



## Smart Monitoring System Development for Solar Box Cookers using IoT Technology

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### ABSTRACT

*The successful implementation of an internet of things (IoT) based monitoring interface has significantly enhanced the solar box cooker's functionality and usability. By integrating cutting-edge technologies like Arduino UNO, MTCBA-G-F1/F2 module, thermal sensors, and a buzzer, this initiative transform the conventional cooker into an intelligent, user-friendly device. Real-world testing at the Centre of Entrepreneurship and Enterprises Development in northeastern Nigeria validated the interface's seamless operation within the cooker's context, ensuring both technical prowess and practical reliability. These tests confirmed the system's potential to revolutionize the traditional solar box cooker, making it smarter, more efficient, and user-centric.*

### ARTICLE INFO

#### Article History

Received: June 2023

Received in revised form: July, 2023

Accepted: August, 2023

Published online: December, 2023

### KEYWORDS

IoT, Arduino UNO, Enhanced, thermal sensors

### INTRODUCTION

Cooking, an essential daily activity for sustenance heavily relies on various energy sources worldwide, spanning fossil fuels, firewood, and charcoal. However, rising costs of traditional fuels like cooking gas and fossil resources, coupled with erratic power supplies, particularly prevalent in developing regions have led many rural and urban dwellers to predominantly use firewood for cooking (Komolafe and Awogbemi, 2010).

The combustion of firewood, charcoal, and agricultural remnants, alongside slash-and-burn agricultural methods, significantly contributes to global carbon emissions, accounting for a substantial 5%–20% Smith et al., (1993). This heightened environmental impact has sparked a global awareness among energy experts about the adverse effects of non-environmentally friendly fuels on the planet, particularly their role in exacerbating global warming.

In response to these environmental concerns, there's a growing momentum towards tapping into renewable energy sources, particularly the abundant and eco-friendly energy provided by the sun. Utilizing solar energy for

cooking has emerged as a compelling alternative due to its inherent cleanliness, safety, and widespread availability. Embracing this sustainable energy source offers a promising solution to mitigate the detrimental environmental effects linked to traditional cooking fuels. This shift signifies a conscientious effort to adopt cleaner and more sustainable cooking practices to safeguard the environment.

The contemporary landscape of energy consumption and resource utilization calls for innovative solutions that harmonize human needs with environmental preservation. In this context, solar cookers represent a remarkable fusion of technology and sustainability, harnessing the abundant and renewable energy of the sun to revolutionize the way we prepare food. Among these ingenious inventions, the solar box cooker stands as a beacon of simplicity and efficiency in the realm of solar-powered culinary devices.

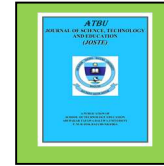
Solar cookers, in their diverse forms and configurations, embody the ingenuity of utilizing sunlight as a primary source of heat for cooking purposes. Among these designs, the solar box cooker distinguishes itself with its straightforward yet highly effective structure.

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Comprising an insulated box with reflective panels, a transparent cover (often glass or plastic), and a darkened cooking chamber, this cooker capitalizes on fundamental principles of physics to create a self-contained, solar-powered oven.

The basic premise underlying the functionality of solar box cookers hinges on the greenhouse effect. Transparent materials, such as glass or plastic, allow sunlight to pass through and trap the radiant energy inside the box. Once inside, this energy is absorbed by the dark interior surfaces, heating the air within the enclosure. The insulation prevents heat loss, creating a consistently warm environment suitable for cooking various types of food.

The versatility of solar box cookers is a key feature that distinguishes them. Their ability to achieve and maintain moderate temperatures makes them adaptable to different cooking styles, from slow-cooking stews and soups to baking bread and pastries. Furthermore, their relatively simple construction using readily available materials and their ease of use make them accessible to a wide range of communities, especially in areas where access to conventional cooking fuels is limited or where their cost is prohibitive.

While solar box cookers offer a sustainable and eco-friendly alternative to traditional cooking methods, their efficiency can be influenced by a multitude of factors. Geographic location, prevailing weather conditions, seasonal variations, and cultural acceptance all play roles in determining their effectiveness. However, ongoing advancements in design, materials, and optimization techniques continually improve their performance and broaden their applicability across diverse regions and climates.

As the world increasingly seeks solutions to mitigate environmental impact, conserve resources, and improve livelihoods, solar box cookers emerge as a compelling option. Solar box cookers are sustainable cooking solutions, and integrating IoT capabilities enhances their functionality. This system enables continuous temperature monitoring and timely

alerts, ensuring safe and efficient cooking processes.

The evolution of solar cooking unfolds across centuries, interwoven with the innovative endeavors of visionaries from diverse backgrounds and regions, each contributing to its fascinating tapestry of progress.

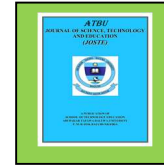
Tschirnhausen, a German physicist, emerged as an early trailblazer in the realm of solar cooking. His pioneering experiments involved utilizing the sun's rays to heat a clay pot, achieving the remarkable feat of boiling water through the focused concentration of sunlight using a sizable lens—an inventive leap into the potential of solar energy for culinary applications. Horace de Saussure, a Swiss geologist and physicist, marked a significant milestone in 1767 by crafting the first documented solar cooker. His creation, essentially a solar collector, demonstrated the capability to reach temperatures of up to 88°C, laying the foundation for harnessing the sun's energy for cooking purposes. The progression of solar cooking continued across time and geography, manifesting in various forms and designs. Sir John Herschel, during his expedition in South Africa in 1830, introduced an insulated solar cooker to prepare meals, showcasing the adaptability and utility of solar cooking methods even in diverse climates and terrains. A pivotal leap forward came in 1869 with Mouchot's innovative development of the parabolic solar cooker. This groundbreaking design innovation not only enhanced efficiency but also found practical application when Napoleon III deployed it for French Colonial troops in Africa, highlighting its relevance in real-world scenarios. India made its mark in the narrative of solar cooking with W. Adams' creation of the first panel solar cooker in 1876. This ingenious solar oven, comprising eight reflecting mirrors, efficiently cooked vegetables and meat, demonstrating its practicality by preparing meals for seven soldiers within a mere two hours—a remarkable feat for its time. Even culinary traditions found a place in the evolving saga of solar cooking. In 1894, Xiao's Duck Shop in Sichuan, China, gained fame for roasting ducks using a solar cooker a

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testament to the integration of solar technology into diverse culinary practices. The timeline of solar cooking continued its march forward with Sri M.K. Ghosh's introduction of the first commercially viable box-type solar cooker in 1945. This milestone paved the way for more accessible and practical solar cooking solutions. In 1979, Dr. Metcalf and Marshall Longuin expanded the scope of solar cookers by employing a solar box cooker for water pasteurization. This crucial step showcased its utility beyond food preparation, emphasizing its potential for addressing health-related concerns. Initially, challenges such as high costs and lower efficiency hindered the widespread adoption of solar cookers. However, as concerns escalated regarding the escalating costs and environmental impact of conventional fuels, governments worldwide began endorsing solar cooking as an eco-friendly and sustainable alternative. India's significant contribution in 1987 came through Mullick's performance evaluation of box-type solar cookers. His introduction of the Figure of Merit testing approach remains a cornerstone in the efficient assessment of solar cookers even in contemporary times. The pursuit of standardization culminated in Dr. Paul Funk's proposal of an international standard based on cooking power (W) for testing solar cookers in 2000, an initiative that gained recognition and acceptance by the American Society of Agricultural and Biological Engineers (ASABE).

In order to make cooking more effective, solar cookers are incorporated with phase change materials (PCMs), that enhances the cooking time period. The PCMs convert their forms from solid to liquid and liquid to solid either releasing or absorbing heat. Heat is absorbed by solid PCMs results in changing their phase from solid to liquid and heat is released by such PCMs when the temperature drops after regaining their shape. (Safdar et al., 2022). Cuce (2018), used Bayburt stone, a beige tuff quarried in Bayburt, Turkey. He compared two identical cookers, one filled with stones and the other without them, Coccia et al. (2018) tested high concentration ratio box cooker provided with a thermal storage

unit. The PCM consisted of a 4 kg mixture comprising  $KNO_3$ ,  $NaNO_2$  and  $NaNO_3$  (melting temperature of  $145^\circ C$  and latent heat of fusion  $101.5 \text{ kJ/kg}$ ) and was included in a double walled pot, maina et al., (2019), experiment stearic acid for solar thermal energy storage in a double compartment solar box cooker.

Generally, the integration of tracking methods significantly enhances the performance, efficiency, and reliability of solar cookers, making them more effective and practical for daily cooking needs while promoting sustainable energy usage. The use of tracking methods in solar cookers offers several significant benefits that enhance their efficiency and effectiveness in harnessing solar energy for cooking purposes. Tracking methods for solar cookers involve different approaches and technologies used to follow the sun's path and maximize its utilization for cooking purposes. These methods aim to optimize the absorption of solar energy and maintain the cooker's alignment with the sun's position throughout the day. Here's an overview of various tracking methods and their types solar trackers based on number of axis and type of drive in solar tracking. Each tracking method has its advantages and limitations. Passive cookers are simple and cost-effective but might not capture maximum sunlight. Active systems offer better efficiency but might be more complex and expensive to implement. The choice of tracking method often depends on factors such as cost, complexity, cooking efficiency, and the user's preference or available resources. (Gokul et al., 2021). Mahmud et al., (2023), carried out A Design and Fabrication of an Automated Solar Energy Tracker Integrated Four-Sided Reflector-Based Box-Type Solar Cooker to Increase Efficiency by Absorbing Maximum Solar Energy, Abdulrahim et al., (2015) development of an automated tracker for the enhancement of energy availability in a solar box oven, Prophan et al., (2016). Designed and constructed an automatic solar tracker and carried out performance evaluation. Nehra and Sanjeev (2015), have developed a sun tracking system for solar cooker. Clement and Clinton. (2022),

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worked on the Evaluation of a Solar Cooking System.

### **Integrated With Tracking Device and Sensible Heat Storage Materials**

Through these transformative milestones and ongoing innovations, the trajectory of solar cooking has evolved from its nascent experiments into a recognized, viable, and eco-friendly culinary practice, offering a sustainable means of cooking across the globe. The genesis of "Smart" and the "Internet of Things (IoT)" marks a pivotal era in technological innovation, redefining how we interact with devices and the world around us: Smart Technology's Rise: "Smart" initially referred to devices or systems exhibiting enhanced capabilities and intelligence. As technology advanced, it encapsulated gadgets and systems empowered with increased connectivity, automation, and data processing abilities. This evolution birthed a diverse array of products—from smartphones and smart appliances to complex industrial setups—offering unprecedented functionalities and interactivity. The IoT Vision: The IoT emerged as a vision of interconnectedness, where objects and devices connect to the internet, enabling data exchange and communication. This concept envisioned a network where everyday devices, spanning from household items to industrial equipment, could collect, share, and act upon data, fostering

efficiency, automation, and insights. The continuous evolution of smart technology and IoT is driving innovations across sectors, leveraging advancements in artificial intelligence, edge computing, and data analytics. This trajectory promises a future where seamlessly integrated, intelligent systems enhance our lives, businesses, and industries, fostering unparalleled levels of efficiency and connectivity. (Hertzog and Swart, 2021).

Solar box cookers offer sustainable cooking solutions, and integrating IoT capabilities enhances their functionality. This system enables continuous temperature monitoring and timely alerts, ensuring safe and efficient cooking processes. kavitha and malathi ( 2019), conducted a study on a smart solar pv monitoring system using IoT.

### **System Components**

1. Arduino Uno microcontroller
2. 4 LM35 precision centigrade sensors
3. LCD 016N002b-CFU display
4. GSM module for SMS notifications
5. ABI 009-RC buzzers

Battery-based power supply with on/off switch Arduino Uno is a microcontroller board based on Atmega328p which allows you to program the Arduino in order for it to be able to execute commands and make decisions based on various inputs. It has 14 digital input/output pins as shown in plate 1.1.



**Plate 1.1:** microprocessor Arduino UNO

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### GSM AT Commands

Plate 1.2 depicts the MTCBA-G-F1/F2 is commands which are used to control the MODEMs where AT stands for Attention. The AT commands can be used with GSM and GPES,

MODEMs or Phone to access these services and information sms, mms, fax, voice link and other data over mobile network, information and configuration concerning the mobile devise or MODEMs and SIM card.

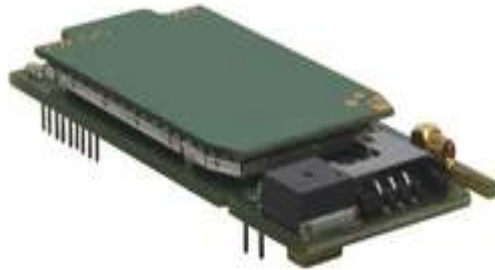


Plate1.2: GSM AT Commands (MTCBA-G-F1/F2)

### LM35 Precision Centigrade Temperature Sensors

The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output

to obtain convenient Centigrade scaling. The low output impedance, linear output, and precise inherent calibration of the LM35 device makes interfacing to readout or control circuitry especially easy. The features of the LM35 make it suitable for many general temperature sensing applications. Plate1.3: shows LM35 Precision Centigrade Temperature Sensors.

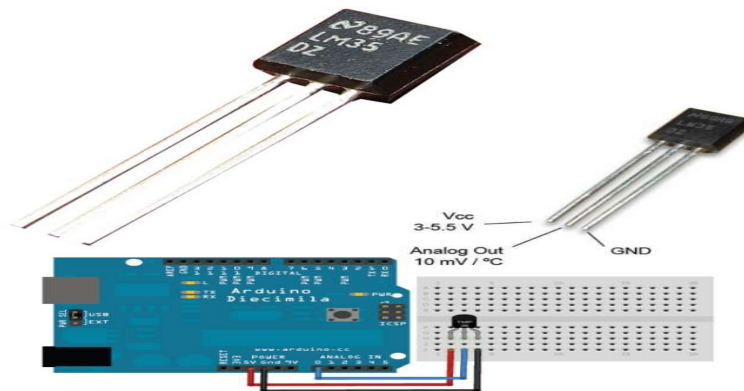


Plate1.3: LM35 Precision Centigrade Temperature Sensors

### LCD-016N002B-CFH-ET

The LCD display Module is built in a LSI controller, the controller has two 8-bit registers, an instruction register (IR) and a data register (DR). As seen in plate: 1.4. The IR stores instruction codes, such as display clear and

cursor shift, and address information for display data RAM (DDRAM) and character generator (CGRAM). The IR can only be written from the MPU. The DR temporarily stores data to be written or read from DDRAM or CGRAM. When address information is written into the IR, then

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data is stored into the DR from DDRAM or CGRAM. By the register selector (RS) signal,

these two registers can be selected.

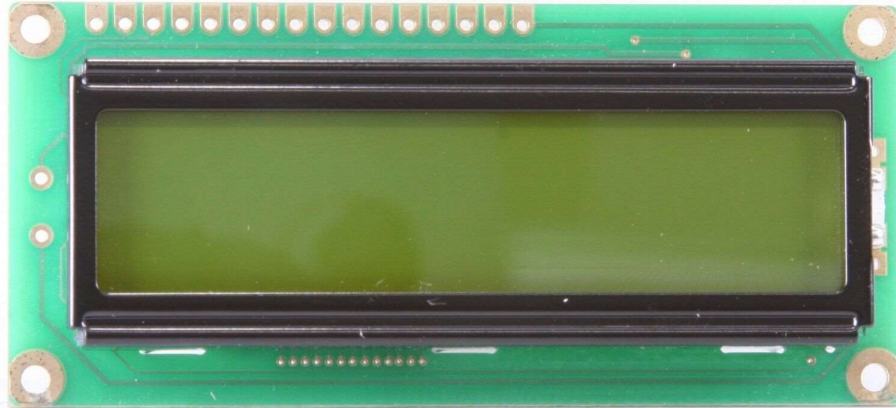


Plate 1.4: LCD-016N002B-CFH-ET

### Buzzer

Buzzer (ABI-009-RC) is an active buzzer module useful for creating sound in a project. Shown in plate: 1.5. The drive circuitry built into it, so a simple active HIGH LOGIC LEVEL SIGNAL will activate the buzzer. Though simple to use, the downside of the active buzzer

is fixed at a particular frequency and the loudness is more or less fixed. These are mainly useful for signaling or an alarm. It is moderately loud at about 85dB with a 2.3 kHz frequency, so it be best suitable for use as an attention getting alarm or beeper.



Plate 1.5: Buzzer (ABI-009-RC)

### System Architecture

#### Hardware Configuration:

1. **LM35 Sensors Connection:**
  - a. Each sensor is connected to the Arduino Uno:

- i. Power (VCC) → Arduino 5V
- ii. Ground (GND) → Arduino GND

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- iii. Signal → Analog pins (A0 to A3)

2. **LCD 016N002b-CFU:**
  - a. VCC → Arduino 5V
  - b. GND → Arduino GND
  - c. RS (Register Select) → Digital pin
  - d. E (Enable) → Digital pin
  - e. Data pins → Digital pins
3. **GSM Module (SIM800L):**
  - a. RX, TX pins connected to specific digital pins on Arduino
4. **ABI 009-RC Buzzers:**
  - a. Connected to digital pins for activation

#### Software Implementation:

1. **Arduino Code:**
  - Reading sensor data and converting it to temperature values.
  - Displaying temperature readings on the LCD screen.
  - Implementing GSM AT commands to send SMS notifications based on temperature thresholds.
  - Triggering ABI 009-RC buzzers for alarm notifications.

#### LM35 Temperature Sensors:

1. **Sensor 1 (Absorber Plate)**
  - VCC → Arduino 5V
  - GND → Arduino GND
  - Signal → Analog pin (A0)
2. **Sensor 2 (Oven)**
  - VCC → Arduino 5V
  - GND → Arduino GND
  - Signal → Analog pin (A1)
3. **Sensor 3 (Water)**
  - VCC → Arduino 5V
  - GND → Arduino GND
  - Signal → Analog pin (A2)
4. **Sensor 4 (Ambient)**
  - VCC → Arduino 5V
  - GND → Arduino GND
  - Signal → Analog pin (A3)

#### LCD 16x12 cm Display (Assumed to be a 16x2 Character LCD):

1. VCC → Arduino 5V
2. GND → Arduino GND
3. RS (Register Select) → Digital pin
4. E (Enable) → Digital pin
5. Data pins → Digital pins

#### GSM Module (SIM800L):

1. RX → Digital pin (e.g., RX pin 10 on Arduino)
2. TX → Digital pin (e.g., TX pin 11 on Arduino)

#### Buzzer (Rated Voltage: 6V, Operating Voltage: 4-8V):

1. Buzzer (+) → Digital pin (Digital pin 8)
2. Buzzer (-) → Arduino

#### System Functionality

1. **Temperature Sensing and Display:**
  - Continuous monitoring of absorber plate, oven, water, and ambient temperatures.
  - Displaying real-time temperature values on the LCD.
2. **SMS Notifications:**
  - Sending SMS alerts to the user's phone:
    - "Cooker warm" when the oven temperature reaches 45°C.
    - "Almost Ready" when the water temperature hits 75°C.
    - "Ready" when the water temperature reaches 100°C.
3. **Alarm System:**
  - Activating the ABI 009-RC buzzers simultaneously with SMS notifications for the specified temperature thresholds.
4. **Power Management:**
  - Utilizing a battery-based power supply with an on/off

switch for easy control of the system.

**Working of proposed IoT interface for Solar Box Cooker**

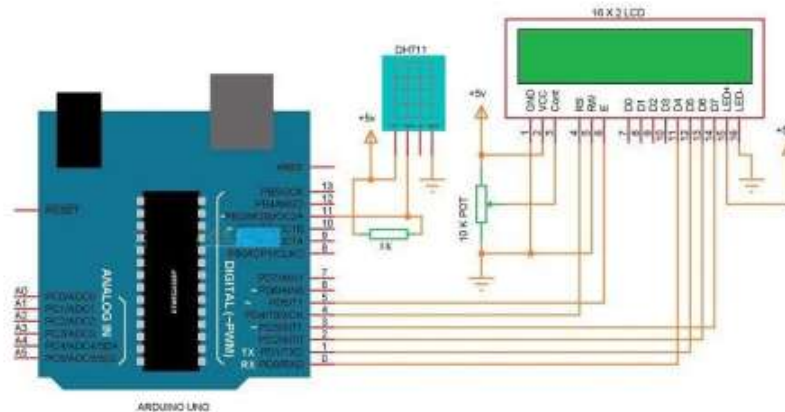
The interface developed for overseeing the Solar Box Cooker (SBC) is an intricate system utilizing Arduino UNO, a **GSM AT Commands** MTCBA-G-F1/F2, and thermal sensors for efficient monitoring and control. Using an Arduino UNO in tandem with the **GSM AT Commands** MTCBA-G-F1/F2, along with the Node MCU serving as the WiFi module's platform, this interface allows for seamless connectivity. The system employs LM35 and PT100 temperature sensors to measure both the ambient temperature and the temperature within the box cooker, respectively.

The Arduino UNO serves as the primary processing unit, gathering data from these sensors to calculate the optimal processing time. The GSM AT Commands

MTCBA-G-F1/F2 plays a critical role in establishing a secure communication channel between the Arduino processor, user phone and

buzzer. To enable real-time monitoring, essential metrics such as ambient temperature, absorber plate temperature water temperature and oven temperature of the box cooker, are continually displayed. This information is visible on an LCD screen. Upon reaching the specified oven temperature, water temperature and completion of the boiling process, the system promptly sends simultaneous notification to the user via The **GSM AT Commands** MTCBA-G-F1/F2 application to the user phone and alarm via buzzer, simplifying the monitoring process for the Solar Box Cooker.

The entire system is powered by a DC battery, ensuring a sustainable and consistent energy source. This battery acts as an energy reservoir, enabling continuous operation of the system. In summary, this robust IoT interface optimizes the supervision and control of the Solar Box Cooker by integrating temperature monitoring, real-time data visualization, remote notifications, and a reliable power supply system DC battery, as depicted by the circuit diagram in figure 3.1 and figure 3.2 .



**figure 3.1:** circuit diagram of Arduino uno with LCD

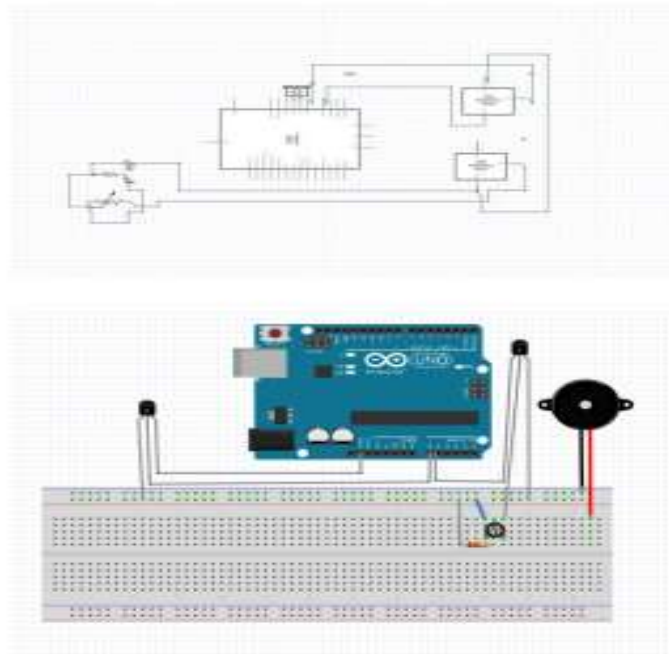
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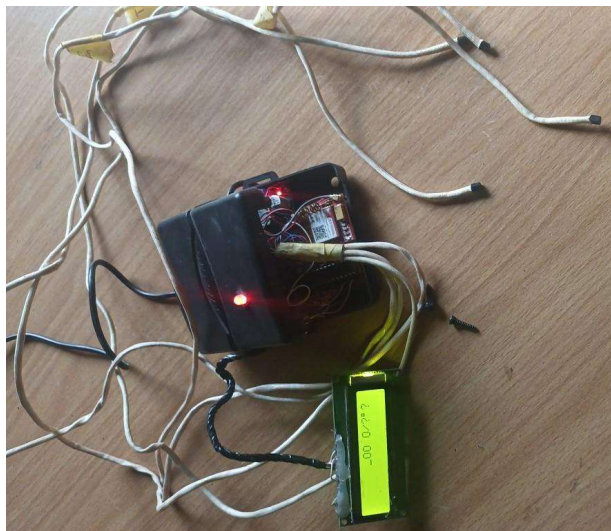


**figure 3.1:** circuit diagram of Arduino uno with Buzzer.

**RESULT**

The developed monitoring interface underwent comprehensive testing at Centre of

entrepreneurship and Enterprises Development University of Maiduguri, Borno state. plate 4.1 showcases the smart system before coupling.



**Plate 4.1:** Smart monitoring system with IoT interface before coupling

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**Plate 4.2:** IoT monitoring interface on solar box cooker experiment

Experiments were conducted using the IoT monitoring interface on solar box cooker as illustrated in plate 4.2: This improvement is attributed to a significant reduction in heat loss, primarily stemming from fewer interruptions caused by the reduced need to open the cooker for manual monitoring during the cooking process. The integration of the IoT monitoring interface yielded tangible benefits, notably enhancing the Solar Box Cooker's efficiency. By enabling remote monitoring, the interface effectively minimized heat loss, thereby streamlining the boiling process and reducing boiling times. The smart solar box cooker system ensures precise temperature monitoring, user alerts, and safety measures, enhancing the water boiling experience while promoting energy efficiency and sustainability.

## CONCLUSION

The successful development and implementation of an IoT-based monitoring interface mark a significant stride in enhancing the functionality and usability of a specific model of solar box cooker, measuring 500 X 400 X 300 mm. This endeavor has been a culmination of integrating cutting-edge technologies, including

Arduino UNO, MTCBA-G-F1/F2 module, thermal sensors and buzzer, aimed at transforming the traditional cooker into an intelligent and user-friendly device.

The practical validation of this novel system took place at Centre of Entrepreneurship and Enterprises Development University of Maiduguri, Borno state, northeastern Nigeria. This real-world testing ground provided a genuine environment for comprehensive assessment, ensuring that the IoT-based interface operates seamlessly and effectively within the context of the operational solar box cooker. By subjecting the system to real-world scenarios and user interaction, this testing phase aimed to validate not only the technical prowess but also the practical usability and reliability of the IoT-based monitoring interface. The results obtained from the testing serve as a testament to the system's capability to revolutionize the conventional solar box cooker into a smarter, more efficient, and user-centric appliance

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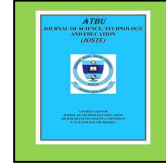
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