Contents

List of abbreviations

DIY	Do it yourself
CAD	Computer Aided Design
V	Volt
gf.cm	Gram-force centimeter
approximately	approx.
Nm	Newton meter

List of figures

Bild 1: https://kamera-foto-zubehoer.de/objektiv-ratgeber

Bild 2: https://youtu.be/hhDdfiRCQS4?t=124

Bild 3: https://youtu.be/hhDdfiRCQS4?t=131

Star Track

Astrophotography thrives on the prolonged collection of light. Whether it's the starry sky, the Milky Way, or faintly glowing gas and dust nebulae, the goal of every astrophotographer is to capture these fascinating celestial objects in detailed images. However, the exposure time is subject to strict limits determined by the focal length of the lens and the Earth's rotation. The focal length significantly influences the image frame: shorter focal lengths cover a larger area, while longer focal lengths result in a narrower field of view

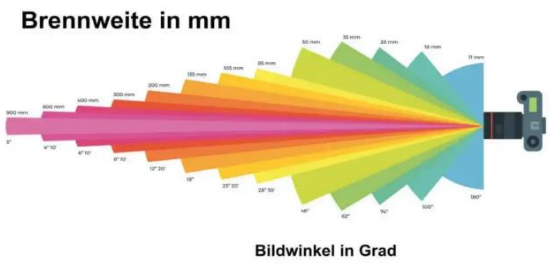

Figure 1

Additionally, the Earth's rotation complicates longer exposure times. Since the Earth moves at different circumferential speeds—faster at the equator compared to northern or southern latitudes—star trails form during extended exposures, which is particularly problematic for large focal lengths.

To enable sharp images even with longer exposures, astrophotographers require a tracking system that compensates for the Earth's movement. Such devices are available but start at around €300 in the amateur range, which represents a significant investment for many hobby photographers. Existing models use stepper motors for smooth motion and often need to be manually aligned with the polar star.

To make astrophotography accessible on a smaller budget, the goal of this project is to develop a low-cost DIY tracking system and make it freely available as an open-source project. This guide will include a list of all necessary components, CAD files for 3D printing the housing, a clear wiring guide, and the software needed to control the stepper motors and other modules. With the open-source approach, the project aims to be accessible to everyone and cost roughly 1/3 of a comparable commercial product.

Project Objective

The objective of this project is to develop a universal tracking system for cameras that compensates for Earth's rotation, enabling long-exposure photography in astrophotography. The tracking system should be compatible with standard tripods and camera models, operate independently of location, and be cost-effective and easy to manufacture.

Requirements, Constraints, Risks, and Challenges

Commercial tracking systems use a polar scope and manually adjust the angle to Polaris. The more precise the initial alignment, the better the result. The motion is either driven by a pre-tensioned spring, which is not always precise, or by stepper motors with worm gear reduction. The average tracking duration is 60 minutes per session. Components exposed to the environment are typically made of weather-resistant materials like aluminum or plastic, which also provide other advantageous properties, such as low density and high strength.

<u>Requirements:</u>

1. Functional Requirements:
   - Motion Control:
     - Enable motion along two axes for precise tracking of celestial objects.
     - Compensate for Earth's rotation to allow long exposures without star trails.
   - Sensor Integration:
     - Facilitate easy determination of position and alignment.
     - Optionally integrate a gyroscope for stabilization.
   - Universal Compatibility:
     - Support standard tripod threads.
     - Work with various camera models and lenses regardless of focal length.
2. Non-Functional Requirements:
   - Cost Efficiency:
     - Target material costs: 1/3 the price of commercial tracking systems (approximately €100).
   - User-Friendliness:
     - Easy assembly and operation, even for users without technical expertise.
     - Provide clear instructions and guides.
   - Open-Source Approach:
     - Publish blueprints, software, and instructions under an open-source license.

Constraints:

- Technological Foundation:
  - Use a microcontroller (e.g., Arduino or Raspberry Pi).
  - Power supply via a battery or external power source.
- Manufacturing:
  - Use 3D printing for housing and mechanical components.
  - All components must be widely available and affordable.

Acceptance Criteria:

- Functional Testing:
  - Demonstrate tracking capability through a long-exposure photograph with sharp stars (no visible star trails).
- Cost Verification:
  - Compare material costs to the target of approximately 30% of the market price.
- Documentation:
  - Provide a complete DIY guide (including components, CAD files, wiring, and software instructions).

Risks and Challenges:

- Technical Risks:
  - Insufficient stability or accuracy of the tracking system for long exposures.
  - Issues integrating sensors or the control unit.
- Project Scope:
- Balancing cost constraints with high precision and stability.

Summary:

The project aims to develop a cost-effective and universal tracking system for astrophotography. The solution will be functional, user-friendly, and accessible to a broad audience.

Research for the requirements

To meet the outlined constraints, such as the use of a microcontroller and cost-effective components, stepper motors are preferred as the primary drive system. Their precise control capabilities, low voltage requirements, and affordable availability make them an ideal choice. Among the various options discussed in online forums, two stepper motor models were frequently mentioned:

1. 28BYJ-48 Stepper Motor: This is a compact and inexpensive motor that operates at an input voltage of 5 V. It has a step angle of 5.625°, which results in low resolution, and a holding torque of 300 gf.cm (approx. 0.03 Nm). This motor often comes equipped with an integrated gearbox with a reduction ratio of approximately 1:64. While the gearbox increases the effective torque, it reduces the rotational speed. Due to its small size and ease of control, the 28BYJ-48 is commonly used in small, budget-friendly projects.
2. Nema 17 Stepper Motor: These are available in various versions and offer torque values ranging from 0.17 Nm to 0.55 Nm. Their input voltage can go up to 24 V, and the step angle is 1.8°, providing significantly higher precision than the 28BYJ-48. Nema 17 motors are frequently used in applications that demand high accuracy and high torque, such as 3D printers and CNC machines.

To implement simultaneous motion along two axes, I sought inspiration from existing designs, such as those used in observatories or radio telescopes. I analyzed their movement mechanisms through time-lapse footage and looked for solutions that closely resemble these concepts. One particularly compelling example was a research paper published by the Institute of Electrical and Electronics Engineers (IEEE) in 2021. The study, conducted by Japanese scientists, is titled "*ABENICS: Active Ball Joint Mechanism With Three-Degrees-of-Freedom Based on Spherical Gear Meshings*" and describes an innovative ball joint mechanism based on spherical gear meshing.

The detailed description of this mechanism explains how two motors are used to control motion. A worm gear is employed to drive the monopole gear, while a second worm gear is responsible for its rotation. This design enables precise control of movement and could serve as a foundation for the development of my project. In this adaptation, the monopole gear is replaced with a standard gear, and a mount is added for attaching the camera.

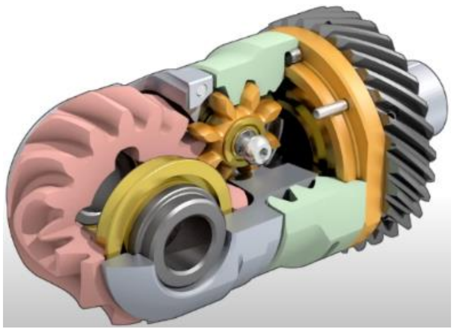

Figure 3

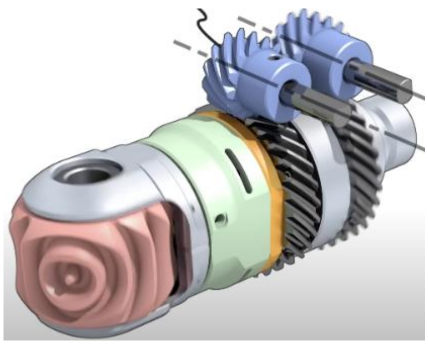

Figure 2

Structure of the tracking system

Stepper motors are used for the construction of the tracking system, enabling movement along two axes. A GPS module and a magnetometer module are employed to determine the location and orientation of the camera. This ensures precise and location-independent operation. Additionally, a gyroscope could be integrated to detect and compensate for unintended camera movements.

The control unit is based on an Arduino, which contains a powerful main microcontroller and processes the sensor data. The software on the Arduino controls the stepper motors based on the sensor data to compensate for Earth's rotation. Power is supplied via a rechargeable battery, allowing for flexible outdoor use. Alternatively, an external power source can be used for extended sessions.

Furthermore, fine adjustments of the stepper motors can be made, either manually or automatically through the software. The tracking system's design is made to be compatible with various camera models and tripod sizes, ensuring universal usability.