RESEARCH REPORT

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Astronomy

The basic process of detecting a star, is converting the device orientation to a coordinate in space. Although stars are stationary, the Earth rotates around its axis. Because we are standing on Earth, the sky seems to rotate. Given the observer's position on Earth and the time and date, this rotation can be calculated.

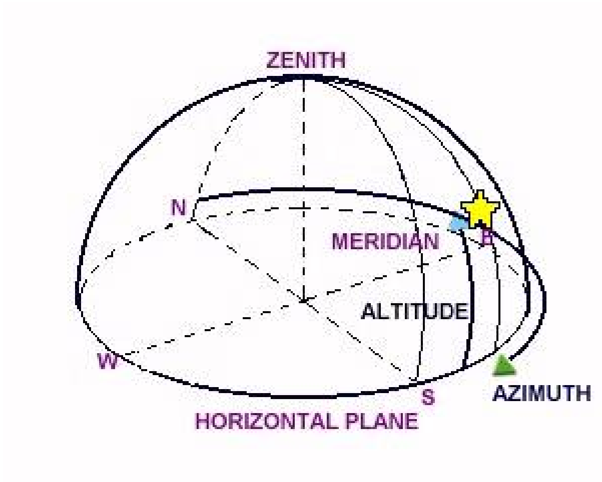
Coordinate systems

There are two spherical coordinate systems primarily used for this application. All coordinate systems define the direction with two angles, relative to an origin, a fundamental plane and a primary direction.

Horizontal coordinate system

Origin: observer
Fundamental plane: horizon
Primary direction: north point on horizon

This coordinate system defines the orientation relative to the horizon (defined by the direction of gravitational pull) and the north pole.
A point is defined by its Azimuth (Az or A) and Altitude(Alt or a). Azimuth is the angle going eastward along the horizon. Altitude is the shortest angle between the point and the horizon, negative below the horizon.



Source: [1]

Equatorial coordinate system

Origin: center of Earth
Fundamental plane: plane perpendicular to Earth's rotational axis (equatorial plane)
Primary direction: vernal equinox (cross product of Earth's orbital axis and Earth's rotational axis)[2]

This coordinate system defines orientation independent of Earth's rotation, but not of
A point is defined by its Right ascension (α) and Declination (δ). Right Ascension is the angle going eastward along the celestial equator. Declination is the shortest angle between the point and the celestial equator. Right ascension is often measured in units of time, not degrees.

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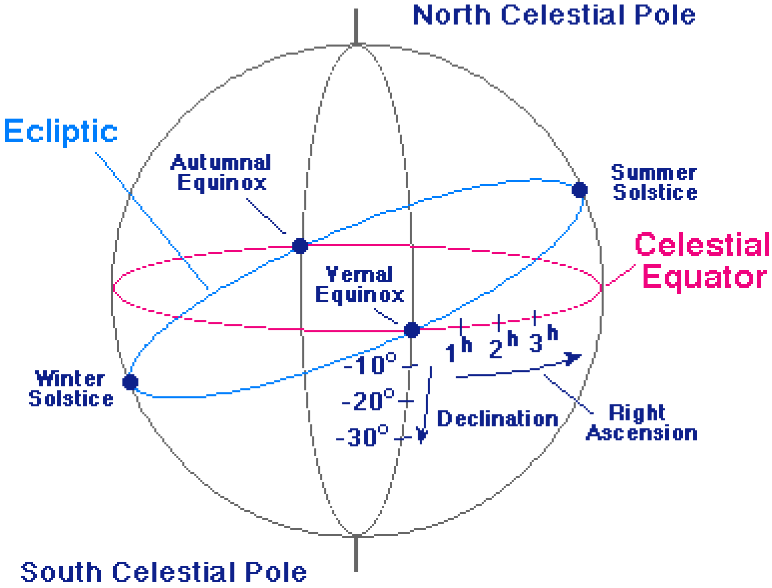
[1] 2013. JTW Astronomy - Tutorials: Celestial coordinates. http://www.jtwastronomy.com/tutorials/celestial_coordinates.html.
[2] Celestial Coordinate System. http://csep10.phys.utk.edu/astr161/lect/time/coordinates.html.

Because this coordinate system is independent of Earth's rotation, stationary objects in the sky (such as stars) stay at fixed coordinates. For this reason, star positions are often measured in the equatorial coordinate system.



Source: [3]

Conversion

To convert between the horizontal and the equatorial coordinate system, the observer's latitude and Local Mean Sidereal Time (LMST) are required. The Local Mean Sidereal Time measures Earth's rotation relative to the stars, not the Sun. Because of Earth's orbit around the sun, a sidereal day is slightly shorter than a solar day, by a difference of about 3 minutes and 56 seconds.[4]
Local Mean Sidereal Time is defined as the right ascension of a celestial body at the local meridian (with an Azimuth of 0°). LMST can be calculated using the observer's longitude and the Greenwich Mean Sidereal Time (GMST):

```
LMST = GMST + λ / 15°
GMST = 18.697374558 + 24.06570982441908 * D
```

Where LMST and GMST are expressed in hours, λ is the observer's longitude in degrees and D is the number of UT days since January 1, 2000 at noon, as a fraction.[5][6]

Equatorial → horizontal

To convert equatorial coordinates to horizontal coordinates, the following algorithm is used, developed by Paul Schlyter in 1979. This algorithm was designed with optimal accuracy and minimal computational costs.[7]

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[3] Celestial Coordinate System. http://csep10.phys.utk.edu/astr161/lect/time/coordinates.html.
[4] Timekeeping. http://csep10.phys.utk.edu/astr161/lect/time/timekeeping.html.
[5] 2005. Astronomical Times. http://www.cv.nrao.edu/~rfisher/Ephemerides/times.html.
[6] 2007. Approximate Sidereal Time - U.S. Naval Observatory ... http://aa.usno.navy.mil/faq/docs/GAST.php.
[7] 2003. Computing planetary positions - Paul Schlyters hemsida. http://www.stjarnhimlen.se/comp/ppcomp.html.

```
HA = LST - RA

x = cos(HA) * cos(Decl)
y = sin(HA) * cos(Decl)
z = sin(Decl)

xhor = x * sin(lat) - z * cos(lat)
yhor = y
zhor = x * cos(lat) + z * sin(lat)

az  = atan2(yhor, xhor) + 180_degrees // Azimuth
alt = asin(zhor) = atan2(zhor, sqrt(xhor*xhor+yhor*yhor)) // Altitude
```

Where HA is the hour angle, between -12 and 12 hours (converted to radians).

Horizontal → equatorial

The following conversion from horizontal to equatorial coordinates is derived from the Astronomical Triangle.[8]

```
Decl = asin(sin(alt) * sin(lat) + cos(alt) * cos(lat) * cos(az))
HA = asin(-sin(az) * cos(alt) / cos(Decl))

RA = LST - HA
```

Star positions

While number of recorded stars is enormous, and expanding daily, this device only needs stars visible to the human eye. To gather this data, a list of the brightest stars is used. Specifically, the Yale Bright Star catalog is used, which contains data for every star with a stellar (apparent) magnitude of 6.5 or lower (stars with a stellar magnitude above 6.5 are invisible to the human eye). This is a list of 9110 stars, taking up 285 kB of computer memory.[9] It might be required to use a smaller list, depending on the software limits.

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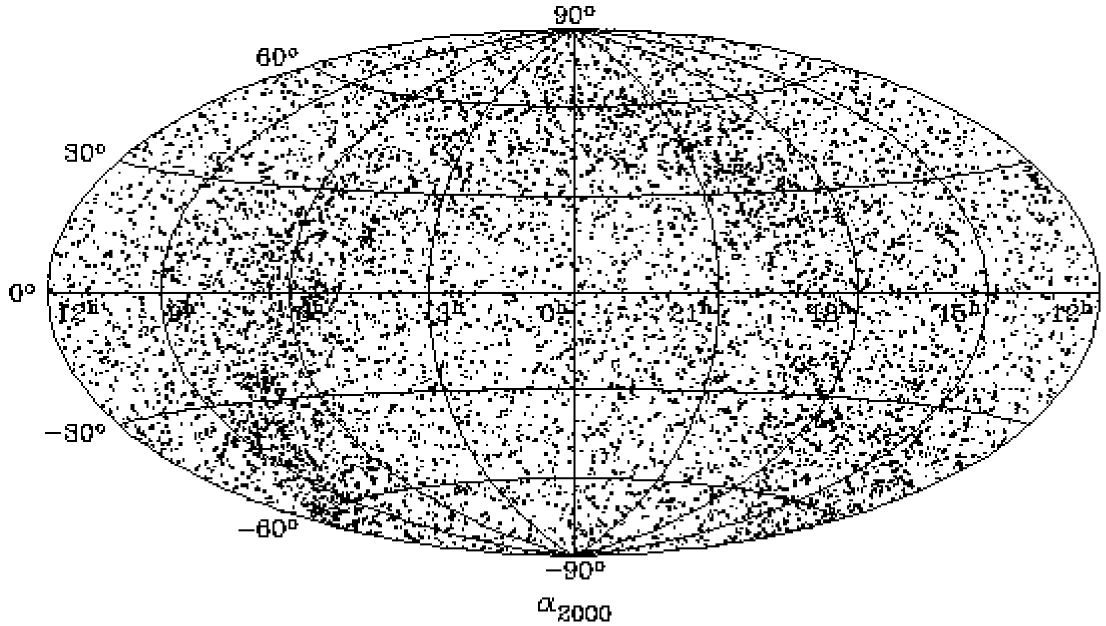
[8] Conversion between horizontal and eq. http://star-www.st-and.ac.uk/~fv/webnotes/chapter7.htm.
[9] 2005. Yale Bright Star Catalog 5 (BSC5). http://tdc-www.harvard.edu/catalogs/bsc5.html.



A map of all stars in the Yale Bright Star catalog.

Planetary positions

To compute planetary positions, the algorithm developed by Paul Schlyter is used. He has written an extensive report and example code in C, which will be used in the software, with minor changes to optimise the algorithm for this application.
Algoritm report: http://www.stjarnhimlen.se/comp/ppcomp.html
Sample code: http://www.stjarnhimlen.se/comp/tutorial.html

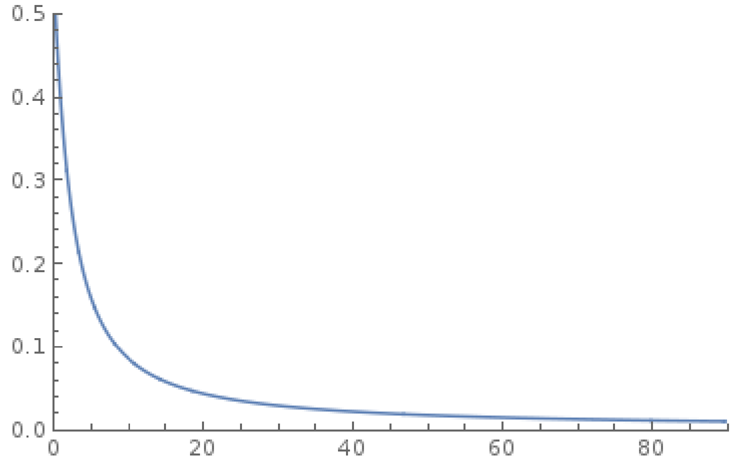
Refraction

Because the atmosphere has a higher density than the vacuum of space, light from stars gets refracted, which decreases the apparent altitude. The amount of refraction is zero at the zenith, and 0.30° at 2° altitude.
Atmospheric refraction can be approximated using the atmospheric pressure, temperature and altitude, using the following formula:

```
Re = Pr * (0.1594 + 0.0196 * a + 0.00002 * a²)/(T * (1 + 0.505 * a + 0.0845 * a²))
```

Where Re is the refraction towards the horizon in degrees, Pr is the atmospheric pressure in millibars, T is the temperature in Kelvin and a is the altitude in degrees.[10]

[10] Refraction Calculator. http://wise-obs.tau.ac.il/~eran/Wise/Util/Refraction.html.



Refraction (y-axis) and altitude (x-axis) in degrees

Existing systems

Because most modern astronomical research is automated and digital, many computer systems have been developed that perform similar tasks. One example is an automated telescope, connected to a computer. On the computer, you can select a celestial object, and the telescope is oriented automatically.
Because most of these programs are designed for academic purposes, they are often open source and well documented.

Hardware

asdf

Orientation sensors

To determine device rotation relative to Earth, orientation sensors are used. There are several orientation sensors worth considering:

Accelerometer

An accelerometer senses acceleration relative to freefall in 3 dimensions. When an accelerometer is laying flat on Earth, the z-axis will read 1g, and the x and y axis will read negligible values. When the accelerometer is rotated, the magnitude of the vector will remain at 1g.
The output for each axis equals the cosine of the angle between that axis and the directional vector of gravity.
An accelerometer is used to sense orientation relative to Earth's gravitational field, but not relative to North. Only two axis of freedom can be derived from accelerometer data.

Magnetometer

A magnetometer senses the direction and magnitude of the magnetic field at the point of the sensor, and outputs a 3D vector. For each axis, the output equals the cosine of the angle between the axis and the magnetic field, multiplied by the magnitude of the magnetic field.
A magnetometer is used to sense orientation relative to Earth's magnetic field. While only two axis of freedom can be derived from magnetometer data, this sensor can be combined with an accelerometer to sense full orientation.

Gyroscope

A gyroscope measures rotational velocity in 3 axis. Gyroscope measurements are unnecessary in this device, because rotational velocity during a measurement should be negligible anyways.

Optical
Another option is to use a camera to recognise a star. However, a camera would be too unreliable and expensive. Furthermore, it takes at least 10 seconds for a high-end camera to take a proper image of the sky.

Mechanical
Using a two rotary encoders, the azimuth and altitude can be calculated directly. This requires the device to be standing on a tripod facing North. While this approach is quite accurate, the device becomes less portable, and requires the user to position the tripod very precisely.

Sensor output
-3d data plots
--offset

User interface
-input
--buttons
-output
--display
---LCD, red light
--audio
--vibration

Microprocessor
asfd

Device list
-devices
--accuracy
--power requirements
--data connections

Power supply
-battery
--reliability & Voltage
--lifetime
--recharge

Software
-sensor calibration
-lookup algorithms
-display
-uProccesor limits