

Motorized star tracker

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Abstract

Astrophotography requires precise, often expensive motorized mounts to counteract Earth's rotation. To democratize this process, an affordable, fully open-source, 3D-printable altazimuth star tracker was designed. By utilizing a heterogeneous dual-processor architecture, the system guarantees real-time, jitter-free motor precision, alongside high-level computational features such as automated tracking and a modern interface.

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1. Introduction

Motivation Astrophotography is a financially challenging hobby to enter. The mounts that are already available are often expensive, heavy, and closed systems. By leveraging 3D printing technology and easily accessible embedded electronics, the barrier to entry can be lowered, allowing hobbyists to capture objects in the night sky without a big budget.

Why is a mount needed? To properly expose the dim objects of the night sky, a camera must capture a significant amount of light. While typical photography adjustments, such as widening the aperture or increasing the ISO, can help, they are severely constrained. Increasing the ISO, or the sensor's sensitivity to light, will also increase the amount of noise in the picture, thereby decreasing the signal-to-noise ratio. [1] Widening the aperture is an easy way to increase the amount of light reaching the sensor, but for a lens to have a large aperture, it also needs larger, more complex glass elements, which increase the lens's cost.

Therefore, the only viable option is to increase the camera's exposure time. However, the Earth's continuous rotation causes the apparent "diurnal motion" of celestial bodies across the sky at approximately 15.04 arcseconds per second. If a camera takes a long exposure without compensating for this rotation, the point-source light of stars will smear across multiple pixels. This effect, known as star trailing, completely degrades the photograph's resolution and is evident in Figure 2 on the poster; thus, a mount that actively counteracts this effect is necessary.

2. Star tracking mount designs

Equatorial mounts are the most common among astrophotographers. They operate by having one rotational axis perfectly aligned with Earth's axis of rotation. This alignment provides a profound kinematic simplification: only a single motor needs to run at a constant velocity to fully counteract the star's apparent motion. However, this asymmetrical design requires heavy, dead-weight counterbalances, making the setup heavy and cumbersome to transport. [2]

In contrast, an **altazimuth mount** uses two mutually perpendicular axes—altitude (up/down) and azimuth (left/right). Mechanically, this is superior because the load is distributed symmetrically, eliminating the need for counterweights. The trade-off is computational complexity. Because neither axis aligns with Earth's rotation, the software must continuously calculate complex coordinate transformations to adjust the speeds of both motors simultaneously. [2]

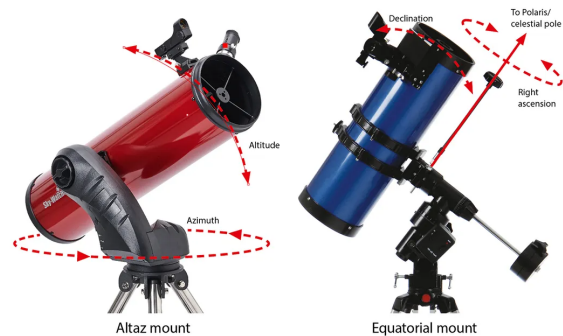


Figure 1. An Altazimuth mount and an Equatorial mount. Image courtesy of BBC Sky at Night Magazine

While the altazimuth topology elegantly solves the problem of bulky counterweights, it introduces a unique optical challenge known as field rotation. Because the mount tracks objects using horizontal and vertical movements rather than arcing along the celestial equator, the target object slowly rotates relative to the camera sensor. This means that even if the mount keeps the target object perfectly centered, the surrounding field will rotate around the center point. [2] To correct this, the mount has to introduce a third mechanical axis.

3. System architecture

As illustrated in Figure 4 on the poster, the system relies on a dual-processor architecture to ensure both usability and microsecond precision. Standard single-board computers running a full operating system, such as Linux, struggle with strict real-time hardware control due to unpredictable software interrupts. To solve this, the responsibilities were split between two separate chips.

The main "brain" of the mount is a Raspberry Pi 5. It establishes a wireless Wi-Fi connection, allowing the user to control the entire system remotely via a custom web application on their smartphone or laptop. The Pi 5 handles computationally intensive tasks, such as mount calibration with plate solving, user interface hosting, and camera communication.

The Raspberry Pi 5 streams commands over a custom protocol built on top of UART to the microcontroller: a Raspberry Pi Pico. Its sole responsibility is to transform these commands into perfectly timed step pulses, immune to jitter and latency issues common to a standard operating system.

These precise pulses are fed into stepper motor drivers that control the NEMA 17 motors on all axes. Crucially, the system's hardware utilizes standard StepStick sockets. This modular design ensures that the system is not locked into a single piece of hardware, allowing users to easily swap or upgrade to different drivers in the future. Currently, Trinamic TMC2209 drivers are used in these sockets. They were chosen for their proprietary StealthChop technology, which enables the silent, vibration-free operation necessary to keep the camera perfectly stable during long exposures. [3]

To reliably integrate all the electronic components, including the Raspberry Pi Pico, stepper motor drivers, power distribution, and peripheral interfaces, a Printed Circuit Board (PCB) was also designed.

4. Software Interface and Control

The mount is controlled via an application built on the Avalonia UI framework, which connects to the mount locally via a Wi-Fi hotspot created by the Raspberry Pi 5.

Because the application will be used almost exclusively in the dark, the interface uses a dark theme with red accents, as red has the lowest impact on the eye's light-sensitive rod cells. [4]

The UI application serves as the centralized "mission control" for the entire setup. It aggregates real-time telemetry from the mount, displays a live video stream from the camera, and provides an intuitive interface for both manual control and complex automated routines, such as plate-solving and guided tracking.

5. Results

The true test of the system's mechanical rigidity and software timing is its photographic output. As shown in Figure 1 on the poster, the system achieves high tracking accuracy, maintaining a sharp image at a 50mm focal length, even with a 10-minute exposure. In comparison, Figure 2 shows an untracked exposure with standard star trailing, even though the exposure length was half that of Figure 1. The tracked image results in pinpoint stars and clearly resolved deep-sky structures, validating the dual-processor approach.

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References

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