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A Gravity-Based Simple Dual-Axis Tracker for Solar Cookers

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Abstract - It is well established that all types of solar cookers and photovoltaic panels exhibit improved performance when equipped with sun-tracking mechanisms. However, the widespread adoption of such systems remains relatively recent. Solar cooker trackers can be broadly classified into two main categories: photovoltaic-powered motor systems that provide high tracking accuracy but are relatively expensive and complex to fabricate, and manual or passive trackers that rely on mechanisms such as springs, thermal expansion, or gravity to follow the sun's trajectory.

This paper provides a comprehensive review of existing passive tracking technologies and introduces a novel, simple, low-cost dual-axis tracking design that is easy to construct and operate using locally available materials. The proposed system is particularly suitable for box-type and panel-type solar cookers in rural and resource-limited settings.

Key words: Solar cooker trackers, Machine trackers, Mechanical trackers, single axis, dual-axis, new design

1. INTRODUCTION

The emergence of solar cookers is relatively recent and stems from an accidental yet significant observation by Horace de Saussure in the 18th century. He noticed that fruits kept under a glass bowl in sunlight were partially cooked, which inspired him to design and construct the first solar box cooker around 1767.

At present, more than 400 distinct designs of solar cookers have been documented by Solar Cookers International (SCI), a leading NGO based in the USA, which serves as a comprehensive source of varied solar cooker designs [1]. Traditionally, these designs have been classified into three or four main categories based on their geometry and operational principles:

1.Box cookers 2. Panel and funnel cookers,

3. Parabolic cookers, 4. Indirect types

However, it is more practical to group them into two functional categories:

Group I: Solar cookers that <u>direct</u> sunrays to the cooking pots (box cookers, panels, funnels, etc.)

Group II: Solar cookers that <u>concentrate</u> sunrays at the base of the cooking pots (parabolic reflectors, Fresnel lenses, mirrors, indirect and commercial cookers)

1.1 Group I:

Solar cookers of the first category include box cookers, panels, funnels, and fun panels. They are commonly

referred to as "slow cookers" because they heat up slowly and temperatures they achieve typically range from 80°C to 120°C, requiring approximately one to one-and-a-half hours to cook food. These cookers are suitable primarily for cooking and baking. They are relatively inexpensive and simple to fabricate, contributing to their widespread popularity.

In 1945, Indian scientist M. K. Ghosh enhanced the performance of de Saussure's Box design by adding a reflector, thereby improving its efficiency and reliability [2]. Subsequent innovations followed across the decades like adding a second reflector at additional front window [3], and modifications from horizontal to inclined facades and the addition of two three, four, or even 4+4 reflectors to improve performance (Fig. 1a–d) [4].

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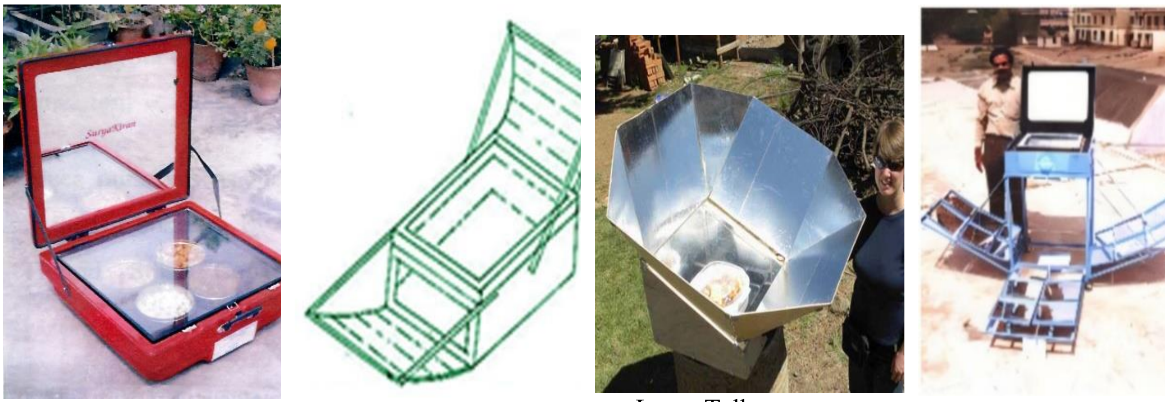
However, it should be noted that adding more reflectors does not necessarily reduce cooking time proportionally (by half or one-fourth). This limitation may be because heating food materials in box-type or funnel-type solar cookers occurs against natural convection currents. However, cooking time may be shorter in inverted-type solar cookers (Fig. 1d) [5].

In 1996, Professor Roger Bernard introduced the panel cooker, and within a year, Professor Steven Jones presented the funnel cooker [6, 7]. The best features of both designs were later integrated to create the "Fun Panel," a popular and efficient model developed by Teong Tan of Malaysia [8]. Ruivo and his team have further developed the 'Funpanel' design [9]. Numerous new designs have been presented by innovators worldwide (Fig. 2).



Common Box Cooker | Cheema's Design | Large Telkes oven | Inverted Box of Ajay

Fig. 1: Types of Solar Cookers of Group I

COOKIT | Funpanel | Copenhagen | Side slit

Fig. 2: Variations in simple panel and funnel types of cookers of Group I

Group II:

In contrast, cookers that concentrate solar radiation onto the base of the cooking vessel can attain much higher temperatures quickly, often reaching 300°C or higher. Such a design was first presented by solar scientists at the University of Wisconsin in 1959. These systems enable cooking, baking, and even frying. However, they are more complex to construct and generally much costlier than slow cookers. These designs include parabolic reflectors, Fresnel reflectors and lenses, compound parabolic designs, water lens and plane mirror combinations, and other types documented in [12] (Figure 3).

Parabolic | Fresnel of VITA | Bin Gu's | Water Lens of Zameer | 'Go sol'

Fig. 3: Concentrating types of solar cookers of Group II

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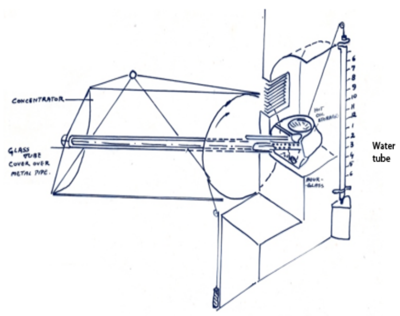
1.3 Solar Tracking: Necessity and Classification

The performance of both types of solar cookers can be significantly enhanced up to 30% through solar tracking. Since the Sun's position changes continuously during the day and across seasons, tracking its movement is essential to maximize incident solar radiation on the cooker. Early attempts at solar tracking relied primarily on manual adjustment. It was probably in 1961 that designers began to introduce mechanical tracking systems [13].

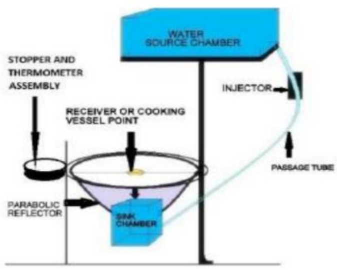
The Sun's movement includes azimuthal (east-to-west) and Altitudinal (elevation angle), and seasonal variations. Therefore, effective tracking systems must account for these aspects to ensure optimal energy capture. Based on the mode and degree of motion, tracking systems can be broadly classified as:

Single-axis trackers: Follow only the azimuthal or east-to-west movement of the sun

Dual-axis trackers: Follow both azimuthal and altitudinal movements



a) Stam type tracker



b) Hemalatha type tracker for parabolic cooker

Fig. 4: Stam and Hemalatha type trackers

1.4 Literature Review on Solar Cooker Trackers

Major reviews on solar cooker trackers deal mostly with photovoltaic (PV)-based systems. Stam presented his water outlet design in 1961. The next notable design without using PVs was presented by Farooqui in 2013 (described in Section 4). An interesting design by Hemalatha (2017) who used a water inlet method to track a parabolic cooker (Fig. 4b) has been described by Ambade [14]. An innovative design using vertical metal strips of different metals for turning solar cookers has been presented [15]. Use of worm gears to fabricate trackers have been described [16]. Some studies deal with trackers using microcontrollers such as Arduino [18]. Many have used Light Dependent Resistors (LDRs) [19]. An excellent review of developments, especially of PV-based trackers can be found in [20]. A recent review again mentions the use of bimetallic strips for trackers [21]. A clockwork mechanism for tracking has been described [22]. Scheffler also uses such a mechanism for orienting his 2 m² parabolic reflector cookers, employing cycle parts and heavy bricks to run the clockwork [23].At Barefoot College, Tilonia, India, illiterate villagers are taught to fabricate large Scheffler cooker complete with tracking mechanism [24]. Most of the work on trackers deal with tracking PV panels or box type cookers a paper on the advantages of tracking panel cookers has been published recently [25]. One more recent review detail various types of trackers [26].

While manual tracking remains the simplest and most economical method, several attempts are being made to automate the tracking process to improve efficiency and ease of use. These automatic tracking mechanisms were designed to follow the Sun's apparent motion without continuous user intervention, thereby maintaining optimal orientation of the solar cooker throughout the day.

1.5 Active vs. Passive Tracking Systems

In active tracking systems, using components such as light sensors (e.g., photovoltaic cells) and microcontrollers detect the position of the Sun and adjust the reflector or cooking assembly through small motors or actuators. These systems, though accurate, are relatively expensive and difficult to fabricate and require periodic maintenance. Their dependence on electrical energy or stored battery power can also limit their use in rural or low-resource settings where simplicity and reliability are preferred.

In contrast, passive tracking systems utilize thermal, mechanical, or gravitational forces for solar alignment. These trackers often employ materials with differential thermal expansion properties, such as bimetallic strips, or sealed canisters partially filled with

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low-boiling-point fluids. As sunlight heats one side of the system, differential expansion or vapor pressure develops, causing the tracker to turn toward the Sun. As the Sun moves, the heating shifts, and the mechanism gradually reorients to maintain alignment [27]. Many passive systems take advantage of gravitational force and turn the cooker toward the sun. Such systems are self-operating and require minimal maintenance, making them particularly suitable for small-scale or domestic solar cooking applications.

Despite their advantages, passive trackers typically respond more slowly and may lose accuracy under cloudy conditions. Hence, the cost considerations, desired level of operational convenience, and, of course, the end user.

2. MANUAL TRACKING

Manual tracking is the least costly option. Here, the user directs the cooker toward the sun manually. For box, panel, and funnel cookers, adjustment once per hour appears to be adequate, while for concentrating-type solar cookers, adjustment every 15 minutes is recommended.

2.1 Manual Tracking for Box Cookers

For box cookers with single-reflector designs, the entire box must be turned to follow the sun's path. The single reflector, generally held in an upright position, can be tilted, forwards or backwards, to adjust for the sun's altitudinal shift to reflect maximum sunlight into the box. The reflector must be inclined forward to "catch" the low angle of the sun in the morning and then tilted upright and backward when the sun reaches maximum altitude.

To enable this adjustment, earlier box cookers were equipped with a *Kamani* (partially curved flat rod with a central slot) with a wing nut (Fig. 5a). One end of the *Kamani* is fixed to the reflector at a slightly lower position, while the other end moves along a bolt with a wing nut on the main box. Many users found this arrangement unsafe, as fluttering reflector due to wind current, loosening the wing nut assembly, resulting collapse of reflector breaking the mirror.

Some Designers Fig.5b) [28] provided a notched iron flat bar of 25 mm wide and 3–4 mm thick. In 1988, the author had suggested using a similar iron flat with holes, (Fig. 5c). Note that in both the cases, the flat is fixed at the higher part of the reflector ensuring more stability, and it is held by a peg on the box with a hole for a pin. This arrangement allows the reflector to be inclined forward as well as backward to capture maximum sunlight. [12].

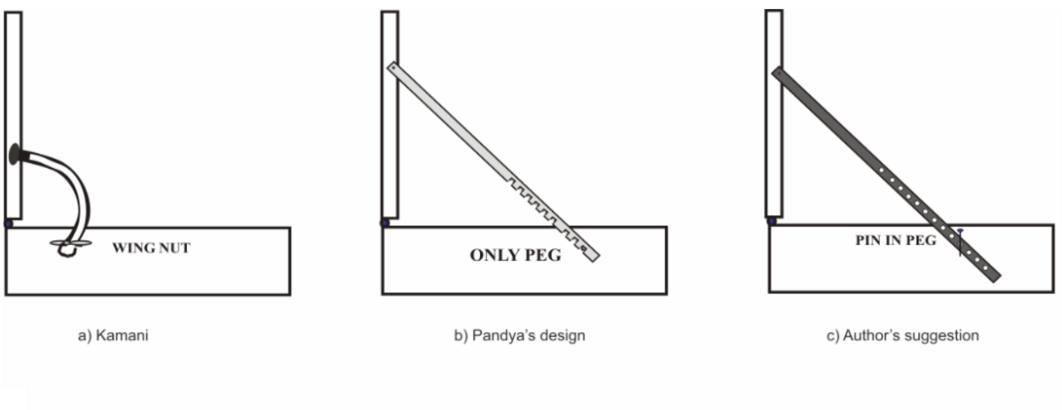

Fig. 5: Altitude adjustment of reflector of box cooker.

For tracking azimuthal movement, many designers, including Bureau of Indian Standards [29]), suggest using caster wheels at the base of the cooker - either four wheels or just two, as in many popular African cookers like ‘Najuba’.

Two interesting variations of reflector adjustment deserve a special mention. Jim La Joie presents an adjustable reflector assembly in his 4+4 reflector design, the "All Season" cooker [30], while Joe Sol [12] suggests moving the reflector assembly fixed on top of the cooker (Fig. 6a & b). The original Telkes oven was fixed to an A-frame with a cradle for holding cooking vessels when the cooker is tilted and suggests moving the reflector assembly fixed on top of the cooker (Fig. 6a & b). The original Telkes oven was fixed to an A-frame with a cradle for holding cooking vessels in the cooking chamber, when the cooker is tilted to track the sun.

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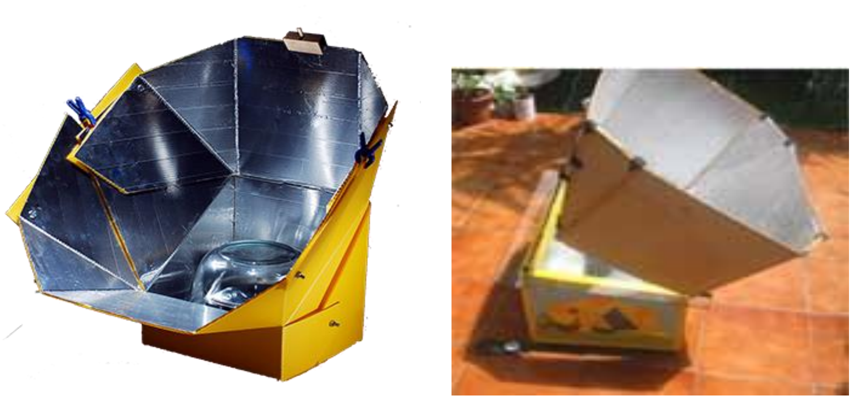
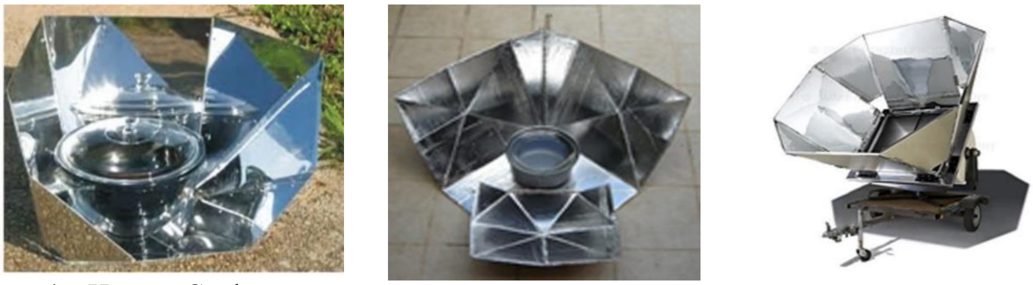


a) All season of Jim La Joie   Joe Sol's reflector assembly

Fig. 6: 'Tracking' in 4+4 reflectors of box cookers



a) Hot pot Cooker   b) Suntastic   c) Village Solar cooker

Fig. 7: In built 'tracking' in Funnel Cookers

2.2 Manual Tracking in Panel and Funnel Cookers

Panel and funnel-type solar cookers also require hourly adjustment to gain maximum benefit [25]. In the 'COOKIT' design, provisions have been made to adjust the main (back) and front reflectors for elevated solar angles, allowing improved energy capture during different times of the day. Similar features are found in the Copenhagen and side-cut panel designs (Fig. 2c & d). The panel and funnel cookers like the Diamond cooker of SHE and the "Suntastic" cooker (Fig. 7a & b) can also be adjusted slightly for altitude. In contrast, larger funnel-type cookers, often referred to as "Village solar cookers," can be conveniently oriented along both azimuthal and altitudinal angles (Fig. 7c).

2.3 Manual Tracking for Parabolic Cookers

The original parabolic cooker developed at the University of Wisconsin incorporated an arc-shaped metal flat with a series of holes to permit angular adjustment of the reflector (Fig. 8a). Some later designs introduced a screw-driven mechanism at the rear of the reflector, operated manually via a small wheel to tilt the dish upward or downward (Fig. 8b). East–west movement was facilitated by mounting the assembly on a pivoted base or wheeled stand, allowing easy rotation to track the Sun's azimuthal movement.

Developers like Solsource parabolic cookers, offer a very simple arrangement to focus sunlight at the base of the cooking vessel with minimal eye strain. The author had also proposed a simplified alternative method using long levers with threaded tips that lock into provided nuts and hold the inner fixed element. In the simple stand made from pipe pieces, lever A helps with azimuthal adjustment, while lever B is for altitudinal adjustment. Additionally, a movable cooking stand with lever C was suggested to regulate thermal input to the cooking vessel by adjusting its height [12].

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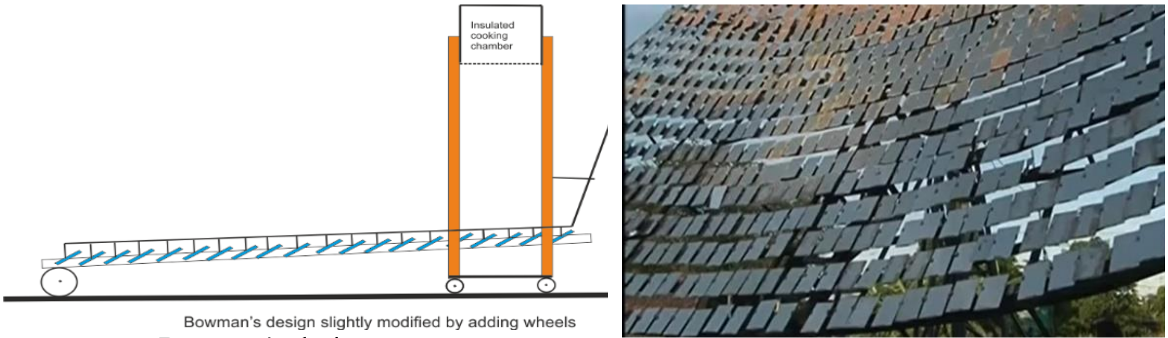
a) Wisconsin Type b) Commercial design c) Authors design

Fig. 8: Tracking of parabolic types of cookers

2.4 Other Innovative Manual Tracking Designs

An innovative tracking modification was presented in early 1978 [32]. It consisted of an improved inverted box-type cooker in which the insulated box was mounted approximately 150 cm above ground with an open bottom. Sunlight was reflected into the box by an array of horizontally aligned mirror strips positioned at ground level (Fig. 9a). This mirror array could be tilted to track the Sun's altitude using a single lever located near the cooker box, while azimuthal adjustment was achieved through wheels attached at the base. This configuration offers a potential for adaptation to "GoSol"-type concentrator cookers (Fig. 3e), which employ an array of plane mirrors to focus sunlight onto the underside of the cooking vessel via a secondary reflector, thereby enhancing efficiency and usability. A similar mechanism was adapted by Sila Sutharat of Thailand for his 1000-mirror solar array to fry food for 30–40 people (Fig. 9b) [33].



Bowman's design 1000 mirror system of Sila

Fig. 9: Orientation of flat mirrors in other designs

In the case of fixed reflectors like the Auroville Bowl, the moving focus is "followed" by a computerized receiver system (Fig. 10a) [34]. For water lens or Fresnel lens systems, the focus is diverted to the base of the cooking pot by moving a secondary reflector. In the author's design, Sedi's Heliac design [35] and Scheffler's cookers, a secondary reflector directs the focus to the cooking pot (Fig. 10b & c).

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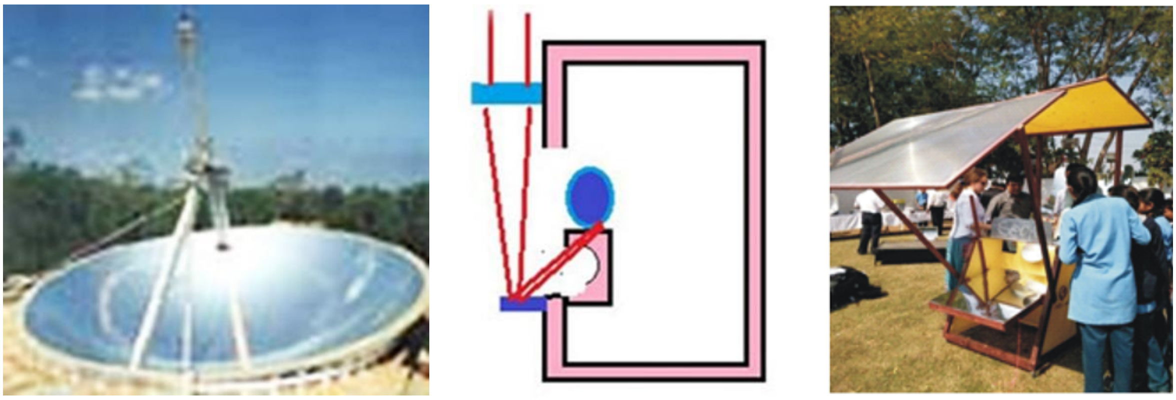

a) Auroville bowl, a) Authors design c) Sedi's Heliac

Fig. 10: Focus tracked by moving receiver or directed by secondary mirrors

3. MACHINE TRACKING

Most solar cooker trackers currently in use, fall under the single-axis category, while dual-axis trackers remain relatively rare. In manual tracking systems, the user is required to stand under direct sunlight to periodically realign the cooker to the sun's position. To overcome this limitation Machine tracking systems were developed, particularly by solar scientists aiming to conduct continuous and precise efficiency evaluations of solar cookers.

Machine tracking systems are broadly classified based on the number of axes they track—namely, single-axis and dual-axis systems [36]. Single-axis trackers provide one degree of freedom, while dual-axis trackers possess two, enabling more precise alignment with the sun's azimuth and altitude movements. Yet another review presented a comprehensive chart illustrating various types of machine trackers [20]. These systems typically employ one or two small motors powered by photovoltaic (PV) cells or other sensors. For a detailed understanding of their operation and classifications, comprehensive reviews may be consulted [37, 38].

Machine trackers vary in complexity - from simple, homemade prototypes to sophisticated automated systems. Numerous demonstration models and do-it-yourself versions can be found on online platforms such as YouTube, contributing to the broader dissemination of solar tracking technology. Some simple units are also available for purchase online.

4. MECHANICAL TRACKING

This paper focuses primarily on gravity-based mechanical tracking systems, also known as Passive tracking. An excellent reference where many earlier designs can be found is Fandom website [39]. In these systems, mechanical motion is induced by the displacement of a weighted element such as a small rock, brick, or water-emptying or water-filling bottles.

A new, simplified dual-axis tracking method with a compatible stand design is proposed in this paper. This approach is particularly well suited for box-type and panel-type solar cookers. Mechanical trackers in this category are predominantly single-axis systems, with hardly any examples of dual-axis variants reported in the literature. The present proposal aims to address this gap by providing a dual-axis tracking system.

One of the earliest gravity-based tracker designs was introduced by (Fig. 4a) [13] for an indirect-type solar cooker. His system utilized a cylindro-parabolic reflector placed outside the kitchen to heat oil circulating through a metallic pipe positioned at the reflector's focus. The heated oil circulated into an insulated cooking chamber located in the kitchen. To achieve east–west (or south–north) solar tracking, Stam used a half-filled bottle (as weight) suspended inside a water-filled tube. As water was gradually released from the outer tube, the partially filled bottle sank, thereby rotating the reflector appropriately.

A similar concept was adopted by Von Oppen (1977) in his deep parabolic cooker design [40]. Swet [41] later introduced a mechanism employing a metallic heliotrope, demonstrating comparable functionality.

These early innovations established the foundation for several subsequent mechanical tracking systems based on the fluid displacement principle. In most trackers, the cooker assembly must be reset to the east in the morning. Only some papers mention

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about "night return mechanism" [42]. Most machine trackers have such a system; however, in mechanical tracking systems, turning the cooker to the east in the morning has to be done manually.

4.1 Air-Medium Tracking

An inventor from Africa, particularly from a water-scarce region, was dissatisfied with Stam's water let-out system, so proposed a pneumatic tracking system utilizing an air-filled automobile tire tube. In this

4.2 Water Let-Out Tracking

Farooqui proposed an innovative spring-assisted tracking system utilizing a curved pipe configuration (Fig. 12) [17]. In this setup, a stretched spring in the curved pipe is held in tension by a water-filled bottle connected to an outlet resembling an intravenous (IV) drip mechanism. As the water is released slowly, the bottle's weight decreases, enabling the spring to contract and turn the cooker. Farooqui meticulously detailed design parameters such as the diameter and length of the pipe, optimal quantity of water in the bottle, the release rate of water, and the resulting angular displacement of the cooker.

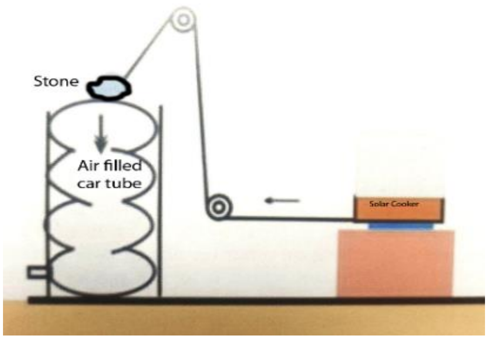

Fig. 11: Tracking with air-filled tube

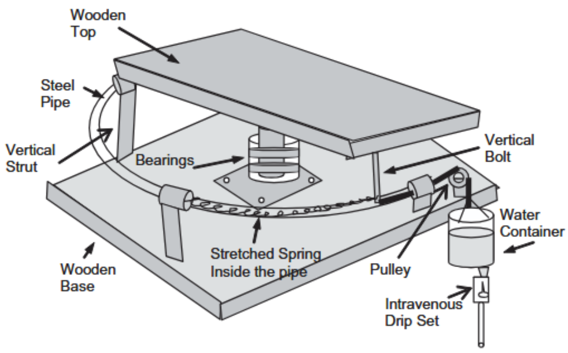

Fig. 12: Farooqui's design

Another simple and effective concept, developed by the Sun Salute Team, [43], employs a "seesaw" mechanism, initially designed for PV panels but adaptable to other types of cookers with slight modifications. In this system, a rectangular shaft (approximately 7 cm square and about 2 meters long) is mounted at its centre on an A-frame stand, allowing free oscillation. One end of the shaft carries a counterweight, while the opposite end supports a water-filled bottle. As water is let out slowly (through a filter into a clean vessel), the shaft tilts toward the counterweight, thereby turning the attached solar panel or solar cooker. An additional benefit of this design is that it produces a small amount of clean, filtered water as a by-product of the tracking process. Many such simple tracking systems are listed in Fandom [39].

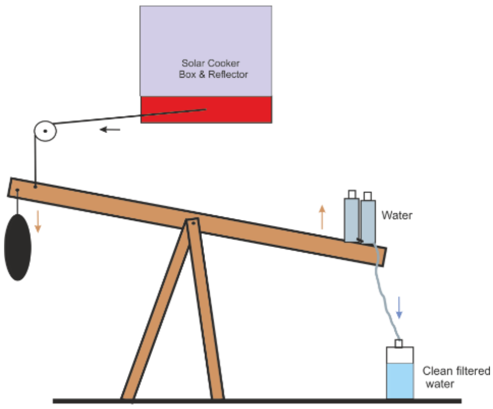

Fig. 13: Seesaw type of Sun Salute Team (modified)

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4.3 Water Let-In Tracking

In another class of mechanical designs, tracking motion is induced by water inflow rather than outflow, as described in the two systems mentioned above. In these systems, water is gradually let into a container attached to the cooker. The increasing weight causes the container to descend slowly, generating the torque required to rotate the cooker in synchrony with the sun's apparent movement.

The system offered in this paper is simple, reliable, and easy to fabricate using locally available materials, hence making it particularly suitable for rural and resource-limited contexts.

Many designs mentioned in the literature use elaborate systems to keep the cooker on a specially built rotatable platform. The use of the popular "Lazy Susan" (common on dining tables to enable easy access to dishes) is suggested by many. Others suggest using steel bearing balls, glass marbles, or even golf balls. All these designs are rather elaborate to construct and costly. The design presented here uses minimal wood or other easily available materials for construction of a stand to support the solar cooker and attach the turning mechanism.

4.4 Proposed Stand Design

The proposed stand design consists of a main supporting shaft fabricated from a square wooden beam with a cross-section of 7.6 cm and an overall height of approximately 60–75 cm. The height of the shaft can be selected to match the user's ergonomic and operational convenience. At the base, two flat wooden members, each measuring approximately 2.5 cm in thickness and 60–65 cm in length, are firmly fastened to the shaft using screws to provide structural stability, as illustrated in Fig. 14. At the upper end of the shaft, two similar wooden members are joined orthogonally to form a precise cross, which is connected to the main shaft using a half-threaded bolt/screw through the central hole. The central hole in the cross is made slightly larger than the smooth (unthreaded) portion of the screw to allow free rotational movement. The threaded portion of the bolt/screw has to be securely embedded into the main shaft. When a bolt–nut assembly is used, it should be ensured that the nut is firmly embedded and fixed within the wooden shaft (Fig. 14). Steps for fabrication of the stand are shown in Fig. 15.

This configuration provides sufficient structural integrity to support a box-type solar cooker with a total mass of 20–30 kg or even more, while allowing smooth rotational motion required for solar tracking along the azimuthal axis.

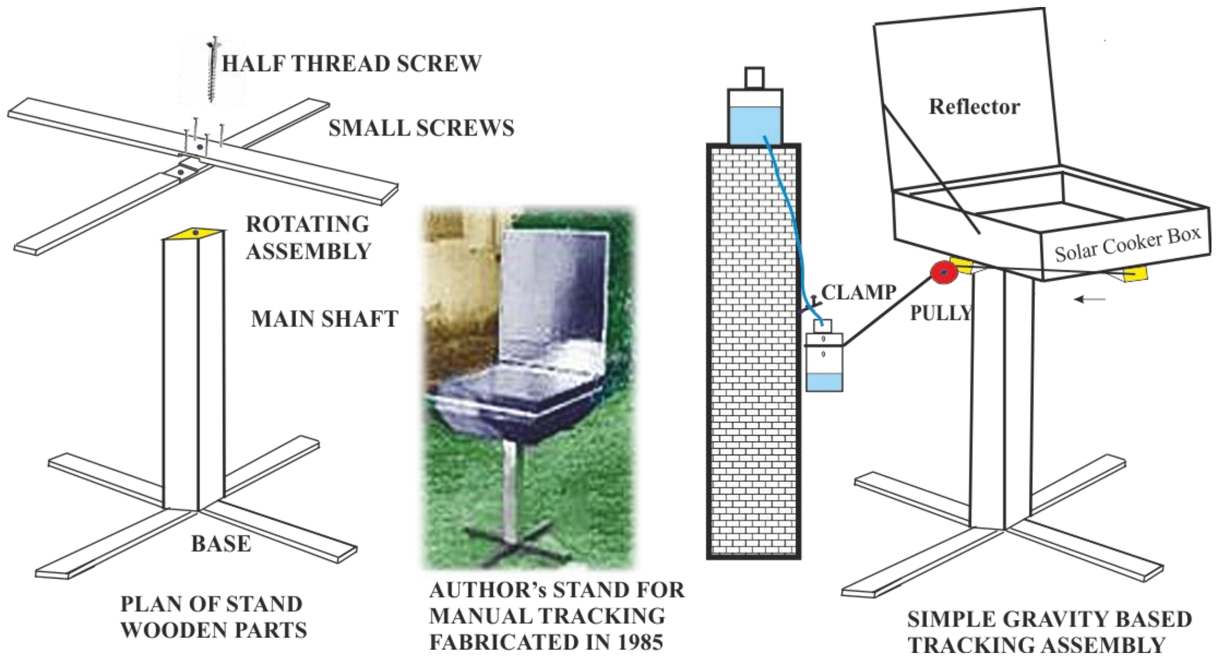

Fig. 14: The stand and arrangement for tracking

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Fig. 15: Actual fabrication of the simple stand

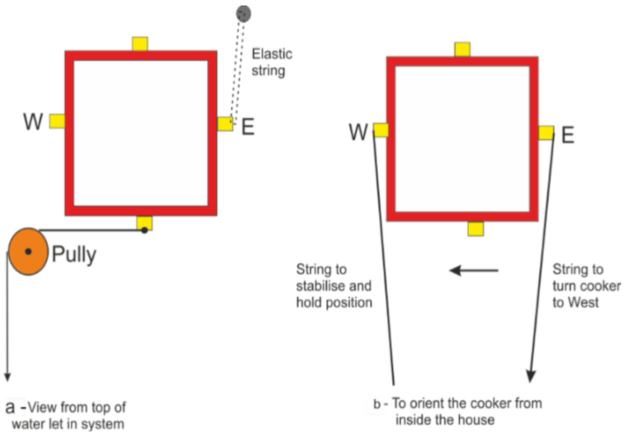

Fig. 16: View from top of simple stand

In the absence of suitable wooden parts, a 7.5 cm diameter PVC pipe can be employed as an alternative. In such cases, the upper and lower sections of the pipe should be filled with a cement–sand mixture to enhance rigidity, while the central section may be compacted with soil to improve stability and dampen vibrations. Pipes of 2.5 to 3 cm diameter, filled with mud, can also be used for lower and upper cross supports.

4.5 Tracking Mechanism

An elastic component, like rubber band or strips of automobile tire tube (or even of a tire bicycle tube) - should be used to prevent abrupt shifts caused by varying loads and wind and also stabilize the assembly. The elastic component is attached to another shaft/stick on the northeast side (Fig. 16a). On the opposite side (west), a partially filled water bottle (with weight matching the tension of the elastic component) is suspended from the cross using another string routed over a smaller pulley. Water is gradually transferred into this bottle from an elevated container positioned on a support shaft adjacent to the main assembly, as shown in Figs. 14 and 15a.

As water slowly accumulates in the suspended bottle, the incremental increase in weight generates a controlled, slow rotational torque, thereby enabling the cooker to track the sun's azimuthal movement throughout the day. Similar to conventional tracking mechanisms, this configuration functions as a single-axis solar tracker.

4.6 Dual-Axis Capability

This design can also be adopted for adjusting the reflector to the sun's altitudinal movement by attaching another bottle assembly at the back (north) of the reflector. After midday, when the sun's angle reaches maximum height and starts declining, this bottle assembly must be switched over to the front (south) of the reflector (Fig. 17). This will pull the reflector forward to face the declining sun angle. This arrangement for the reflector is totally independent of the main system that turns the cooker to adjust to the azimuth angle. Thus, this design becomes a dual-axis tracking system. The concept can also be adopted with some changes, for the entire dish of a parabolic reflector.

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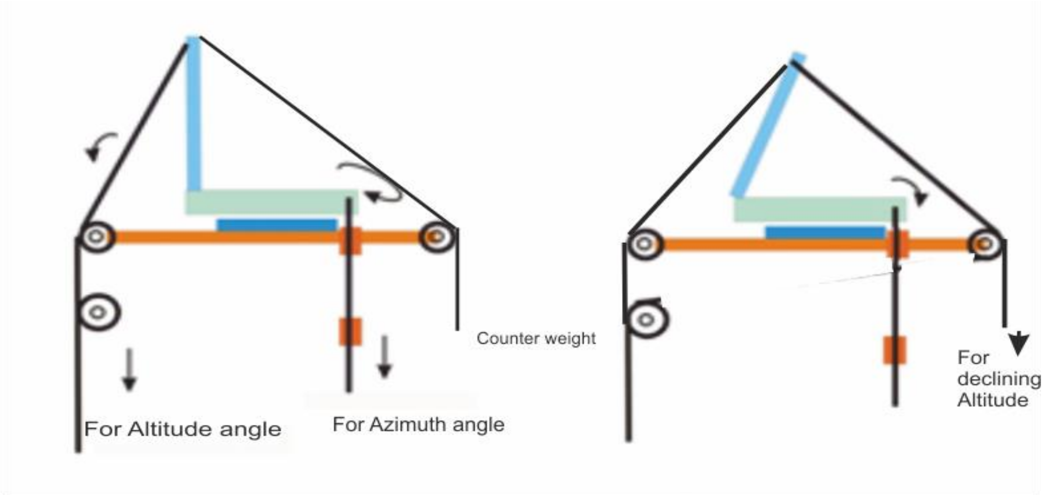

Fig. 17: Dual-axis reflector adjustment

The design presented here uses very little wood, recycled bottles, and water. It can also be made from cardboard, as suggested by NightHawkinlight. Instead of using glue as suggested, slightly diluted Polyvinyl Acetate glue or similar adhesive or paint can be used.

The cooker on the stand can also be operated manually from the comfort of one's home using a set of strong 2–3 mm diameter strings—one for turning the cooker toward the west and another to stabilize and hold against wind. Two more strings can be used to adjust the reflector of a box cooker to the sun's altitude angles (Fig. 16b). Alternatively, if available, very fine sand, as used in hourglasses, can also be used in the system. The water used in the system can be recycled; hence, it can be beneficial in water-scarce areas as well.

5. CONCLUSION

Users who wish to improve the performance of their solar cookers by 22–30% should use a tracker. If they can afford it, a machine tracker that uses PVs or LDR systems to run a motor to track the sun would be the best option. Many others can use any one type of mechanical tracker described here. In most cases, cooking can be completed in 2–3 hours. Thus, tracked solar cookers can be used for storing solar heat, which can be used to warm food for dinner. Or if the stored heat is not used, it can help the cooker achieve a quick warm-up the next morning.

The proposed dual-axis gravity-based tracking system offers a simple, low-cost, and effective solution for enhancing solar cooker performance, particularly in rural and resource-limited settings. The use of locally available materials and recycled components makes this design accessible and sustainable.

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