International Journal of
Electrical and Computer System Design
ISSN: 2582-8134 www.ijecsd.com

Enhanced Solar Cooker with Automatic Sun Tracking and Vacuum Insulated Cooking Chamber

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Abstract: This project proposes an innovative solar cooker design that integrates a microcontroller, potentiometer, and motor to efficiently harness solar energy for cooking purposes. The system intelligently tracks the sun's movement using an Arduino-based application, enabling the reflective panel to optimize solar exposure throughout the day. Inside the cooking chamber, the cooking tray receives consistent illumination from the reflective panel, which is connected to an outer ring of bearings and gears. The unique cylindrical shape of the chamber ensures that the reflected rays are evenly distributed along two lines, minimizing the risk of accidental burns from concentrated focal points. To further enhance the system, Light Dependent Resistors (LDRs) are employed for automatic sun tracking. These sensors provide real-time feedback on sunlight intensity, allowing the solar cooker to automatically adjust its position for optimal alignment with the sun's position throughout the day. Additionally, the use of a transparent vacuum flask surrounding the cooking chamber enables the system to reach higher cooking temperatures and retain heat for extended periods, ensuring the cooked food remains warm. By combining these cutting-edge features, the solar cooker delivers exceptional efficiency, safety, and user-friendliness. The implementation of sun tracking technology and vacuum insulation significantly improves cooking performance, making it a sustainable and practical solution for preparing meals using renewable solar energy.

Keywords: Sustainable cooking; Energy Efficiency; Solar Tracking System; Vacuum Insulation Technology; Eco-Friendly

1. Introduction

Harnessing solar energy for daily needs has emerged as a viable and environmentally friendly option in a society increasingly focused on sustainability. Among the various innovative applications of solar energy, the solar cooker has gained significant attention. Solar cookers offer a greener alternative to traditional cooking methods reliant on fossil fuels, as they harness the abundant and renewable energy from the sun. While conventional solar cookers have been applauded for their user-friendliness and positive environmental impact, recent technological advancements have ushered in a new era of solar cooking, pushing its potential to unprecedented heights.

The increasing global energy demand has led to a heavy reliance on traditional fuel sources with negative health and environmental impacts. Solar energy presents a promising alternative in many developing countries, but the adoption of solar cooking devices remains limited due to intermittent radiation and technological challenges. Various types of solar cookers, including box, panel, parabolic, and tube designs, have been developed, along with advancements like PV conversion to electricity. Research has focused on improving solar cooker performance, addressing issues like sun tracking, thermal storage, and sociocultural considerations. Further efforts are needed to enhance adoption, energy storage capacity, and policy considerations for a sustainable future [1].

The paper reviews recent advances in solar cooker technologies, focusing on performance analysis and critical components like booster mirrors, absorber trays, and glazing systems. It evaluates thermal performance parameters, tracking mechanisms, and CO_2 mitigation potential. Despite the promise of solar cooking, widespread dissemination and adoption remain limited in the domestic sector [2].

This study analyses a portable evacuated tube solar cooker with a stainless steel tank, validating the model against experimental data. Important design and weather parameters, such as vacuum envelope pressure, absorber coating properties, and solar radiation, are evaluated for their impact on the solar cooker's performance. Using the Taguchi method, the research optimizes the solar cooker's useful thermal power and efficiency. The findings highlight the significance of vacuum envelope pressure and absorber coating properties while identifying solar radiation as a crucial factor affecting the useful thermal power [3].

The twin-chamber design improves cooking performance and reduces side heat loss. The TCCS cooker offers larger capacity compared to single-chamber cookers, making it suitable for community-scale cooking. Techno-economic analysis shows favourable results, and it has the potential to significantly reduce CO2 emissions compared to traditional cooking methods [4].The literature extensively covers the developments in box-type solar cookers and solar ovens globally. Recent research highlights their potential in solar cooking, fuel-saving, and non-polluting energy solutions. The study focuses on optimizing various parameters, leading to improved performance in low ambient temperatures. The fabricated solar box cooker demonstrated enhanced efficiency, and innovative features like the wiper-type mechanism further contributed to its effectiveness [5].

A novel multi-shelf solar cooker-cum-dryer (ISCCD) designed with a North Facing Booster Mirror (NFBM) to enhance cooking and drying performance, especially during winter. The innovative parallelepiped vessel design further improves cooking efficiency. ISCCD's solar radiation capture model is validated in Ludhiana, India. The optimized ISCCD can cook three times more food than conventional cookers and efficiently functions in extreme winter conditions. Techno-economic analysis shows cost recovery within 65 months, and its drying capabilities offer additional savings and reduced CO2 emissions compared to conventional cookers [6].To address the limitations of solar cooking appliances, a conceptual electrical and solar hybrid cooking appliance is introduced, designed to replace both electric ovens and solar cookers. The hybrid mode optimizes solar energy usage, resulting in approximately 51% energy savings and significantly reduced cooking time compared to electric ovens and solar cookers, respectively [7].

The solar box cooker cum dryer (SBCD) dual-mode operation allows simultaneous cooking and drying using a simple moisture removal method. Performance analysis based on Cooker Opto-thermal Ratio (COR) and kinetic studies demonstrates the cooker's efficiency in cooking and drying food products. The cost of cooking meals (LCCM) is used to assess the economic viability of the SBCD, making it a practical and self-sustaining solution for decentralized communities [8].

An experimental investigation of a solar cooking system for preparing concentrated sugarcane juice used in jaggery making. An evacuated tube solar collector was used as the heat collecting medium, and experiments were conducted on sunny and clear sky days with varying cooking loads. The system demonstrated a 76% and 59% increase in peak exergy power compared to box-type and parabolic trough-type solar cooker designs, respectively, for the 2-liter cooking load. Additionally, the cooking time was observed to increase by 53.3% for the 2-liter load compared to the 1-liter load. The study highlighted the potential of the evacuated tube-based solar cooking system to maintain sugarcane juice temperature above its boiling point even during low solar intensity hours [9].

The development of an Electric-Solar hybrid cooking appliance that combines solar and electrical energy is used for efficient cooking. The hybrid oven saves up to 51% of energy and reduces cooking time compared to electric ovens and solar appliances. It offers a relatively quick return on investment, with payback periods of 2.3 years in hybrid mode and 3.7 years in solar mode. The STEPCO oven demonstrates an impressive efficiency of 63% in hybrid mode, emitting minimal CO2 during cooking and zero emissions in solar mode [10].

Burning conventional fuels for cooking in developing countries causes air pollution. Although abundant, solar energy is underutilized for cooking due to lack of awareness, high costs, intermittent availability, and equipment inefficiency. The paper explores the potential of heat pipe solar collectors to develop efficient, reliable, and cost-effective indirect solar cooker designs for addressing this challenge. The research aims to harness solar energy for cooking and reduce air pollution in poor communities [11].

The review discusses the significance of clean cooking technology, emphasizing electric and solar cookers for reducing harmful emissions. While outdoor solar cookers have low social acceptance, the review explores indoor solar cooker designs to meet current needs. Handpicked designs, including the solar chulha, show promise for sustainable and efficient indoor solar cooking without relying on auxiliary power. The aim is to promote clean and environmentally friendly cooking options to mitigate climate impact [12].

This project aims to develop a high-tech solar cooker featuring automatic sun tracking and a vacuum-insulated cooking chamber. The solar cooker will autonomously adjust its position to follow the sun, optimizing solar energy utilization without manual intervention. The vacuum-insulated cooking chamber will enhance heat retention, maintaining higher cooking temperatures for extended periods, even during limited sunlight. The project seeks to compare the solar cooker's cooking efficiency to conventional methods, evaluating its potential for energy savings, environmental impact, and cooking effectiveness.

2. Methodology

The solar cooker incorporates a microcontroller and potentiometer to control the motor, enabling the rotation of the panel as shown in Fig 1. This functionality is achieved through a programmed Arduino, which receives input from the potentiometer and adjusts the motor's angles based on calibrated readings. Gears and bearings transmit power from the motor to the flat bar that connects to the panel. As the gear rotates, it moves the outer ring of the bearing, adjusting the position of the reflective panel while keeping the camber attached to the inner ring of the bearing steady. This design maximizes the reflection of sunlight into the chamber throughout the day, allowing the food to be warmed whenever the sun is shining. Future plans involve enhancing the system using LDR (Light Dependent Resistor) to automatically track the sun's movement, leading to further modifications and improvements.

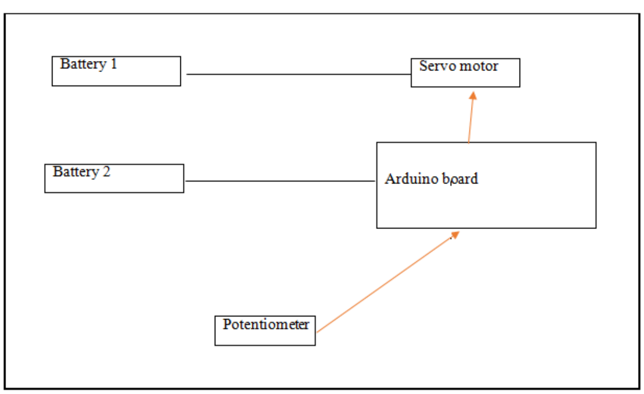

Fig.1 *Block Diagram*

3. Component description

3.1. Reflective Panel

The reflective panel is a smooth, flat surface designed to achieve total light reflection. In our solar cooker, we have utilized a stainless-steel mirror-finished panel due to its exceptional reflection ability, lightweight nature, and increased durability compared to other reflective panels.

3.2 Cooking Chamber

The cooking chamber serves as the designated space for placing food or water that requires heating. It is crafted from a cylindrical tin can. For our project, the cooking chamber is coated with a thin layer of matte black paint, enabling efficient heat absorption from the reflected sun rays.

3.3. Main Frame

The main frame, also referred to as the main body of the solar cooker, serves as the support structure for the entire system. It consists of the chassis and the base, both of which provide support to all other components. We have opted to use a wooden base, which acts as the legs of the cooker, providing a sturdy foundation and ensuring stability even in the presence of light winds.

3.4. Arduino Uno

The primary controller employed for the sun tracking system is the Arduino board. It can be programmed to track the movement of the sun, maximizing the number of rays that strike the panel. At present, we are utilizing a potentiometer to demonstrate the rotation capability of the system.

3.5 Servo Motor

The servo motor is connected to the reflective panel base through gears, enabling rotational movement. The rotation of the panel is controlled by the potentiometer, which sends a signal to the motor to rotate it to the desired position. The Arduino calibrates the signal and angle for precise control. The servo 996-R metal geared motor used in this project has a torque specification of 10kgf-cm at 6V and rotates between 0° to 120° (60° clockwise and anticlockwise). The operating voltage of the motor ranges from 4.8v to 7.2v.

3.6 Batteries

All the electronic components in this project are powered by 9v batteries. Two batteries are used; one powers the Arduino independently, while the other is dedicated to powering the servo motor for optimal performance.

3.7 Potentiometer

A potentiometer is a variable resistor with a third adjustable terminal. By adjusting the position of a sliding contact along a uniform resistance, it can provide any fraction of the potential across its ends. In our project, we use a 10k ohms potentiometer to vary resistance and control the position of the reflective panel.

3.8. Gears

The gears are connected between the servo motor and the reflective panel base. When the potentiometer sends a signal, the Arduino instructs the motor to turn, resulting in the rotation of the reflective panel according to the potentiometer's signal. Spur gears are used in this project, with an internal diameter of 25mm and an external diameter of 60mm, attached to the bearing to enable smooth rotation of the panel base around the chassis.

3.9. Bearing

A bearing is a machine element that allows only the desired motion while reducing friction between moving parts. In this project, the bearing is used to facilitate relative motion between the panel and the chassis, playing a crucial role in the rotation of the reflective panel.

4. Working Principle

The working principle of our solar cooker bears similarities to the parabolic solar cooker. The reflected rays are directed towards the cooking tray, which is coated in black for optimal heat absorption. However, unlike the parabolic cooker, our design is cylindrical, ensuring that the reflected rays are spread along a single line on each side of the chamber, preventing any accidental burns from concentrated points. Additionally, the panel is ingeniously designed to rotate and tilt independently of the tray, enabling us to position the tray to maximize ray reflection. A potentiometer is used to control the motor's rotation, which, in turn, adjusts the panel's orientation. For further enhancements, we plan to incorporate Light Dependent Resistors (LDRs) for automatic sun tracking. Additionally, the implementation of a transparent vacuum flask around the cooking chamber will aid in achieving the required cooking temperatures and keep the food warm for an extended duration. With these modifications and improvements, our cylindrical solar cooker aims to provide an efficient and user-friendly cooking experience, harnessing the power of solar energy for sustainable and eco-friendly culinary practices.

5. Software coding and Interfacing

The sun tracking mechanism is a sophisticated integrated system that combines mechanical and electronic components. For the electronic aspect, the Arduino IDE (Integrated Development Environment) is utilized to program the Arduino board. This IDE enables the creation, testing, and compilation of the program used for solar tracking. The combination of these systems ensures precise and efficient sun tracking for optimal performance of the solar cooker.

5.1 ARDUINO CODE

```
#include <Servo.h>

Servo myservo; // create servo object to control a servo

int potpin = 0; // analog pin used to connect the
potentiometer

int val; // variable to read the value from the analog pin

void setup () {

myservo.attach(9); // attaches the servo on pin 9 to the
servo object

}

void loop () {

  val = analogRead(potpin); // reads the value of the
potentiometer (value between 0 and 1023)

  val = map (val, 0, 1023, 0, 180); // scale it to use it
with the servo (value between 0 and 180)

myservo.write(val); // sets the servo position according
to the scaled value

  delay (15); // waits for the servo to get there

}
```

6. Fabrication Results

The cylindrical solar cooker is an innovative fusion of electronic and mechanical components, thoughtfully crafted from eco-friendly materials to ensure minimal environmental impact. It incorporates essential elements like the servo and Arduino, efficiently powered by rechargeable batteries, offering prolonged usability. The cooking chamber's choice of Aluminium material proves advantageous, as it facilitates rapid heating, prioritizes user safety, and ensures cost-effectiveness for an affordable price point. Furthermore, the use of eco-friendly materials and energy-efficient mechanisms aligns with sustainable principles, making the cylindrical solar cooker a promising solution for eco-conscious cooking needs.

Fig 2 shows the front view of the cooker, Fig 3 shows the isometric view of the cooker and Fig 4 displays the control box

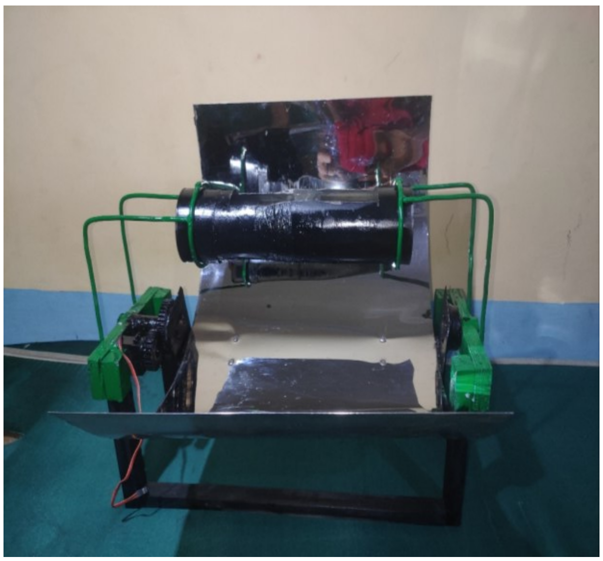

Fig.2 *Front view of the cooker*

Fig.3 *Isometric view of the cooker*

Fig.4 *Control box*

7. Conclusion

This research showcases an innovative solar cooker design that efficiently utilizes solar energy for cooking. Advanced technologies like microcontrollers, potentiometers, and sun tracking systems improve performance by maximizing solar exposure throughout the day. Light Dependent Resistors enhance efficiency, while a vacuum flask ensures higher temperatures and prolonged heat retention. Future development could include smart IoT features for remote control, exploring energy storage options, and optimizing materials for improved cooking efficiency, contributing to a greener and more sustainable future.

References

[1] O. Kapting'ei, M. N. Muchuka and D. M. Nyaanga, "Advances in Solar Cooking in Developing Countries - A Review," *Journal of Engineering in Agriculture and the Environment*, vol. 7, no. 1, pp. 1-10, 2021.

[2] F. Yettou, B. Azoui, A. Malek, A. Gama and N.L. Panwar, "Solar cooker realizations in actual use: An overview," *Renewable and Sustainable Energy Reviews*, vol. 37, pp. 288-306, Sep. 2014.

[3] M. Hosseinzadeh, A. Faezian, S.M. Mirzababaee and H. Zamani, "Parametric analysis and optimization of a portable evacuated tube solar cooker," *Energy*, vol. 194, pp. 116816, Mar. 2020.

[4] MandeepSekhon& V.P. Sethi,"Thermal modeling and analysis of novel twin-chamber community solar cooker as a replacement of biomass-based cooking, "*International Journal of Green Energy*, vol. 16, no. 2, pp. 167-184, 2019.

[5] A. Saxena, V. Varun, S.P. Pandey and G. Srivastav, “A thermodynamic review on solar box type cookers,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 3301-3318, Aug. 2011

[6] M. Singh and V.P. Sethi, “On the design, modelling and analysis of multi-shelf inclined solar cooker-cum-dryer,” *Solar Energy*, vol. 162, pp. 620-636, Mar. 2018.

[7] S. Pandey, S. Goswami, P. Saini, S. Powar and A. Dhar, “Hybrid Electrical-Solar Oven: A New Perspective,” in H. Tyagi, P.R. Chakraborty, S. Powar and A.K. Agarwal (eds.), *New Research Directions in Solar Energy Technologies*, Energy, Environment, and Sustainability, Springer, Singapore, 2021, pp. 105-116.

[8] N.A. Sagade, A.A. Sagade, M.A. Tawfik and A. Saxena, “Ensuring self-sustainability in decentralized communities through solar cookers combined with food dryers,” *Solar Energy*, vol. 260, pp. 83-93, Aug. 2023.

[9] R. Chaudhary and A. Yadav, “Experimental investigation of solar cooking system based on evacuated tube solar collector for the preparation of concentrated sugarcane juice used in jaggery making,” *Environ Dev Sustain*, vol. 23, pp. 647-663, 2021.

[10] P. Saini, S. Pandey, S. Goswami, A. Dhar, M.E. Mohamed and S. Powar, “Experimental and numerical investigation of a hybrid solar thermal-electric powered cooking oven,” *Energy*, vol. 280, 128188, Oct. 2023.

[11] P.V. Chilbule, L.P. Dhole and N.M. Yewale, “Solar cooking system employing heat pipe solar Collector: A review,” *Materials Today: Proceedings*, vol. 56, part 4, pp. 1972-1981, 2022.

[12] K. Varun, U.C. Arunachala and P.K. Vijayan, “Sustainable mechanism to popularise round the clock indoor solar cooking – Part I: Global status,” *Journal of Energy Storage*, vol. 54, 105361, Oct. 2022.