect heat energy in the surrounding environment. These two sensors sit beside each other, and when the differential signal between the two sensors changes (if a person enters the room, for example), the sensor will engage. PMOD PIR is used for detecting motion at low power. With the EKMC1601111, its range is five meters.

F. PMOD STEP

This device is utilized to operate a stepper motor that features four or six control pins, and it employs GPIO interfacing. While it is capable of being operated at 3.3V from an FPGA, it is recommended that any external power supply used to drive a heavy motor be within the range of 4.5 to 36 volts. It is advised to operate PMOD STEP at 5 Volts for optimal performance.

G. PMOD SSR

The PMOD Solid State Relay is capable of blocking a maximum voltage of 48 volts and switching up to 6 Amps RMS of continuous current. Additionally, it features an integrated LED to signify the open and closed conditions of the circuit and exhibits low ON resistance during rapid switching.

II. Literature review

Several academic papers have been examined concerning the development of an automation solution using Field Programmable Gate Arrays (FPGA). In reference [7], the authors present a concept for wirelessly implementing a remotely controlled home system through the use of FPGA and WiFi. The Internet of Things (IoT) module, ESP8266, plays a crucial role in communicating with the cloud. The system allows for manual access through a mobile application to send data signals for turning ON and OFF the end devices. However, it relies on human intervention continuously. Therefore, we have devised a solution to embed different sensors and employ sensory data to send data signals automatically without any human intervention. In reference [8], the authors propose a solution to automate the home system using sensors and controlling end devices interfaced with FPGA without the need for human effort. This system also uses the ESP module to access the cloud. Nevertheless, there is no provision for manually overriding the actions taken based on sensory data, leading to unnecessary power consumption and decreased efficiency. In reference [9], the authors present a solution for developing a home automation system using Very High-Speed Integrated Circuit Hardware Description Language (VHDL) and FPGA. The Global System for Mobile (GSM) network facilitates communication between the mobile and the primary controller through Short Messaging Service (SMS).

III. MOTIVATION

The primary focus is to mitigate the physical exertion for elderly and disabled individuals and additionally enable remote monitoring and control of the device status through cloud-based systems from any location. Microcontrollers have been traditionally used all over the world for designing IoT applications. On the other hand, FPGAs are more flexible and scalable than microcontrollers, enabling them to cater to various diverse features and specifications [2]. The evaluation of these factors constituted a pivotal component of our home automation research. Our inquiry has revealed the difficulties confronted by those seeking to achieve home automation via sensors and IoT-controlled appliances.

IV. PROBLEM STATEMENT

A. Problem Domain

The present study delves into the complex challenges that arise when dealing with sensor interfacing, motor speed control, FPGA implementation, and system design in the domain of automation. These challenges have been thoroughly addressed and analyzed, and a comprehensive understanding of the issues involved has been gained. Moreover, the study goes further and explores the problem of automating the control of equipment when multiple individuals enter or exit a room. To tackle this problem, a novel solution in the form of a combination of sensor-based automation and a cloud-based IoT system has been proposed. The proposed system is expected to enhance the overall automation process by allowing for efficient and effective management of equipment control. The integration of these two technologies is envisioned to enable seamless communication between the sensors and the cloud-based system, thereby optimizing the automation process. This approach is also expected to increase the efficiency of the system and reduce the need for human intervention, thus minimizing the likelihood of errors and improving overall performance. In summary, this study has not only addressed the challenges associated with automation but has also proposed a cutting-edge solution to one of its most persistent problems. The proposed system has the potential to revolutionize the automation industry and usher in a new era of efficiency and precision in equipment control.

B. Problem Definition

The aim of this study is to design an end-to-end solution for home automation by utilizing the capabilities of FPGA, microcontrollers, and IoT. The primary objective of this research is to address the challenges associated with designing an integrated system that can efficiently control and monitor various home appliances and devices. The study will explore the potential of FPGA, microcontrollers, and IoT to create a robust and reliable home automation solution that can improve the quality of life for homeowners.

V. METHODOLOGY

A. Method

In this study, the automation of home appliances has been achieved through the utilization of sensors and IoT platforms. This approach involves the integration of a variety of sensors, including the PMOD PIR sensor, PMOD stepper, ultrasonic sensor, temperature sensor, and a light-dependent resistor (LDR). The Digilent ZedBoard Zynq-7000 Development Board [10] has been employed as the FPGA Board. The fan motor (stepper motor) has been connected to the FPGA using a PMOD STEP, while an LED has been connected to the FPGA using a PMOD SSR (relay). The speed of the fan is controlled by digital circuits, which generate four frequency levels, as implemented on the FPGA. The PMOD PIR, PMOD STEP, and PMOD SSR are connected to the FPGA, while the ultrasonic sensor, temperature sensor, and LDR sensors are connected to the NodeMCU.

As individuals enter the room and the counter (number of persons) increments, the appliances are automatically switched on. The motor speed is adjusted based on the room's temperature and light intensity, and the LED is also automatically switched on/off accordingly.

B. Innovative content

1. The implementation of a person entry/exit detection system that utilizes a combination of ultrasonic and PIR sensors.
2. A counter to maintain an accurate count of individuals is proposed. Moreover, the stepper motor's speed control is suggested to be done both manually and automatically, taking into account the ambient temperature.

   Fig. 3 is the circuit diagram of modules in Vivado that includes the clock divider, counter, MUX, relay, and driver for the motor. The circuit operates as follows:

1. A new clock named new_clk0 is generated.
2. This new_clk0 is given as a reference clock to the 3-bit counter, which generates three different frequencies of count0=new_clk0/2, count1=new_clk0/4, and count2=new_clk0/8.
3. These three counter outputs are given as the input to 4x1 MUX along with new_clk0, with the select lines s1 and s0.
4. With the help of select lines, different frequencies can be selected and given as input to the driver of the motor, which is named clk_for_driver, to get four different speeds.
5. When a person crosses the threshold distance set by the user for the connected Ultrasonic sensor, one of the pins on the NodeMCU board switches to a high or low state. This signal is then transmitted to an FPGA variable named Ultra_Sonic.
6. When the manual switch of the Blynk IOT [12] platform is turned on, LED_Control, which is sent from Node MCU to FPGA, is used to control the LED that is connected to PMOD SSR.
7. The input signal pir is obtained from the PMOD PIR, which is connected to the FPGA. Additionally, the LDR sensor is connected to one of the analog pins of the NodeMCU. This signal is then provided as input to the FPGA and is named "ldr". The circuit uses an internal clock of the FPGA named "clk" and has a reset pin "rst" that can be enabled to bring the circuit to its initial condition. Finally, the enable pin "en" controls the motor, which can only rotate if the enable pin is high.

Manual Control **-** When the level of manual control is set to a high value, it is possible to exercise control over the Motor and LED components by means of the Blynk IOT application [12]. The speed of the motor may be adjusted via the slider feature of the aforementioned application, and such adjustments may be made independent of ambient temperature. Similarly, independent control of the LED may be achieved regardless of input from the LDR sensor or ambient light conditions. Additionally, the status of the appliances, whether in the OFF or ON position, can be automatically or manually monitored via our mobile application.

Automatic Control **-**In the automated mode, we utilized an Ultrasonic sensor and PMOD PIR to activate the Appliances and keep track of the number of individuals present in the room. The outputs from the variable Ultrasonic and PIR sensors are utilized to regulate the count. The count is incremented when both outputs are HIGH, which in turn activates the appliances. After a specified time delay, both variables become low. This process repeats for every person entering the room. When the PIR is high (motion detected near the PMOD PIR sensor) and the Ultrasonic becomes low (distance detected by the ultrasonic sensor is increasing, implying someone is exiting the room), the count is decremented. Once the count reaches zero, all appliances are deactivated. Furthermore, we have implemented a case logic to regulate two actuators, namely LED and Motor. An LDR sensor is employed to regulate the switching condition of the LED. In addition, an LM35 temperature sensor is utilized to vary the speed of the fan in accordance with the room's temperature, providing four different speeds for four different temperature ranges.

VI. RESULTS

A. Manual Control is HIGH

In this system, the user is able to initiate the movement of devices as required, even from remote locations. The control lines s1 and s0 are utilized to determine the speed of the FAN (stepper motor) [11], resulting in the production of four distinct frequencies that are clearly depicted in Fig. 5 below. Similarly, the LED can be turned on and off by means of its control signal, LED_Control. If manual control is activated, the output remains unaffected by the presence or absence of individuals, and therefore COUNT[2:0] remains at 0 during simulation.

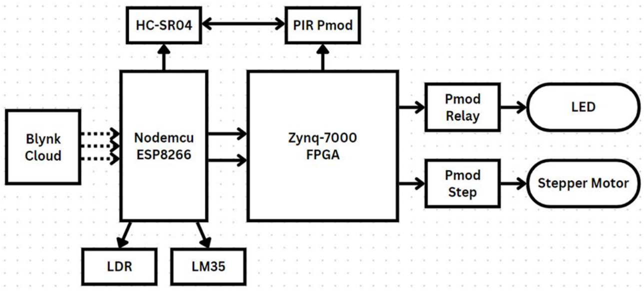

Figure 1. Block diagram

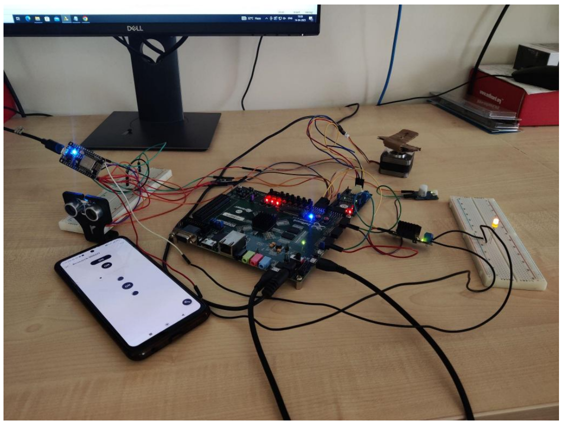

Figure 2. Lab Setup

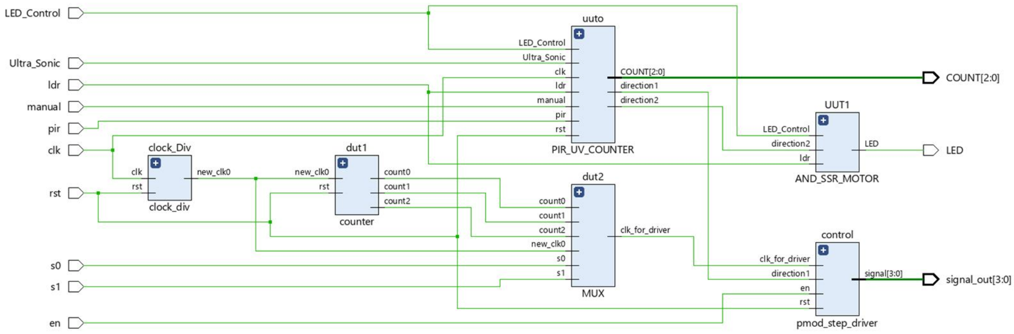

Figure 3. Synthesized circuit diagram on Xilinx Vivado

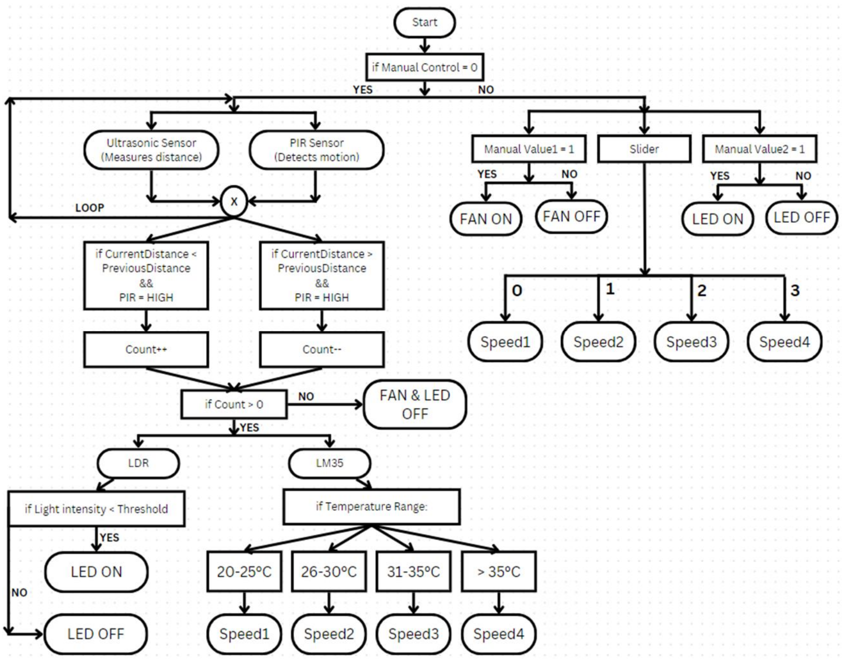

Figure 4. Full system Flowchart

The four frequencies, f1, f2, f3, and f4, which control the stepper, are selected through the use of select lines s1 and s0.

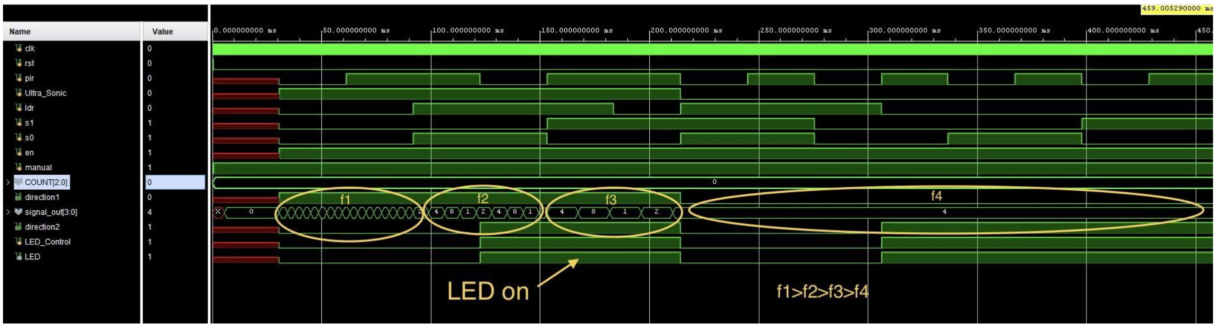

Figure 5. Simulation result of manual control using Blynk IoT

B. Manual Control is LOW

When the manual control parameter has a value of zero, the system utilizes the sensor outputs that are provided to the FPGA in order to arrive at a decision. It can be observed that as the PIR and Ultrasonic sensors attain a HIGH state, the count value is incremented. Conversely, when the PIR sensor attains a HIGH state and the Ultrasonic sensor attains a LOW state simultaneously, the count value is decremented. Assuming that the count value is positive and taking into consideration the temperature range that has been specified in the testbench, control signals s1 and s0 are generated, resulting in the corresponding frequencies of the FAN being observed. Similarly, the LED is switched ON or OFF based on the intensity of the light. The frequency with which the FAN rotates, based on temperature, can be observed from the circled parts. When the count value is zero, the direction1 and direction2 pins are set to a LOW state in order to turn OFF the end devices since there are no occupants in the home. The COUNT[2:0] parameter keeps track of the number of individuals entering or exiting the room.

Figure 6. Simulation result of automatic control using sensors

VII. CONCLUSION

The logic of automation has been implemented through the utilization of sensors and the cloud. A novel solution has been devised to address the issue of automation by relying solely on sensors, as the underlying logic is contingent on the number of individuals entering and exiting the room.

FUTURE SCOPE

The entirety of the circuit connections depicted in this illustration can be produced as a single Printed Circuit Board (PCB), as the complete design can be miniaturized [14], rendering it a superior choice for actual implementation within a home or office environment. The present research showcases the interconnection of merely two domestic appliances. However, due to the high pin count of the FPGA device, which offers an abundance of input and output channels for interfacing with various other devices, additional appliances may be integrated into this system. Furthermore, given the FPGA's exceptional data processing capabilities, a facial recognition feature [15] can be incorporated into this home automation system from a security standpoint. By implementing specific protocols and algorithms, the FPGA can be utilized to provide heightened security, as cybersecurity [16] is a significant threat to automation. The complexity of AI algorithms can be processed by the FPGA, utilizing an AI framework, which will augment the system's intelligence. As IoT devices become more prevalent, there is an increasing demand for low-power FPGAs that can handle the compute-intensive tasks required by these devices without consuming excessive energy. Ways to optimize the FPGA design to reduce power consumption while maintaining performance [17] is an important field to work on.

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REFERENCES

[1] Rahmani, A.M., Bayramov, S. & Kiani Kalejahi, B. Internet of Things Applications: Opportunities and Threats. Wireless Pers Commun 122, 451–476 (2022). https://doi.org/10.1007/s11277-021-08907-0.

[2] P. H. W. Leong, "Recent Trends in FPGA Architectures and Applications," 4th IEEE International Symposium on Electronic Design, Test and Applications (delta 2008), Hong Kong, China, 2008, pp. 137-141, doi: 10.1109/DELTA.2008.14.

[3] Wu, Z.; Qiu, K.; Zhang, J. Smart microcontroller architecture for the Internet of Things. Sensors 2020,20, 1821.

[4] Muhammad Zaman Fakhar, Emre Yalcin, Alper Bilge” Survey of smart home energy conservation tech,” October 2022, ScienceDirect.

[5] Lee, H., Ruppert, K. C., Porter, W. A., & Prescott, T. (2008). Energy Efficient Homes: Appliances in General. Retrieved from http://edis.ifas.ufl.edu/FY1032.

[6] R. Grisso, M.A. Walker, J. Ignosh, ENERGY SERIES: What about Refrigerators and Freezers?, Virginia Tech, February 2020, Retrieved from https://www.pubs.ext.vt.edu/2908/2908-9022/2908-9022.html.

[7] Aadesh Pawar, Shubham Gurav, Vanshika Parkar, Swarnima Patole, Satendra Mane“IoT based home automation using FPGA”2021, International Journal of Advance Research, Ideas and Innovations in Technology.

[8] S. Sharma, J. Boddu, G. S. Charan, S. Sharma, S. Sivanantham and K. Sivasankaran, "Home automation through FPGA controller" 2015, Online International Conference on Green Engineering and Technologies (IC-GET), Coimbatore, India, 2015, pp. 1-4, doi: 10.1109/GET.2015.7453813.

[9] M. R. Mukkawar, S.D. Sawant, “Home Automation through FPGA Controller” IJERT, vol. 3, March 2014.

[10] ZedBoard Zynq-7000 Development Board Reference Manual, Version 2.2, January 2014.

[11] Khan Zarrarahmed Zaferullah, Rajesh Bansode, S.N. Pethe, Mandar Vidwans and Kelvin Dsouza, “FPGA based Speed Control of Stepper Motor,” Volume 2, Issue 12, December 2013

[12] H. Durani, M. Sheth, M. Vaghasia and S. Kotech, "Smart Automated Home Application using IoT with Blynk App," 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), Coimbatore, India, 2018, pp. 393-397, doi: 10.1109/ICICCT.2018.8473224.

[13] S. Palaniappan, N. Hariharan, N. T Kesh, V. S, and A. Deborah S, “Home automation systems - a study,” Int. J. Comput. Appl., vol. 116, no. 11, pp. 11–18, 2015, doi: 10.5120/20379-2601.

[14] M. Suárez-Albela, P. Fraga-Lamas, T. Fernández-Caramés, A. Dapena, and M. González-López, “Home Automation System Based on Intelligent Transducer Enablers,” Sensors, vol. 16, no. 10, p. 1595, Sep. 2016, doi: 10.3390/s16101595.

[15] S. Chakraborty, S. Roy, and P. Kundu, "FPGA Implementation of Real-Time Face Detection and Recognition System for Home Security," 2019 IEEE 11th International Conference on Advanced Computational Intelligence (ICACI), 2019, pp. 620-625.

[16] Alexandre Proulx, Jean-Yves Chouinard, Paul Fortier, and Amine Miled. 2023. A Survey on FPGA Cybersecurity Design Strategies. ACM Trans. Reconfigurable Technol. Syst. 16, 2, Article 20 (June 2023), 33 pages. https://doi.org/10.1145/3561515.

[17] R. Sharma, A. Saini, and S. Mittal, "Low-power FPGA Design Techniques for IoT Applications," 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), 2019, pp. 999-1004.