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SMART THERMAL-BASED STOVE SAFETY SYSTEM

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Abstract: Unattended cooking is a significant source of home fires and gas-related incidents. To mitigate this problem, a thermal imaging-based smart stove safety system with autonomous response is proposed. A miniature thermal camera is employed to continuously observe the temperature pattern of the burner and cooking pot. The observed information is analyzed in real-time using embedded hardware to determine the operating status of the stove. The system recognizes potentially dangerous situations like an open burner, removing the cooking pot with the burner still ON, and unattended cooking. Once a danger is recognized, it first raises local notifications using a buzzer and LEDs. If the situation is not remedied, a stepper motor connected to a specially designed 3D-printed knob cap is used to automatically turn the gas regulator to the OFF position, thereby shutting off the gas supply. This non-invasive system allows for physical control without altering the gas line inside, making it safe, easily installable, and applicable to real-world kitchens without compromising user privacy.

***Index Terms* -** Thermal imaging, smart stove safety, embedded systems, automatic shut-off.

I. INTRODUCTION

With the increasing use of gas stoves in modern households, kitchen-related accidents such as unattended cooking, overheating, and fire hazards have become a significant safety concern. These incidents can lead to severe consequences including property damage, injuries, and even loss of life. Traditional safety measures rely heavily on human supervision and manual intervention, which are often unreliable due to factors such as distraction, fatigue, multitasking, or forgetfulness. In many cases, delayed human response is the primary reason why small hazards escalate into dangerous situations. This creates a strong need for an intelligent and automated system that can continuously monitor kitchen conditions, detect potential risks at an early stage, and respond promptly without depending entirely on human presence. The proposed project, Thermal Imaging Assisted Smart Stove Safety System, aims to enhance kitchen safety by integrating advanced sensing, processing, and automation technologies into a single cohesive system. The core component of the system is a thermal camera, which captures real-time temperature distribution of the cooking area. Unlike conventional sensing methods that measure temperature at a single point, thermal imaging provides a complete visual map of heat patterns. This allows the system to accurately detect abnormal conditions such as excessive heat buildup, uneven heating, unattended flames, or sudden temperature rise that may indicate the onset of a fire hazard. The use of thermal imaging significantly improves reliability, as it is less affected by environmental noise such as smoke, lighting variations, or airflow. The system is designed to process thermal data using a microcontroller or embedded processing unit, which continuously analyzes temperature variations using predefined thresholds and intelligent decision-making algorithms. Based on this analysis, the system can distinguish between normal cooking conditions and potentially dangerous situations. When an unsafe condition is detected, the system initiates immediate responses such as activating alarms to alert users or automatically turning off the stove through a control mechanism. This rapid response capability ensures that risks are mitigated at an early stage, thereby preventing escalation into major accidents. Furthermore, the system is designed with a modular and scalable architecture, allowing future enhancements such as integration with IoT platforms, mobile notifications, or machine learning algorithms for improved accuracy and adaptability. The design emphasizes real-time operation, low power consumption, and ease of installation, making it suitable for practical household applications.

II. METHODOLOGY

The Thermal Imaging Assisted Smart Stove Safety System aims to automatically and intelligently reduce the risk associated with hazards in the kitchen. The design of the system consists of multiple interactive components that can sense, process data, perform decision making and take control actions by working together.The first component in this process is the thermal camera (the sensor) that captures thermal imagery of the stove and the area surrounding it. Unlike traditional temperature sensors which only measure heat from one particular location or at one instant in time, the thermal camera creates a temperature distribution map of the cooking surface.

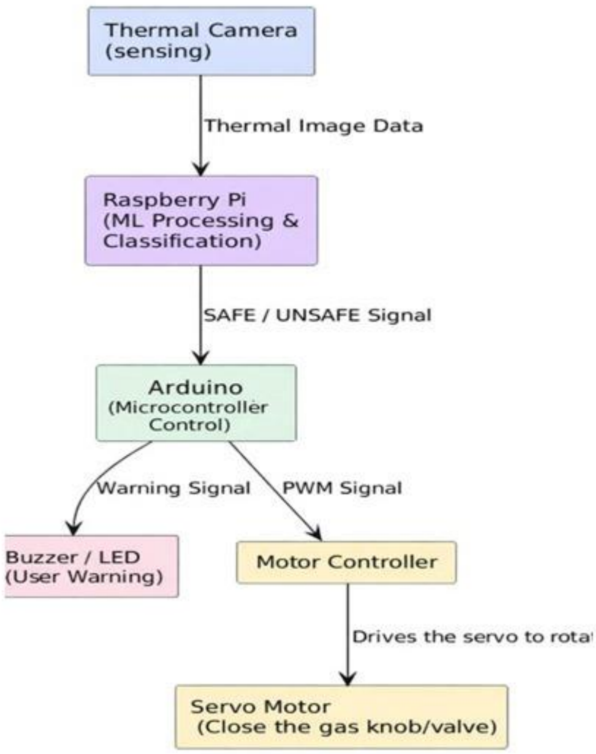

Figure 1. Block Diagram of Smart Thermal-Based Stove Safety System

The thermal camera allows the system to look at the entire area of the cook surface to see the patterns of heat and to identify differences in those patterns that indicate dangerous situations (overheating, unattended cooking or abnormal flaming).Thermal imagery (captured by the thermal camera) is transmitted to the Raspberry Pi, which acts as the main processing and analyzing unit for the thermal data. The Raspberry Pi uses techniques for image processing and machine learning algorithms for interpreting the thermal data collected by the thermal camera. The Raspberry Pi compares the heat distribution pattern for a situation with either a pre-defined condition or trained model to classify the current situation as safe or unsafe. This intelligent classification provides greater accuracy and reliability from the system because it reduces the number of false alarms and ensures that only genuine threats are alerted. When the analysis of the previous paragraph has been completed, the Raspberry Pi will produce either a SAFE or UNSAFE output signal, which is transmitted to the Arduino microcontroller (which is the system's control unit). Once the Arduino has received this input signal, it will carry out the correct response to the signal received, allowing for rapid responses and synchronization between the various components outputting from the controller. Instead of just alerting the user to an unsafe situation by using an audible alarm and/or LED light (as a quick way to alert the user of an unsafe state), the Arduino will generate a PWM signal, which it transmits to the motor controller, which will interpret the PWM signal as an input to control the servo motor operating the stove's control knob or valve, turning off the fuel supply from the stove by closing the control knob. This automated shut-off procedure can help to prevent accidents from happening, particularly where a user is not present or does not respond to the hazardous condition in time. When the analysis of the previous paragraph has been completed, the Raspberry Pi will produce either a SAFE or UNSAFE output signal, which is transmitted to the Arduino microcontroller (which is the system's control unit). Once the Arduino has received this input signal, it will carry out the correct response to the signal received, allowing for rapid responses and synchronization between the various components outputting from the controller. Instead of just alerting the user to an unsafe situation by using an audible alarm and/or LED light (as a quick way to alert the user of an unsafe state), the Arduino will generate a PWM signal, which it transmits to the motor controller, which will interpret the PWM signal as an input to control the servo motor operating the stove's control knob or valve, turning off the fuel supply from the stove by closing the control knob. This automated shut-off procedure can help to prevent accidents from happening, particularly where a user is not present or does not respond to the hazardous condition in time. When the analysis of the previous paragraph has been completed, the Raspberry Pi will produce either a SAFE or UNSAFE output signal, which is transmitted to the Arduino microcontroller (which is the system's control unit). Once the Arduino has received this input signal, it will carry out the correct response to the signal received, allowing for rapid responses and synchronization between the various components outputting from the controller. Instead of just alerting the user to an unsafe situation by using an audible alarm and/or LED light (as a quick way to alert the user of an unsafe state), the Arduino will generate a PWM signal, which it transmits to the motor controller, which will interpret the PWM signal as an input to control the servo motor operating the stove's control knob or valve, turning off the fuel supply from the stove by closing the control knob. This automated shut-off procedure can help to prevent accidents from happening, particularly where a user is not present or does not respond to the hazardous condition in time. Overall, the block diagram represents a well-coordinated system that enhances kitchen safety by minimizing human dependency and enabling real-time monitoring and response.

III. HARDWARE DESIGN AND IMPLEMENTATION

3.1 SENSING AND DECISION LOGIC

The sensing mechanism of the proposed system is based on real-time thermal data acquisition using the MLX90640 infrared thermal camera and combustible gas detection using the MQ-series gas sensor. The thermal camera is continuously capturing a 32×24 pixel temperature matrix of the stove area, which allows for non-contact temperature measurement of heat distribution around the burners and cookware. A Region of Interest (ROI) is defined for the burner and cookware area to remove background noise. From the ROI, thermal parameters such as maximum temperature, minimum temperature, and average temperature are extracted. Additionally, temperature variation patterns over a series of frames are analysed to detect unusual heating patterns. These parameters are then compared with the predefined safe operating temperature ranges of common cooking materials, as shown in Table 7.1.(e.g., plastics: 100–150°C, silicone/wood: 200–250°C, PTFE coatings: ≤260°C, aluminium: 400–500°C, stainless steel: 700–800°C).This reference-based assessment ensures that conditions of overheating beyond the material safety limits can be accurately identified. The decision logic is designed with a threshold-based classification model and not a machine learning approach. The system identifies the stove conditions based on pre-defined states such as safe operation, risk of overheating, active burner without utensil, and unattended heating. When the maximum temperature in the ROI goes beyond the allowed limit corresponding to the identified cookware type, or when the rapid increase in temperature without thermal diffusion is noticed, the condition is marked as unsafe. At the same time, the MQ gas sensor is continuously checking the gas concentration levels. When the output of the sensor goes beyond a calibrated threshold, marking the leakage, an alert state is immediately activated. The final decision signal from the Raspberry Pi is sent to the Arduino controller, which turns on the visual and audio alerts and updates the LCD display accordingly.

TABLE I
MAXIMUM SAFE USE TEMPERATURES OF COMMON COOKING MATERIALS

Material	Max Safe Use Temperature (°C)
Plastic utensils	100 – 150
Silicone utensils	200 – 250
Wooden utensils	200 – 250
Non-stick coatings (PTFE/Teflon)	$\leq$ 260
Aluminum pans	400 – 500
Copper pans	600 – 800
Cast iron	600 – 700
Stainless steel	700 – 800
Ceramic / Glass	500 – 600

3.2 ACTUATION MECHANISM

In this smart stove's actuator mechanism, the actuator will provide the physically controlled mechanism to operate the stove in a way that will prevent dangerous conditions associated with stove use. This is done by converting the electric control signals provided by the stove system into a mechanical energy output capable of operating either the stove valve or stove knob. The actuator will begin its action once the processor of the stove system registers an unsafe condition, and it sends a signal to the Arduino Microcontroller. Based on this information, the Arduino generates a PWM (Pulse Width Modulation) signal for driving the actuator's position and travel. The PWM signal is sent directly to the Motor Controller. The Motor Controller serves to amplify and regulate the control signal so it can be used to actuate the Servo Motor. The Servo Motor is the most essential component of the actuator mechanism since it provides precise angular movement. The Servo Motor is coupled directly to the stove gas valve and/or stove gas knob through a suitable attachment or coupling. Therefore, the angular displacement of the Servo Motor will directly correspond to the angular displacement of the stove gas knob. The Arduino detects and sends a command to rotate the servo motor to a predefined angle if it is unsafe. The angle is set up so that when the servo rotates, it will rotate the stove knob to "OFF". The servo uses high-precision and repeatable motions, giving you the same results every time the system is activated. The design of the actuator must take into account the torque required to rotate the stove knob, the proper alignment of the actuator and stove knob, and the mechanical stability of both. Different stove knobs have very specific torque values to reach their "OFF" position, so it is essential for the actuator selected to have enough torque to operate the actuator without failure. The actuator needs to be mounted properly and coupled securely so that it stays in alignment during operation. Another consideration for the actuator design is how fast the actuator will react to the detection of a hazardous condition. The system is designed for maximum speed once a hazardous condition is detected to minimize any time between detection and action. This rapid response will aid in preventing the dangerous situation from becoming worse.

IV. EXPERIMENTAL SETUP AND RESULTS

The experimental validation of the proposed Thermal Imaging-Assisted Smart Stove Safety System was carried out in a controlled kitchen-like setting to test the accuracy of sensing, decision-making, and actuation. The MLX90640 thermal camera was placed above the stove with a clear view of the burner and utensil area. The MQ-series gas sensor was placed close to the burner at a suitable height for effective gas accumulation sensing. The Raspberry Pi was used for real-time thermal image processing, while the Arduino was used for controlling the warning and actuation modules. Power supply units were used to ensure the stable operation of the system components. Various test conditions were developed to evaluate the performance of the system. For the safe condition test, a vessel with water was placed on the burner, and the normal heating process was carried out. The thermal distribution indicated a steady increase in temperature within the safe operating limits, as referenced from Table 7.1, and the LCD indicated “SYSTEM SAFE” in Fig.2.

Fig 2. LCD display showing system is safe

Fig 3. LCD display showing high temperature

If the stove detects a high temperature in Fig.3 , the system activates when the burner or cookware temperature goes above a set safety limit established through experiments. The thermal imaging sensor keeps an eye on temperature distribution in the defined area of interest, and the embedded controller picks up the highest temperature for analysis. To avoid false alarms from temporary changes, a time-based validation algorithm makes sure the temperature stays above the critical limit for a specific duration before it’s considered a dangerous event. Once the overheating situation is confirmed, the system starts a multi-stage safety response. An audible buzzer and visual LED indicators alert the user. Then, the stepper motor mechanism automatically turns the gas regulator knob to the OFF position. The LCD module displays the message “HIGH TEMPERATURE, STOVE OFF,” giving immediate visual confirmation of the system's action. This detection and response strategy improves safety, reduces fire risk, and provides reliable protection against thermal hazards in home cooking.

Fig 4. LCD display showing unattended stove alert

When the stove is left unattended, this is shown on the LCD as illustrated in Fig. 4. This condition is detected through continuous monitoring of thermal patterns and time-based decision making. The embedded processor checks the area around the burner to see if there is a stable heat signature from cookware. If the burner stays active but no heat pattern from a vessel is detected, or if the heat patterns suggest the cooking utensil has been removed while the gas is still ON, a timer-based verification process starts. If the unattended condition lasts longer than the set safety duration, the system considers the situation dangerous. An audible alarm then sounds, and the motorized mechanism activates to turn the gas regulator OFF. The LCD display gives clear visual feedback that the stove has been shut down automatically due to being left unattended. This feedback improves transparency, increases system reliability, and supports safe kitchen habits while keeping monitoring unobtrusive.

V. CONCLUSION

This paper presents a Thermal Imaging–Assisted Smart Stove Safety System that integrates real-time temperature monitoring, gas leakage detection, and automated intervention to improve kitchen safety. The system uses an MLX90640 thermal camera for non-contact heat analysis and an MQ-series gas sensor for detecting combustible gases. A threshold-based decision logic on the Raspberry Pi processes thermal features, including maximum and minimum temperatures and temporal variations within a defined region. When unsafe conditions are detected, an Arduino-controlled mechanism activates alerts and automatically shuts off the gas using a stepper motor and a custom 3D-printed regulator interface. Experimental validation showed reliable detection of both safe and hazardous conditions, including overheating and simulated gas leaks. The LCD status display, buzzer alerts, and mechanical shut-off confirmed the system's real-time performance and operational feasibility. The modular hardware design allows for easy integration and retrofit installation without modifying existing stoves. Overall, the proposed system provides a cost-effective, non-invasive, and practical solution for proactive stove safety monitoring. By combining thermal analysis with gas sensing and controlled mechanical intervention, the system significantly reduces the risk of fire hazards and gas-related accidents in domestic environments. Future work may focus on enhanced automation, long-term field testing, and improved robustness for large-scale deployment.

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