Implementation and Automated Data Acquisition of a Dual-Axis Offset Parabolic Solar Concentrator

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***Abstract*—This study presents the implementation and experimental data evaluation of a solar radiation concentrator using a recycled offset parabolic antenna coupled to a dual-axis tracking mechanism. Data acquisition is fully automated through an integrated sensor network and datalogger system. System control is performed by an ESP32 microcontroller, a NEO-6M GPS module, and pulse-driven (PWM) digital servomotors executing the Solar Position Algorithm (SPA). Experimental data logging is carried out every 5 minutes using 8 Type-K thermocouples (interfaced via MAX6675 digital amplifiers) distributed across a 10×15 cm stainless steel receiver plate, 2 current sensors for electrical power monitoring, and a meteorological station measuring wind speed and atmospheric pressure. The concentrator features a geometric concentration factor of $C = 6.45$ and an optical efficiency of $\eta_o = 68.4\%$.**

I. Introduction

Concentrating solar power technologies offer a viable renewable route for thermal processes; among them, parabolic trough solar collectors (PTSCs) have reported irradiance efficiencies between 19% and 31% in applications such as solar distillation [2]. However, while PTSCs are line-focus collectors, point-focus parabolic dish concentrators are more suitable for reducing radiation losses and achieving higher concentration ratios by converging incident solar radiation onto a single focal receiver, which strictly requires continuous two-axis tracking [1], [4]. Existing optical trackers based on light-dependent resistors (LDRs) tend to lose focus under partial cloud cover, whereas standard astronomical trackers designed for symmetric reflectors do not account for the displaced focal point and inclined optical axis ($\theta_{\text{offset}} = 29.59°$) of offset parabolic antennas. Therefore, this study presents the implementation and automated data experimentation of a dual-axis offset parabolic solar concentrator controlled by an ESP32 microcontroller executing the Solar Position Algorithm (SPA) [3].

II. Methodology

The solar concentrator utilizes an elliptical offset parabolic dish (60×69 cm, depth $h = 7$ cm) coupled to two degrees of freedom driven by pulse-operated high-torque digital servomotors (150 kg $\cdot$ cm), as shown in Fig. 1. The optical collector exhibits a geometric concentration factor of $C = 6.45$ and an optical efficiency of $\eta_o = 68.4\%$. System control is executed by an ESP32 microcontroller programmed in C/C++, which parses NMEA sentences from a NEO-6M GPS module (latitude, longitude, altitude ≈ 2325 m a.s.l., and UTC time) to compute the real-time solar vector via the SPA algorithm. The ESP32 generates calibrated Pulse-Width Modulation (PWM) signals (50 Hz, 500–2500 μs) to position the azimuth and elevation servomotors while compensating for the intrinsic offset angle ($\theta_{\text{el}} = \alpha_s - \theta_{\text{offset}}$).

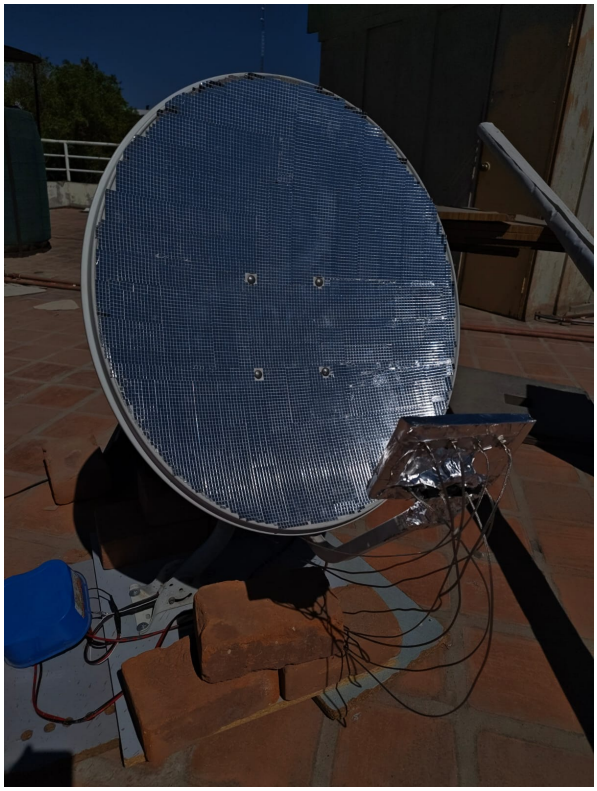


Figure 1. Assembled mechanical structure of the dual-axis offset parabolic solar concentrator.

Automated data acquisition is managed every 5 minutes by the ESP32 and stored in a solid-state datalogger. Thermal profiling on the focal stainless steel plate (10×15 cm) is performed using an array of 8 Type-K thermocouples coupled with MAX6675 cold-junction compensated SPI digital converters. Simultaneously, 2 current sensors (INA219/ACS712) monitor the electrical consumption of the servomotors and the photovoltaic charging circuit. Furthermore, an integrated meteorological station measures local atmospheric pressure and wind speed (V) to incorporate local atmospheric refraction into the SPA calculation and evaluate convective heat transfer

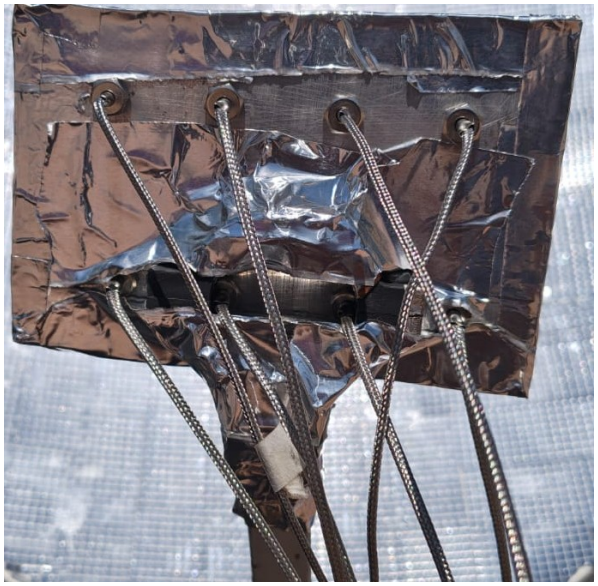


Figure 2. Spatial distribution of the 8 Type-K thermocouples over the 10×15 cm stainless steel receiver plate.

coefficients (h_{conv}) on the stainless steel receiver.

III. Results and Discussion

The ESP32 control architecture effectively managed SPA astronomical calculations, PWM pulse generation for the digital servomotors, and automated multi-sensor datalogging at 5-minute intervals. Measurements from the 2 current sensors confirmed stable electrical operation under the discrete 10-second tracking update cycle, registering current peaks exclusively during servomotor actuation pulses.

Experimental tests validated that the geometric offset compensation kept the concentrated solar beam focused on the 10×15 cm stainless steel receiver plate throughout the operating window. The spatial arrangement of the 8 Type-K thermocouples across the receiver (Fig. 2) enabled continuous monitoring of the thermal gradient, recording an average exterior surface temperature of $300\,^{\circ}\text{C}$ and an internal system temperature averaging $120\,^{\circ}\text{C}$.

With a geometric concentration factor of $C = 21.68$ and an optical efficiency of $\eta_o = 68.4\%$, the synchronized thermocouple array and meteorological station data allowed the quantification of convective and radiative thermal losses, yielding an instantaneous thermal efficiency of up to 32.3% [4].

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