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Real-Time Gas Leakage and Flame Detection System with Automatic Shutoff Mechanism

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Abstract: The Real-Time Gas Leakage and Flame Detector System with Automatic Shutoff Mechanism is created to increase the safety of the home kitchen with the help of multiple sensors and automatic hazard control. The system consists of MQ-series gas sensor to detect LPG leaks, infrared flame sensor to check combustion and cookware detection mechanism to check the conditions of the use of a stove. A microcontroller calculates real-time sensor data and categorizes the operation modes like normal cooking, gas leakage and unsafe conditions. Once such dangerous conditions are detected as either the presence of unburned gas or the presence of a flame without cooking utensils, the system turns off the gas supply. The shutoff actuator uses a stepper motor-driven actuator which rotates the stove knob 90 degrees allowing automatic control without altering the gas pipeline. An LCD module of 16x2 is used to give real-time status to the user. The proposed system can be used to reduce domestic risks due to LPG and it is cost-effective and can be retrofit-compatible by incorporating multi-sensor assessment, integrated control logic, and mechanical actuation.
Keywords: LPG Gas Detection, Kitchen Safety System, Stepper Motor Actuation, Potentiometer-Based Cookware Detection, Automatic Gas Shut-Off, Embedded Safety Control.

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) is widely applied in the kitchen of the house because it has a good thermal efficiency, it is easily stored and it has a relatively clean combustion behaviour. Although these are the benefits, there are inherent safety risks associated with LPG based cooking systems that include gas leakage and unsafe operation of the stoves. Within closed spaces, the concentration of combustible gas may cause fire risks, explosion or complications to health and thus domestic gas safety is a key research issue [1], [4]. Moreover, using open flame stove without cookware can lead to unnecessary burning of fuel as well as risk exposure. These safety issues bring to view the necessity of smart monitoring systems that are able to detect hazards and intervene on them through immediate action. The traditional domestic gas safety systems mainly emphasize on leakage detection and the production of alarm [16], [17], [19], [21]. Even though audible alert features may inform the user about abnormal conditions, these types of systems largely rely on human intervention and do not automatically prevent the source of threat. Where the user is not available or cannot respond immediately, the risk has not been contained. The recent progress in embedded monitoring systems and IoT-oriented safety architectures focuses on automatic detection and remote monitoring to increase domestic safety resilience [2], [11], [12]. Some of these implementations however are still restricted to alert-based mechanisms and not directly mechanical controlled [3], [8]. To overcome these shortcomings, the current paper discusses a Real Time Gas Leakage and flame detection system with automatic shutoff mechanism that incorporates multi-parameter sensing and mechanical actuation without altering the existing gas infrastructure. The system constantly measures LPG concentration with MQ-series gas sensor, confirms the presence of combustion with infrared flame sensor and detects position of cookware with threshold detection system based on a potentiometer. The microcontroller uses a combination of these inputs to analyse structured logical conditions and determine the stove operation into different states to include; system idle condition of the stove, normal cooking condition of the stove, gas leak condition of the stove, and no cookware condition of the stove. In the condition when the stove is off the system goes to a state of idle monitoring without assessing hazard conditions. When the system is in operation, the presence of cookware in the absence of a flame is detected and automatic shut-off is activated. On the same note, when the flame is not present and the concentration of the gas is more than a set limit, the system will sense the gas leak-off and will automatically shut-off. The intervention mechanism is carried out with the help of a precision stepper motor which turns the stove knob by 90 degrees, which is practically an inhibition of the gas flow by mechanical means instead of breaking the pipeline [14], [15]. Through real-time sensor fusion, deterministic embedded control logic, and retrofit-compatible mechanical actuation, the proposed system will change domestic gas safety to no longer be a passive alert-based system but passive hazard mitigation. The design is meant to focus on utility, cost-efficiency, and the feasibility of installation, thus fitting into the typical LPG stove setting without any structural changes.

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II. PROPOSED SYSTEM ARCHITECTURE

The suggested system design is based on combining multi-sensor monitoring with embedded control and mechanical actuation in order to make the gas stove safe to operate. The architecture comprises of sensing units, central processing unit, actuation mechanism as well as user display interface [5]. Every module plays a certain role but works in harmony according to some stipulated logical requirements.

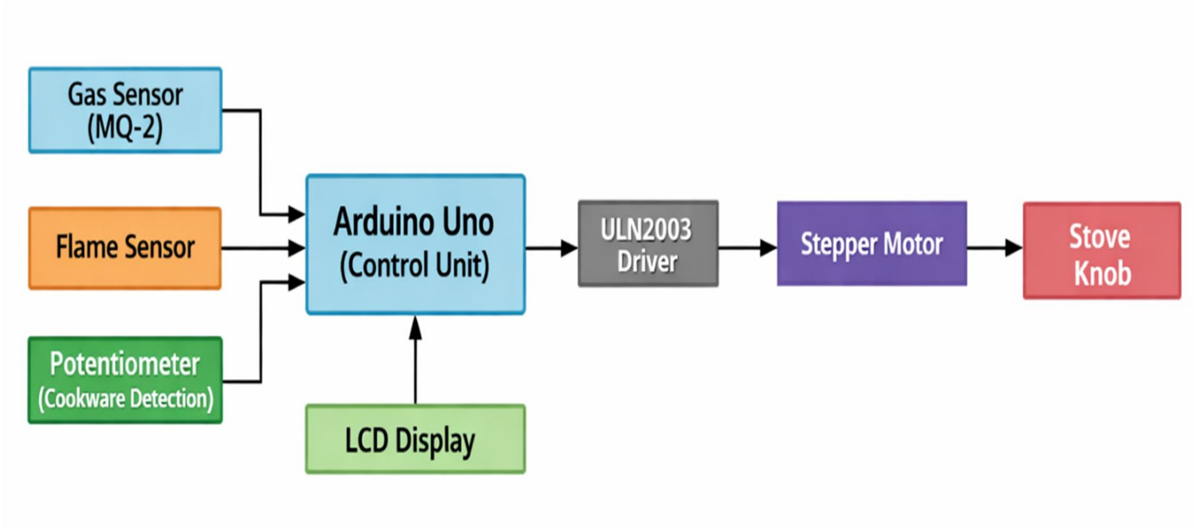

Fig. 1 : Block diagram of the proposed real-time gas leakage and automatic shut-off system.

Fig 1 demonstrates the block diagram of the proposed system. The sensing layer has three major inputs which include the MQ-series gas sensor that detects LPG, infrared flame sensor that verifies that there is combustion and the cookware detection input that consists of a potentiometer. The gas sensor is used to monitor the number of combustible gases in the surrounding environment at all times [13], [18]. The flame sensor gives digital feedback as to whether the flame is present or not. The potentiometer can produce an adjustable analog signal, which mimics the placement of cookware, so that threshold-based vessel detection is possible when conducting an experiment.

All sensor values are connected into the Arduino Uno microcontroller, which acts as the control centre [7]. The controller acquires real time data and applies organized conditional logic to analyse the current state of the work of the stove. Relying on the conditions assessed, the system identifies four unique states of operation whereby the system is in Idle state (stove OFF), normal cooking, and condition of no cookware and gas leak. A stepper motor connected with a ULN2003 driver module [14] makes up the actuation layer. In case a dangerous situation is detected, the controller sends control messages to the driver circuit that activates the motor coils in turn to move the stove knob by 90 degrees, effectively switching the stove OFF. This is a mechanical shut-off system that avoids any physical alteration of the gas pipes, increasing retrofit ability with already-installed domestic stoves. The user interface includes a 16×2 LCD module that is used to show real-time messages about the status of the system. The display gives good indication of operation states such as System idle, normal cooking, Stove OFF -No cook ware and Stove OFF -Gas leak. This enhances awareness to the user and there will be transparency in the operation of the system. In general, the system architecture focuses on the modularity, real-time monitoring, and deterministic safety control. The design will provide dependable and sensitive domestic gas safety management as a result of sensing, decision-making, and mechanical intervention being integrated into one framework.

III. HARDWARE DESIGN AND CIRCUIT IMPLEMENTATION

The proposed system is implemented in hardware via a microcontroller platform embedded system that is connected to sensing modules, a motor driver circuit, and a mechanical actuation system. The design assures of real time monitoring which is reliable and automatic shut-off during hazardous conditions.

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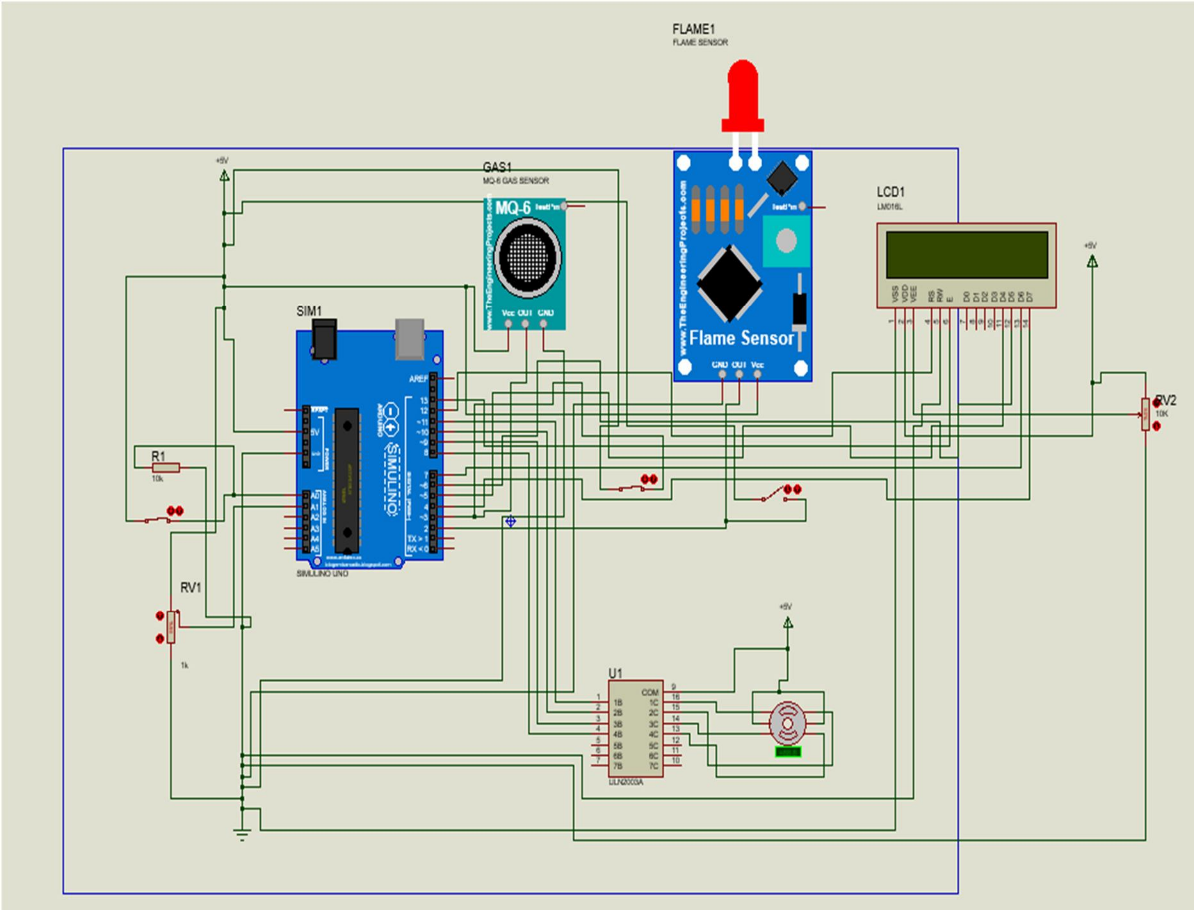

Fig. 2 : simulation circuit of the proposed gas leakage and automatic shut-off system using proteus.

Fig 2 gives the overall circuit diagram of the system. Arduino Uno, the microcontroller-based system is an ATmega328P that serves as the central controller and coordinator of sensing, logical evaluation, and actuation activities [15]. The analog input pin of the microcontroller to also constantly measure the concentration levels of LPG is connected to the MQ-6 gas sensor [13]. Gas leakage conditions are detected through a threshold-based comparison which is implemented in software because the sensor provides an analog voltage that is proportional to the presence of gases. The infrared flame sensor is connected to a digital input pin to check whether it is present or not. The sensor gives a logic-level output that enables the controller to check the presence of flame in the stoves that are in operation. This input is indispensable in differentiating normal cooking and gas leak situations. The prototype is detected with a potentiometer coupled to an analogue input channel to detect cookware. The potentiometer is a simulator of the presence of cookware, which produces a variable voltage level. An analog threshold is defined to say whether cookware is present or not. This design enables uncodified sensitivity to be used in testing and makes it easier to experimentally establish unsafe open-flame environments. The stepper motor is directly linked to the stepper motor to the stove knob to do an automatic shut-off. The motor is connected to a ULN2003A Darlington transistor array driver circuit that offers the required current amplification and electrical isolation [14]. A controller is used when a dangerous situation is observed, which then switches on the motor and rotates the stove by 90 degrees, switching it back to the OFF position. The system is also designed to include a 16x2 LCD module which is interconnected in 4-bit with the system, and which is used to present real-time operation states. The LCD offers system messages such as system idle, normal cooking, no cookware and gas leak, to make the user aware of the prevailing conditions. The whole hardware prototype works on a controlled 5V power supply [6]. The design was initially validated using the Proteus simulation environment before implementing the physical hardware prototype. Validation of simulation could be conducted with design tools before actual hardware is implemented but the actual hardware implementation proves the possibility of an integration of multi-sensors and controlled mechanical intervention.

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A. Hardware Prototype Implementation

The below Fig.3 shows the hardware implementation,

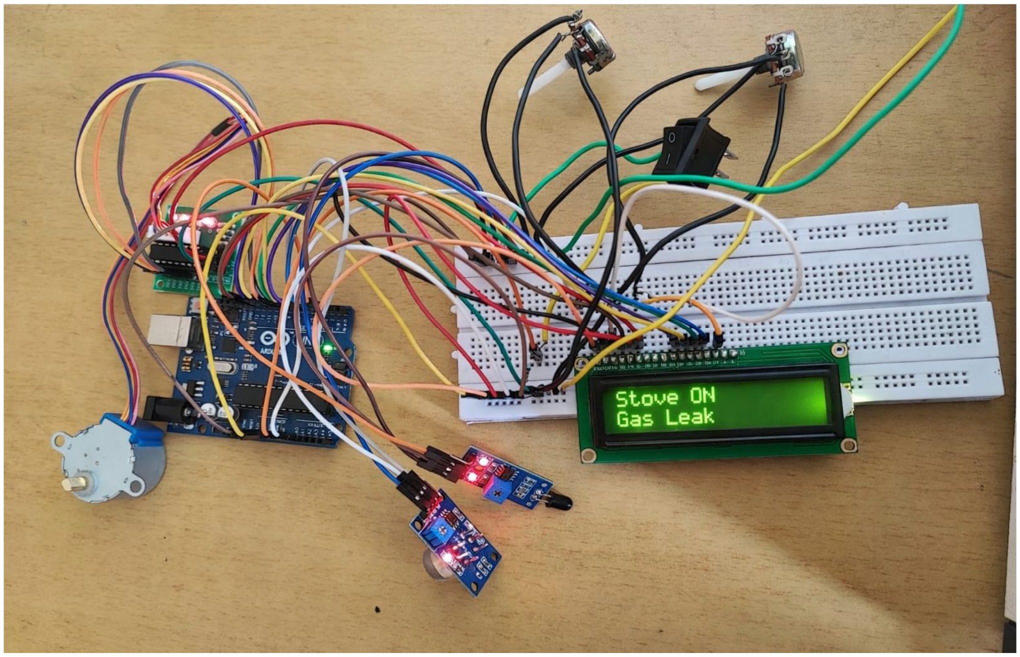

Fig. 3 : Hardware prototype of the implemented gas leakage detection and automatic shut-off system.

Fig 3 demonstrates the physical hardware prototype of the suggested system. Arduino Uno board, MQ-6 gas sensor module, infrared flame sensor, potentiometer-based cookware detection input, ULN2003A motor driver, stepper motor and LCD display were connected and tested at the laboratory. To be able to shut-off the stove precisely, the stepper motor was mechanically synchronized with the stove knob. The prototype justifies the practicability and retrofitting compatibility of the safety mechanism proposed.

IV. WORKING METHODOLOGY

The proposed smart gas stove safety system works according to the real-time monitoring and logical conditions analysis through multi-sensors input. The system continuously monitors the state of the stove switch, cookware detecting input, flame sensor and gas sensor and implements pre-set decision logic to maintain safe operation. The control algorithm is also installed in the Arduino Uno microcontroller to ensure immediate feedback in case of unsafe conditions [7].

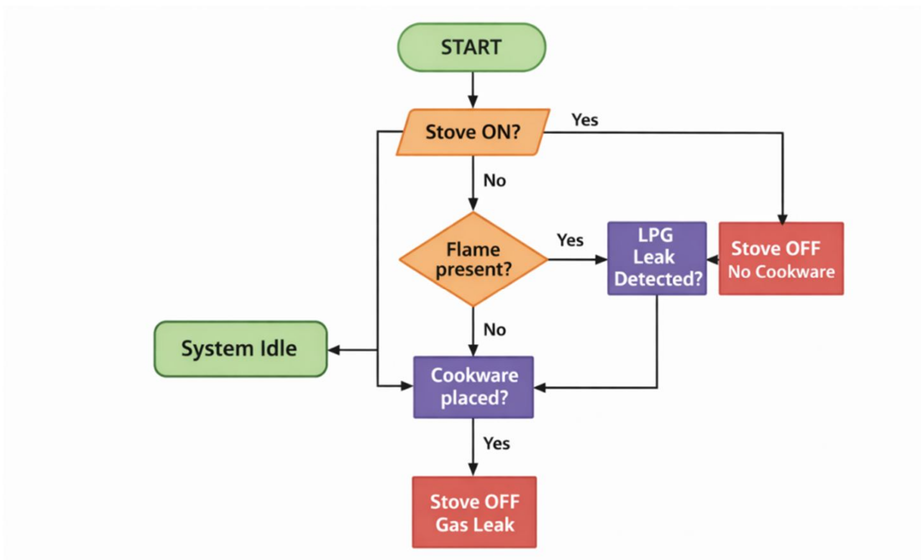

Fig. 4 : Flowchart of the proposed gas stove safety system logic.

The system first receives the switch to the stove as shown in Fig 4. When the stove is at the OFF state, the system will be in the idle state and the state of no-fault will be considered. This state has an LCD that shows System Idle -Stove OFF and the stepper motor is not moving. This will make sure that more sensor processing is not done even in cases where the stove is not being used. The controller starts monitoring the sensors continuously when the switch on the stove is switched to the ON position. The initial criterion measured is the presence of cookware. The input is simulated through a potentiometer which offers an analog voltage level that is used to represent cookware. In case a stove is on, there is no cookware, and flame is detected the system recognizes it as an unsafe open-flame state. The stepper motor then in turn rotates to switch the stove knob to off and the LCD displays Stove OFF No Cookware. The second emergency situation is when the flame sensor at the stove detects no flame but MQ-6 gas sensor states that LPG gas is present above the preset limit. This phenomenon is referred to as gas leakage condition. The stepper motor is turned on by the controller, which causes the stove to turn off and shows the LCD the text, Stove OFF -Gas Leak. Such quick response reduces the chances of fire hazard and gas build-up. In the normal cooking environment, i.e., the ON position of the stove, the existence of cookware, and the sensing of flame, the system carries its normal functioning. The screen of the LCD shows Normal Cooking, and no mechanical activity is activated. This will make sure that the intervention with respect to safety only takes place when there are abnormal or dangerous conditions. Sequential conditional logic is used in the design of the decision-making process, which gives the high-priority of safety-critical faults over normal operation [5]. The system response time also varies based on the sensor sampling rates and threshold calibration yet still falls within the realms of usefulness in a domestic kitchen safety need.

V. RESULTS AND DISCUSSION

The proposed system was validated through both Proteus simulation and experimental hardware testing to verify logical correctness and mechanical response accuracy. The safety system of the suggested smart gas stove was tested in experimental conditions to check its stability and the accuracy of response to the chosen operating conditions. The system was experimented through manually simulated tests to various combinations of the statue of the stove, the existence of cookware, the flame detection and the gas leakage conditions. The evaluation aim was to ensure proper logical performance, and automatic shut-off performance.

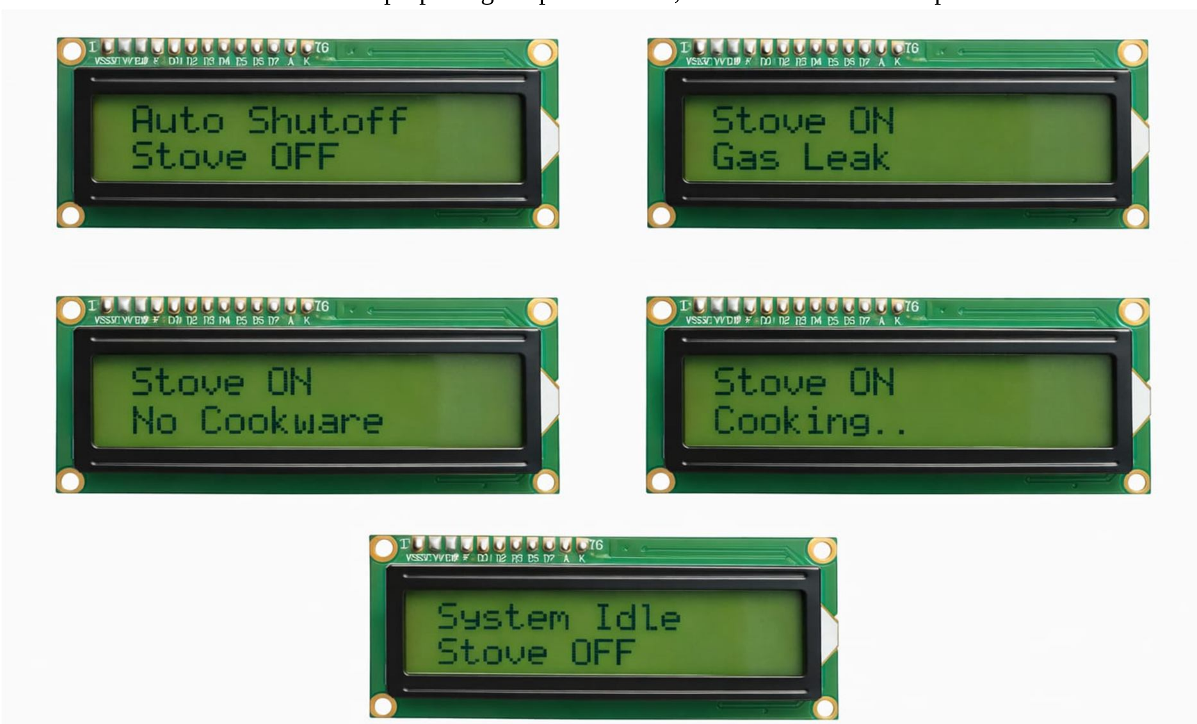

Fig. 5 : System response under different operating conditions displayed on LCD.

When the stove switch was still in the OFF position, the system went into idle mode correctly and showed on the LCD System Idle - Stove OFF. No sensor-based fault evaluation was done in this state, and ensured that the control logic does not process any unnecessary data in the absence of the stove. When the condition of the turn-on of the stove with flame detected but no cookware was present (emulated by the potentiometer below threshold) the system recognized the unsafe open-flame situation.

The stepper motor was able to turn the stove knob to the OFF position and the LCD showed Stove OFF -No cookware. If any abnormal condition is found, the system identifies it and displays the corresponding alert message on the LCD module, as shown in Fig.5. The mechanical shut-off was repeatable over time and trial-to-trial. The gas leakage test scenario involved the case situation where the stove was set ON, and the flame sensor did not detect a flame, and the presence of LPG was simulated close to the MQ-6 gas sensor. When the concentration of the gas was more than the predefined limit the system turned on the stepper motor and showed “Stove OFF - Gas Leak immediately. The response time was noted to be quick enough in order to stop a lengthy gas exposure. Under normal working conditions during the cooking process, with the ON of stove, cook ware, and presence of flame, the system did not conduct unwarranted interruptions. The LCD showed the correct validation of safe operating condition since it was set to Normal Cooking. The results of the experiments prove that the suggested system can reasonably recognize normal and dangerous states relying on the pre-set logical rules. Multi-sensor inputs combined with mechanical actuation leads to the attainment of reliability in terms of safety, and simplicity in terms of operation. It has been proved that the system can be adapted to domestic gas stove safety and allows to decrease the number of accidents, which occur due to unattended cooking or gas leaking, to a great extent [1], [9].

VI. CONCLUSION

In the current paper, the engineering and construction of an intelligent gas cooker safety system was described, which was able to automatically identify dangerous cooking conditions and make mechanical interventions such as turn-off. The system combines an MQ-6 gas sensor to detect LPG, a flame sensor to detect combustion, and a cookware recognition system based on a potentiometer to assess the safety of work in reality. The Arduino Uno microcontroller is programmed to interpret set logical conditions to distinguish between idle status, unsafe open-flame conditions, gas leakage conditions, and normal cooking operation. The prototype that was developed was able to prove the automatic shut off of the stove whenever dangerous conditions were identified. Particularly, the system reacted well in instances where cookware was not in the presence of the flame even in cases where the presence of a flame was indicated by gas leakage whereas the reverse is not true. In both instances, the stepper motor could be trusted to rotate the stove knob to the OFF position, which prevented the possibility of fire hazard and gas build-up. The system continued to operate without failure even under safe cooking conditions, thus, safety mechanisms are not intrusive to the normal operation. Multi-sensor monitoring and mechanical actuation offers a simple and affordable solution in improving domestic kitchen safety. The results of the experiment prove the practicality of the suggested approach and indicate its appropriateness in practical application. As more optimization and integration occurs, the system can be a major contributor to minimizing accidents in the household which are gas related and the level of user awareness regarding safety.

VII. FUTURE SCOPE

To serve smart home safety frameworks, the proposed system can be extended with the addition of the IoT-based communication modules that will allow it to monitor remotely and send alerts in real-time. To enhance the future, it could be changed to a load cell that could be used to detect the cookware in the potentiometer and add more sensors to increase the reliability. Intelligent data processing methods may be applied to minimise false alarms, as well as to improve decision accuracy. Through these developments, the system will be able to become more scalable and cost effective as a kitchen safety solution.

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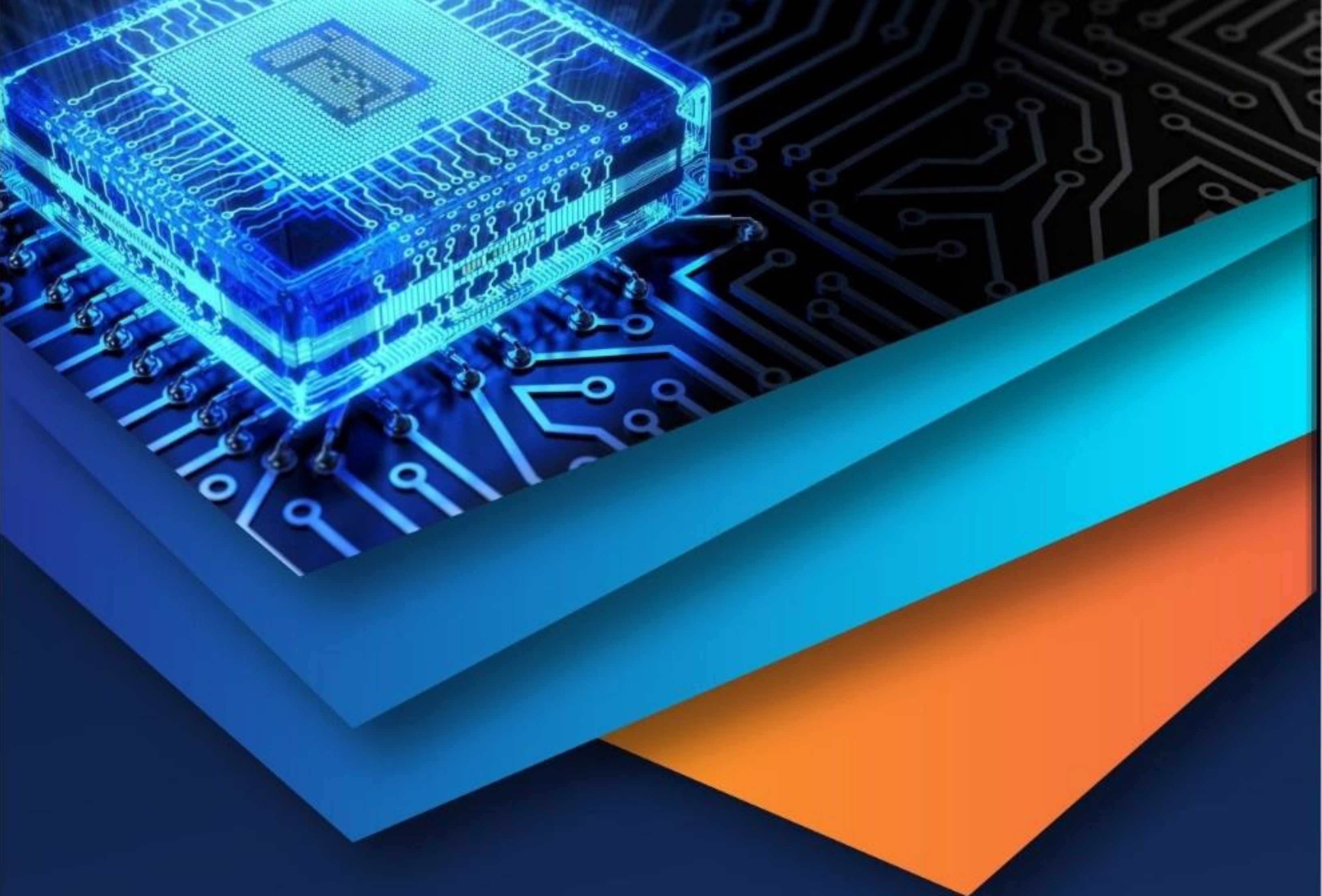

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