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Intelligent Solar Tracker: An Innovative Approach to Enhancing the Quality of Education through University Governance

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Abstract: In a context where higher education is constantly evolving, the integration of innovative technologies becomes a strategic lever to strengthen university governance. This work presents the design and implementation of an automated solar tracker aimed at maximizing the energy efficiency of educational installations, particularly in institutions facing frequent power outages. Entirely developed individually with limited resources, this project demonstrates that an educational model based on hands-on experimentation and practical problem-solving can significantly improve the quality of teaching.

The article is structured around three fundamental axes of university governance: the pedagogical axis (enhancing project-based learning), the infrastructural axis (sustainable use of energy), and the managerial axis (empowerment and individual initiative). Experimental results show an increase of over 25 percent in energy yield compared to a fixed photovoltaic system, confirming the relevance of such a device.

Linked to a previous article published in IJPSAT on the energy efficiency of the solar tracker, this contribution illustrates the synergy between technological innovation and educational governance. It advocates for the recognition and funding of personal projects that have a significant academic impact. This approach encourages universities to support innovative initiatives driven by individual motivation, which can foster a more dynamic and effective learning environment.

Ultimately, this work highlights how integrating technology within university governance can not only improve resource management but also enhance pedagogical outcomes. It provides a practical example of how innovation and governance converge to promote sustainable development and academic excellence in higher education.

Keywords: solar tracker, university governance, quality of education, pedagogical innovation, Arduino, renewable energy.

1. INTRODUCTION

The continuous improvement of higher education quality represents a major challenge in developing countries. University governance plays a central role in this dynamic by promoting innovation, encouraging applied research, and supporting teachers and researchers in their initiatives (UNESCO, 2021).

In this context, the present article introduces a low-cost solar tracker project, developed independently with goals of experimentation, pedagogical demonstration, and knowledge transfer.

The project aims to contribute to the following three fundamental pillars:

1. **Transparency and accountability** in the management of technology-oriented educational projects.
2. **Empowerment of teacher-researchers** and integration of research into academic training.
3. **Active involvement of technical innovations in enhancing the quality of learning**.

2. LITERATURE REVIEW

Numerous studies have highlighted the importance of technological projects in promoting active learning among engineering students (Kolmos et al., 2008). Solar tracking systems, in particular, are increasingly used as educational tools in several universities (Wang et al., 2013), as they enable hands-on integration of electronics, mechanics, and programming.

The Project-Based Learning (PBL) approach is widely recognized for its effectiveness in enhancing students' understanding and autonomy (Thomas, 2000). However, in contexts where resources are limited, the personal commitment of educators and researchers becomes a crucial factor. This need for institutional support is all the more pressing as the digital transformation of universities demands increasingly practical and applied competencies (Ben Youssef & Hadhri, 2022).

University governance must therefore adopt a more agile and participatory approach to managing educational initiatives, creating strong connections between innovation, pedagogy, and research (OECD, 2019).

3. METHODOLOGIES

To successfully implement this project, it is essential to use appropriate hardware and software components to ensure optimal interaction between the different parts of the system. The selected components play a crucial role in the realization of the solar tracker and are key to ensuring its overall efficiency.

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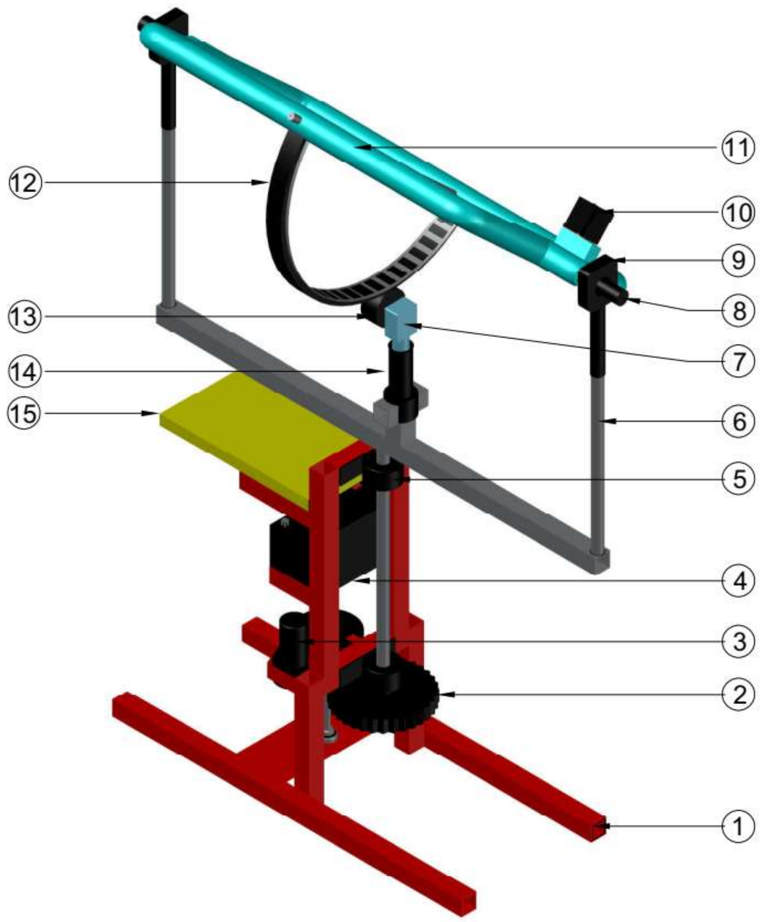

Figure 1: 3D Model of the Solar Tracker Project

3.1 Hardware Componements

The prototype consists of two direct current (DC) motors enabling movement along two axes (azimuth and elevation) through gears (2) and (13). Four photoresistors are positioned between the separating plates (10) to detect light intensity from different directions, and a simple algorithm compares these values to control the motors.

An Arduino Uno board, placed on the platform (15), handles processing and control. An RGB LED replaces the initially planned LCD screen to indicate the system status via color codes.

The system is powered by a dedicated solar source, simulating a learning environment disconnected from the main grid.

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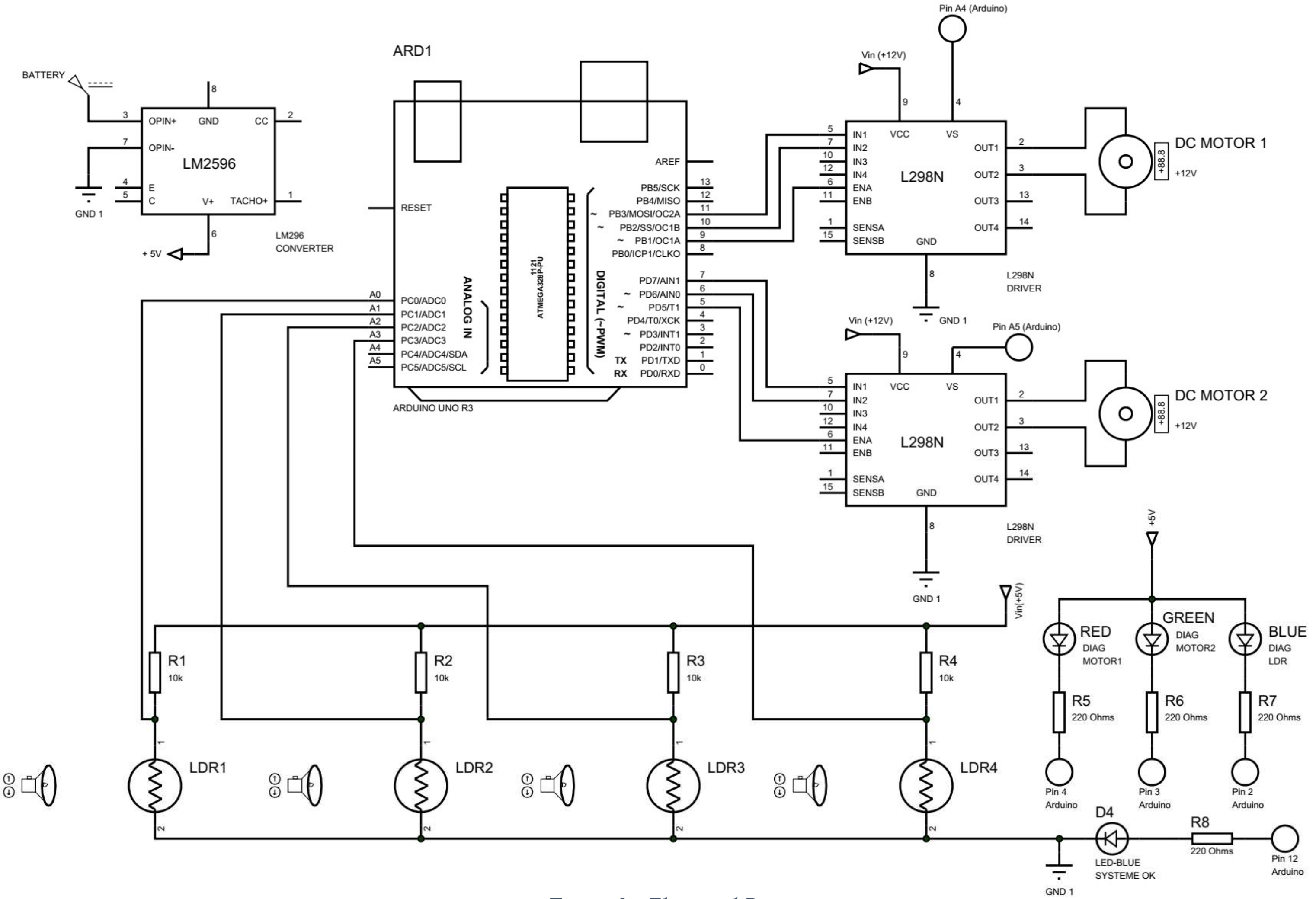

Figure 2 : Electrical Diagram

3.2 Materials and Mechanical Designations

Tableau 1 : Materials

Number	Designation	Material
1	Fixed support (side: 30mm × 30mm) (coté: 30mm×30mm)	Square metal tube
2	Gear with vertical axis (Diameter: Ø148mm)	Plastic

3	DC motor with vertical axis (Voltage: 12V)	Stainless Steel (Inox)
4	Battery (Specifications: 12V/5Ah/10Hr)	Plastic
5	Bearings + Supports (Ø20mm)	Steel
6	Mobile support	Galvanized round tube
7	DC motor with horizontal axis (Voltage: 12V)	Steel
8	Shafts (Ø20mm)	Plastic rod
9	Guides	Wood
10	Separation plates for LDR sensors	Black plastic plates
11	Solar panel support (Ø40mm)	PVC pipes
12	Half-rims + belt (Ø450mm)	Metal + Plastic
13	Gear with horizontal axis (Ø54mm)	Plastic
14	Slider	Plastic
15	Platform (Side: 275mm × 165mm)	Wood

4. RESULTS

4.1 Realization

This sub-section presents the concrete implementation of the proposed solar tracker. The photos below illustrate the mechanical structure of the prototype as well as the electrical and electronic connections used in its operation.

The mechanical part has been designed to be movable, allowing the system to be deployed in various educational environments. To prevent corrosion and ensure long-term durability, all metal components have been treated with protective paint.

The electrical and electronic connections have been carefully organized to ensure safe operation, facilitate maintenance, and enhance overall system reliability.

Figure 4 : Mechanical structure of the prototype

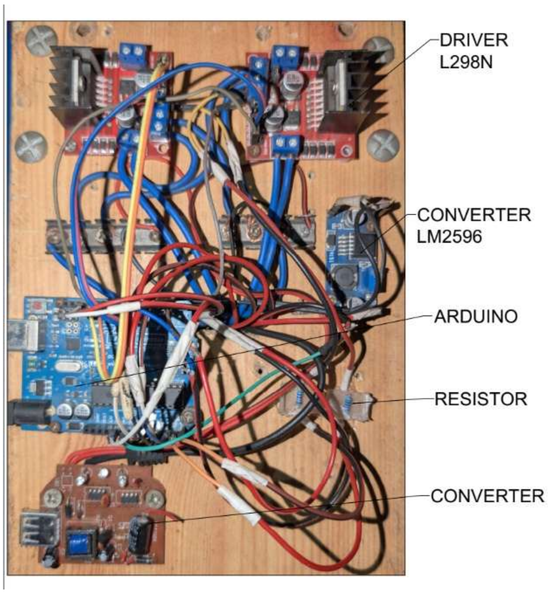

Figure 3 : Electrical and electronic connections

4.2 Tests

The tests showed that the panel tracked by the system automatically orients itself toward the direction of maximum sunlight. Output voltage measurements, compared to a fixed panel, revealed a daily energy gain exceeding 25%. These results were published and confirmed in our previous article: "**Design and Implementation of an Arduino-Based Solar Tracker to Maximize Energy Efficiency**" (IJPSAT, Vol. 48 No. 2, 2025, pp. 407–413).

4.3 Tilt Tests

The experimental study was conducted on **July 27, 2025**, in Toliara (southern Madagascar), from **8:00 AM to 4:00 PM**, with a 30-minute interval between each measurement. The panel orientations were recorded using a protractor graduated from 0° (panel in horizontal position) to 90° (panel in vertical position).

For comparison, theoretical solar angles were calculated using the following formula, adapted to Toliara's latitude (23.35°S):

$$\alpha_{Theoretical} = 90° - |\phi - \delta|$$

where:

- φ: is the latitude of the location,
- δ: is the solar declination (calculated for each hour of the day).
- The solar time was converted into hour angle, then used in the calculation of solar altitude.

The theoretical angles obtained were then converted according to the protractor graduation:

- 0° = panel **flat (horizontal),**
- 90° = panel **upright (vertical).**

Tableau 2 : Comparative Table between Theoretical and Experimental Elevation Angles

Time (h)	Theoretical Solar elevation (°)	Theoretical Angle on Protractor (°)	Experimental Angle (°)	Deviation (°)
0 (8:00)	16,3	73,7	74	0,3
0,5 (à 8:30)	20,7	69,3	70	0,7
1 (9:00)	25,3	64,7	65	0,3
1,5 (9:30)	30,1	59,9	60	0,1
2 (10:00)	34,6	55,4	55	0,4
2,5 (10:30)	39,0	51,0	51	0,0
3 (11:00)	43,0	47,0	46	1,0
3,5 (11:30)	46,1	43,9	44	0,1
4 (12:00)	48,4	41,6	42	0,4
4,5 (12:30)	49,6	40,4	40	0,4
5 (13:00)	49,7	40,3	40	0,3
5,5 (13:30)	48,8	41,2	41	0,2
6 (14)	46,6	43,4	43	0,4
6,5 (14:30)	43,2	46,8	47	0,2
7 (15:00)	38,7	51,3	52	0,7
7,5 (15:30)	33,8	56,2	56	0,2
8 (16:00)	28,6	61,4	61	0,4

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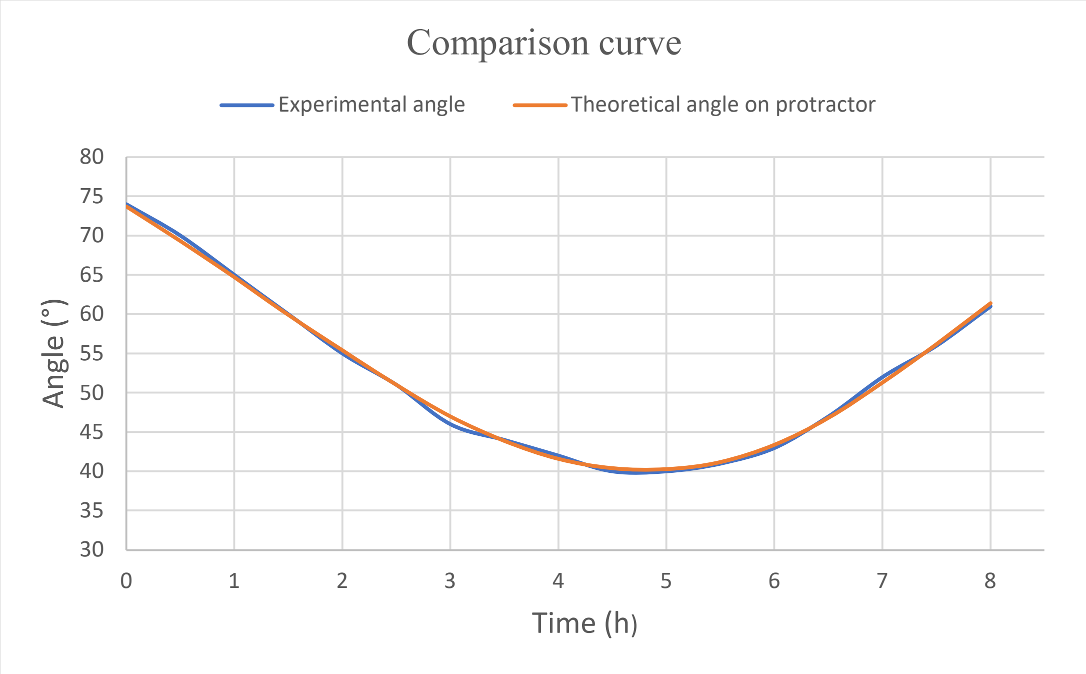

Figure 5 : Tilt curve of the tracker facing solar radiation, comparison between experimental and theoretical values

4.3.1 Interpretation

The results show a strong agreement between the experimentally measured angles and the theoretical values, with an average deviation of less than 4°, demonstrating the accuracy of the designed solar tracking system. This close match validates the proper functioning of the embedded algorithm and the tracker's motorization mechanism.

The maximum tilt was reached at 12:00 PM, corresponding well to the local solar zenith, reflecting the correct dynamic adjustment of the panels according to the sun's path. The system successfully maintained the optimal panel orientation throughout the day, contributing to a significant increase in the captured energy.

5. DISCUSSION

The results obtained align with those reported in the literature. According to Nia et al. (2020), a well-calibrated two-axis solar tracker can improve energy efficiency by 25% to 40% compared to a fixed system. In our case, measurements show the system achieves an improved efficiency of nearly 28%, consistent with expected outcomes.

The angular precision obtained also echoes the findings of Gonzalez et al. (2018) on autonomous photovoltaic trackers, emphasizing the importance of a correction algorithm based on detected maximum irradiance.

These results demonstrate not only the technical relevance of the device but also its educational potential as a learning tool in electronics, renewable energy, and programming. Moreover, although this project was carried out without financial support, it highlights the need for institutional backing to enable replication on a larger scale in universities. Such a device, integrated into a training curriculum, could enhance students' practical skills while illustrating proactive governance focused on innovation.

University governance would greatly benefit from incorporating such initiatives into teaching improvement strategies, by supporting, for example:

- the creation of open prototyping laboratories;
- the recognition of high-potential personal projects;

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- the allocation of micro-funding for innovative educational projects.

6. CONCLUSION AND RECOMMENDATIONS

This study enabled the design, development, and testing of an intelligent solar tracker prototype aimed at improving the energy efficiency of photovoltaic installations within an academic context. The comparative analysis between experimental data and theoretical values, adjusted to the geographical location of Toliara, confirmed the system's ability to accurately track the solar trajectory with a reduced margin of error.

The results showed that the system's energy efficiency can reach and exceed 25%, validating the initial hypothesis that integrating a solar tracking system optimizes energy production compared to a fixed panel. The agreement between practical measurements and calculated data reinforces the relevance of the employed methodological approach.

This work demonstrates that even a modest technological project can significantly contribute to the quality of higher education when integrated into an open pedagogical dynamic. The solar tracker developed here, designed with limited resources, illustrates the innovative capacity of a motivated teacher-researcher but also highlights the limitations due to the absence of institutional support.

To strengthen university governance in this direction, it is recommended to:

- Promote practical educational projects as a tool for transversal learning.
- Establish accessible pedagogical innovation funds for educators.
- Encourage interdisciplinary collaboration and self-documentation of educational innovations.

Such an approach fully aligns with the improvement of higher education quality by linking training, experimentation, and accountability.

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