

An Automated Astronomical Observation System

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Abstract

We present an automated control system, to support astronomical observations for amateur astronomers. Our system provides the trajectory calculation of a specific astronomical object, and controls the astronomical telescope to immediately observe that astronomical object, based on the various information such as the current time, the current location, and the astronomical databases. Comparing with the previous commercial systems, our system provides more automated supports to the user, in a more cost-effective way.

Keywords: *Astronomical observation; telescope; automated support*

1. Introduction

Due to the development of optics technology and astronomic theories, astronomical observations are now more specialized to the professional astronomers, and also more easily-accessible to the amateur astronomers. Many amateur astronomers start to own their own astronomical telescope and use them to observe the night sky. However, current astronomical telescopes are, in fact, hard to handle. Even for professional astronomers, they need to calculate the exact trajectory of the target astronomical object, and calibrate the azimuth and elevation angles of the telescope to find it.

A typical process of the astronomical observation can be summarized as follows:

- step 1.** Place the telescope mounting system aligned to the correct directions. The mounting system should be kept horizontal.
- step 2.** Calculate the proper azimuth and elevation angles for the target astronomical object. Typical astronomical algorithms can be used to calculate these angles from the current time and location of the observer. Notice that these calculations are often too complex to get it without computers.
- step 3.** Calibrate the telescope directions and observe the target object. In almost cases, we need some corrections due to calculation errors and mechanical inaccuracy.
- step 4.** Re-calibrate the telescope as time goes on. Since the stars move as time goes on, we also need to re-calibrate the angels of the telescope to trace the target object.

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As you can easily find, all these steps are easy to be supported by computers and other electronics devices, including GPS modules and step motors.

In this paper, we present an integrated system for automated astronomical observation. We first show the *virtual night sky* on the PC screen, from the current time and location of the user. This 3D astronomical simulator provides an easy way of finding the target astronomical object, in the monotonous night sky. Additionally, the controller module with the GPS support enables more automation through providing the current location and time from the GPS signals. When the user selects a specific astronomical object, our system controls the step-motors of the telescope mounting system, to finally direct the telescope to the target object.

At this time, some 3D astronomical simulators are commercially available. They include Stellarium [1], Google sky [2], Starry night [3], and others. These simulators provide helpful screens for the amateur astronomers. However, setting the telescope to a certain astronomical object is another problem. Some simple telescope mounting systems provide easier control for the telescopes. However, they are still hard to use for novice astronomers.

Our final implementation shows an integrated and automated system for astronomical observation. This system can display the virtual sky on the PC screen. After selecting an astronomical object, our system automatically calibrates the telescope to observe it. We provide this more integrated and more automated system, at the more affordable price.

Section 2 shows the overall design of our automated astronomical observation system. Some implementation details are also given in this section. In Section 3, we show the final product and its demonstration results. Our conclusions and future work are followed in Section 4.

2. Overall Architecture Design

Our system consists of three major components: a *3D astronomical simulator*, a *telescope mounting system*, and a *controller module* to connect these two components, as shown in Figure 1. The 3D astronomical simulator shows the simulated images of the night sky, and various user interface modules to control the finally simulated astronomical images. Precise and detailed astronomical algorithms are also included to calculate exact trajectories of stars and solar system planets.

The controller module is accomplished with a Linux-based embedded board with a GPS sensor module, to feedback the GPS information to the astronomical simulator, working on a PC. This embedded board is connected to the PC with Bluetooth communications. High-level control signals from the astronomical simulator are converted to low-level signals to the telescope mounting system, on this embedded board.

The telescope mounting system provides two-axis controller features for the azimuth and elevation angles of the mounted astronomical telescope. For astronomical tracking purpose, these angles are required to be controlled much accurately. So, our mechanical reduction gear system provides accurate controls of the angles even to the 0.06 degree precision, which is sufficient for most widely-used astronomical telescopes. Low-level signals from the controller board are used to control the step motors. Positional sensors are used to construct the loop feedbacks for the motors. Thus, the current status values can be verified on both of the 3D astronomical simulator and the embedded board.

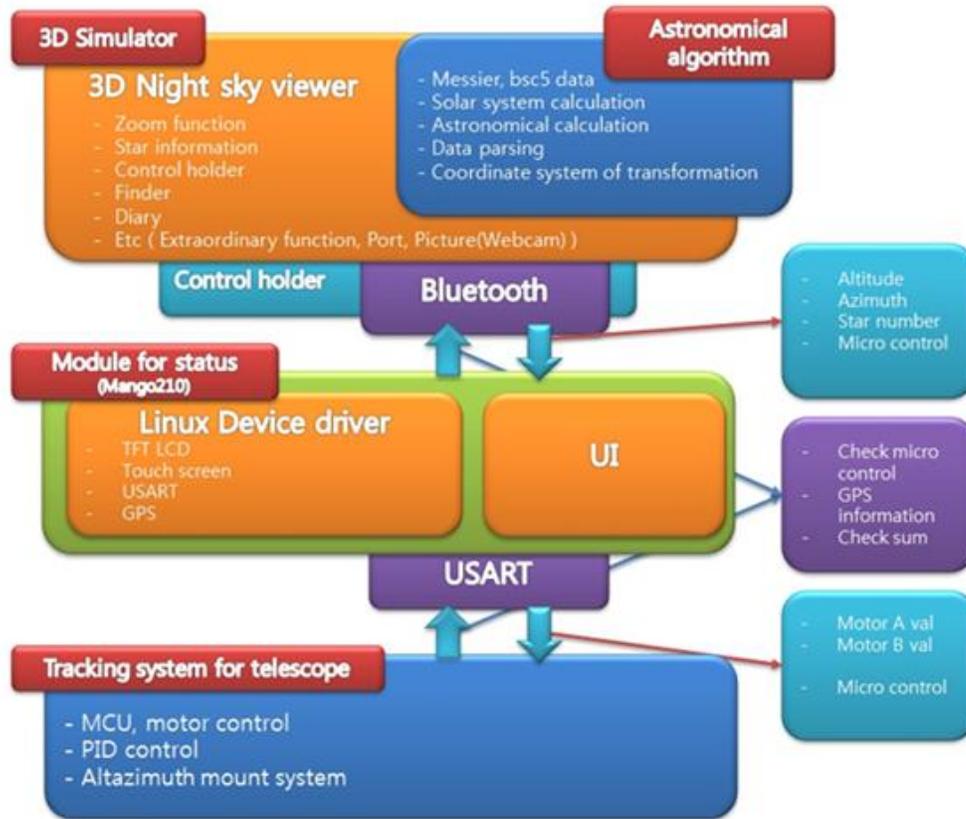


Figure 1. Overall system architecture

On the simulator, the virtual night sky is rendered with the OpenGL graphics library [4], to effectively represent the night sky and to provide higher readability. The overall layout of the simulator is shown in Figure 2. At the top of the screen, the system accepts the current time, the latitude and longitude of the current location, to render the current night sky at the current location. In the more automated mode, the GPS signals provided from the controller module are used to automatically get the current location and the current local time. On the right side, some user interface buttons are used to turning on and off the rendering of the whole sky, constellations, and planets. We used the Stellarium system [1] as a reference model for the simulator part. Thus, it shows similar components and features.

For the precise rendering of the night sky, we exacted information on each astronomical object from the astronomical databases. The configuration of our solar system is much easier to get their astronomical details. In contrast, there are more scholarly databases, such as the Messier list [5] and the BSC list [6], from various astronomical societies. We finally used the Messier list, the BSC list, the nebula list, and the solar system, to render the virtual night sky. Our system covers more than 10,000 astronomical objects, and can be extended to additional databases.

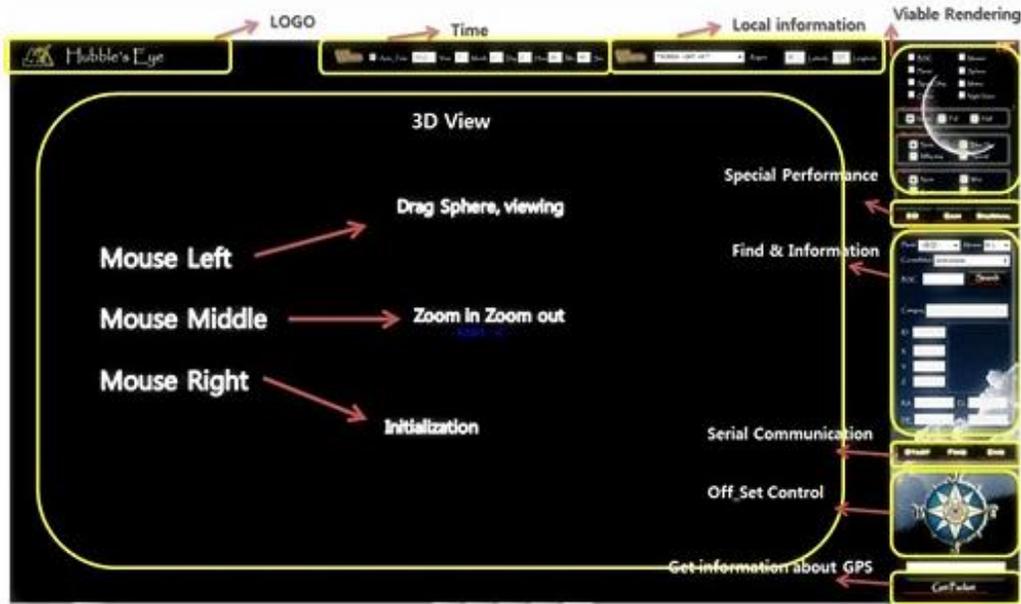


Figure 2. Our GUI Design for the 3D Astronomical Simulator

From these astronomical databases, we get the current location of a specific astronomical object in the sky. However, we need some astronomical calculations to convert that information to the azimuth and elevation angles of our telescope. In this calculation process, we need totally for coordinate systems as follows:

Horizontal coordinate system: The horizontal coordinate system is a celestial coordinate system that uses the observer's local horizon as the fundamental plane. This coordinate system divides the sky into the upper hemisphere where objects are visible, and the lower hemisphere where objects cannot be seen since the earth is in the way. The azimuth and elevation angles of the telescopes are specified in this coordinate system. Notice that in this coordinate system, the astronomical objects are naturally moved as the time goes on.

Equatorial coordinate system: The equatorial coordinate system is a widely-used method of specifying the positions of celestial objects. It may be implemented in spherical or rectangular coordinates, both defined by an origin at the center of the Earth, a fundamental plane consisting of the projection of the Earth's equator onto the celestial sphere (forming the celestial equator), a primary direction towards the vernal equinox, and a right-handed convention [7].

Ecliptic coordinate system: The ecliptic coordinate system is a celestial coordinate system commonly used for representing the positions and orbits of Solar System objects. The system's origin can be either the center of the Sun or the center of the Earth, its primary direction is towards the vernal equinox, and it has a right-handed convention [8]. Because most planets and many small solar system bodies have orbits with small inclinations to the ecliptic, it is convenient to use it as the fundamental plane.

Galactic coordinate system: The galactic coordinate system is a celestial coordinate system in spherical coordinates, with the Sun as its center, a primary direction aligned with the approximate center of the Milky Way galaxy, and a fundamental plane approximately in the galactic plane [9].

Table 1. Summary of Celestial Coordinate Systems

| coordinate system | center point (origin) | fundamental plane | poles | coordinates | | primary direction |
|-------------------|-----------------------|-------------------|-----------------|-------------------|--------------------|------------------------|
| horizontal | observer | horizon | zenith | elevation | azimuth | north point of horizon |
| equatorial | center of the earth | celestial equator | celestial poles | declination | right ascension | vernal equinox |
| ecliptic | | ecliptic | ecliptic poles | ecliptic latitude | ecliptic longitude | |
| galactic | center of the sun | galactic plane | galactic poles | galactic latitude | galactic longitude | galactic center |

These coordinate systems are converted each other, time to time, to get the proper location. Table 1 shows a summary of these coordinate systems. Additionally, we need at least three time systems, as follows:

Universal time: Universal Time (UT) is a time scale based on the rotation of the Earth [10]. It is a modern continuation of Greenwich Mean Time (GMT), i.e., the mean solar time on the Prime Meridian at Greenwich, and GMT is sometimes used loosely as a synonym for UTC.

Sidereal time: Sidereal time is a time-keeping system. Astronomers use it to keep track of the direction to point their telescopes to view a given star in the night sky [11]. A sidereal day is a time scale that is based on the Earth's rate of rotation measured relative to the fixed stars. From a given observation point, a star found at one location in the sky will be found at nearly the same location on another night at the same sidereal time.

Local time: A time zone is a region on Earth that has a uniform standard time for legal, commercial, and social purposes. It is convenient for areas in close commercial or other communication to keep the same time, so time zones tend to follow the boundaries of countries and their subdivisions. From the astronomer's point of view, the local time in a specific time zone should be correctly processed to get the universal time and sidereal time. Notice that the time zones are often skewed due to some cultural or political reasons. These skews should be corrected.



Figure 3. Our Implementation: Telescope Mounting System and its Control Module

3. Implementation Results

Overall layout of our system is shown in Figure 3. Figure 4 shows screen shots from our embedded system board. Typical telescope mounting systems are used as reference models for our system. Thus, the overall layout is similar to the commercial telescope mounting systems. We actually use two step motors to control the azimuth and elevation angles of the telescope. One is located near the center axis of the mounting device, while the other is at the rotation axis attached to the telescope.

For the 3D astronomical simulator part, the BSC and Messier lists are fully processed to produce the final azimuth and elevation angles. These angles are used to render the corresponding star on the virtual night sky, as shown in Figure 5. For users' convenience, we provide two-ways of controlling the system. User can use the 3D astronomical simulator interface. Additionally, the embedded board also provides a simple button-based user interface for low-level but direct control of the step motors.

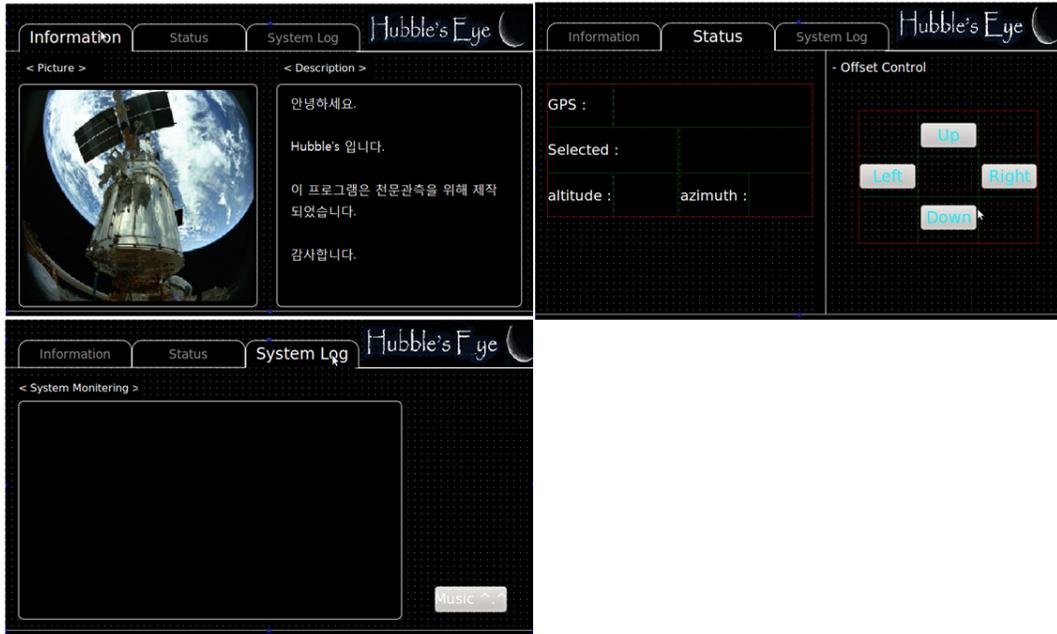
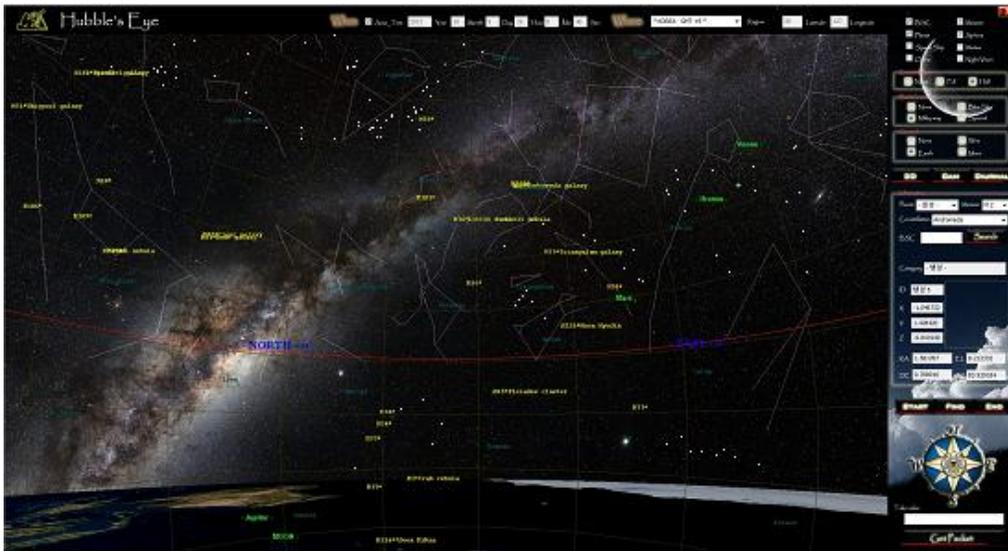


Figure 4. Screen Shots from our Embedded System Board



(a) the whole screen



(b) magnified view

Figure 5. Our 3D Astronomical Simulator Implementation

4. Conclusion

We aimed to provide an automated astronomical observation system, which allows even the novice astronomers to easily use high-precision commercial astronomical telescopes. Typical astronomical telescopes require at least several month training to track a certain astronomical object. Although high-end astronomical telescopes provide some automated or semi-automated devices to set the telescope, our purpose is to build a more simple and easy-to-use system at an inexpensive price. Our final implementation shows that we accomplished a cost-effective solution for the automated astronomical observation.

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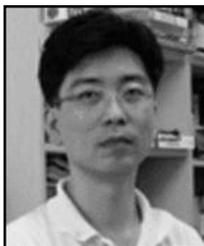
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