GPS SENSOR MODEL FOR ROBOTICS SIMULATOR

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In the introduced article, the GPS sensor and atmospheric model are presented. These models are valuable for robotic GPS sensor simulation when realistic error source is needed. Models take into account geometric, atmospheric and ionospheric error sources in GPS signal propagation. These models were tested to be similar as real equipment; the precision of models is 96.744%.

Keywords: Robotic vehicles, GPS, atmosphere, signal processing, navigation, emulator, Unreal Engine.

Modern computer systems make it possible to solve numerous problems. Especially, among all areas, stands interest of modern science to the control algorithms and robotics. At present moment, begins the era of robotic vehicles, which would be able to follow the designated route autonomously. Precise autonomous vehicle self-positioning in the outer world is a critical factor that affects traffic safety in general. This article presents the theoretical development and practical implementation of the GPS sensor and atmosphere signal attenuation model for the simulator environment. This model with the simulator itself is then used to test control algorithms for car-like robots in a simulated environment.

The aim of this work is to develop simulation model for generic GPS sensor and configurable model for atmospheric effects in order to simulate measurements of real GPS receiver in realistic environment.

The GPS system concept is based on time and known positions of satellites at this time. Each GPS satellite continuously broadcasts its position and time. A GPS receiver tracks multiple satellites and solves equation for its position and time deviation from real GPS time. In addition, high-precision and military GPS receivers use phase difference between two different carriers. We will not cover this case in the article.

To model GPS orbit parameters, we use almanac file. The almanac consists of coarse orbit and status information for all satellites period. In addition, it contains ionospheric correction model, which will be described further. Almanac files in RINEX (Receiver INdependent EXchange) format is common tool for GPS supplementing and they are provided by many observatories all over the world. We use RINEX files provided by NASA observatory. In our model, satellites positions are predicted only based on almanac record for certain hour of the day and are valid for two hours from this time. GPS broadcast ephemerides are accurate to ~10 m.

We are working in Unreal Engine 4 environment, so our sensor is just a regular object in scene. To simplify development, we use a priori known position in local coordinate frame (GLF, game level frame) and then add errors according to modelled situation. We use approximation of local tangent plane for small pieces (up to 4 km). This was considered acceptable, as mean distance from this plane to the satellites is sufficiently larger (20000 km). Using these considerations, we can use ECEF (earth-centered, earth-fixed) coordinate frame for both sensor and satellites, which is suitable in error model calculation. To get user output, noised ECEF coordinates are than converted to generic LLA coordinates (latitude-longitude-altitude). Velocity and heading are computed based on these LLA coordinates.

GPS measurements are affected by dilution of precision or DOP. DOP is a term to specify multiplicative effect of navigations satellites geometry on measurement precision. We compute the DOP directly, using vectors from sensors to satellites in ECEF frame. Also, position reading is affected by additive errors. These errors include signal arrival time imprecision, atmospheric effects, multipath effects and clock errors. In our model, we consider multipath and arrival time imprecision negligible as contemporary GPS receivers do well with filtering these errors.

When DOP implies directly on sensor error, SNR (signal-to-noise ratio) implies satellite's visibility and thus DOP. Signal-to-noise ratio is implied by surrounding buildings, atmosphere losses and free space losses. We consider each reflection of signal from building wall consumes half of the beam power regardless to material of the wall. If there is no viable path with up to 16 reflections to satellite, this satellite is considered as invisible at the current point.

We implemented fully configurable model of the Earth atmosphere with following objects: troposphere, stratosphere, mesosphere, thermosphere, ionosphere, clouds of different types and rain.

In Earth atmosphere, main attenuation factors at GPS frequencies (1575.42 MHz) are oxygen and water vapor. For consistent and reliable measurements, we calculate the path of a beam through each layer of the atmosphere. In this calculation, we use spherical approximation of earth instead of the geoid, as we already reject satellites that have elevation lower than 5 degrees. For higher elevation angles, difference between geoid and spherical approximation is negligible. When the path length trough each layer is found, we calculate vapor and oxygen attenuation. We use nonlinear curve fit for equivalent concentration relative to height (h):

$$k = e^{-\frac{gmh}{RT}} \tag{1}$$

Where *g* is a gravitational constant, *m* is a molar mass of dry air, *R* is a universal gas constant and *T* is a temperature at sea level in the given point. Equivalent concentration is then used in signal attenuation calculation. Attenuation models are taken from [1] unchanged.

We divide several types of clouds by their density from fog to thunderstorm. They are considered as water vapor of predefined density [1], we compute clouds attenuation in the same way as for water vapor in the atmosphere. At the moment, we consider cloud as a thick layer at the given height, not considering its complex shape and borderline refraction.

At the receiver, signal strength and SNR of satellite is computed as:

$$\begin{aligned} P_{rec} &= P_{sat} - L_s - L_{atm} - L_{iono} - L_{clouds} \ (dB) \\ SNR &= P_{rec} - P_{ambient} \end{aligned} \tag{2}$$

$P_{ambient}$ is an normal ambient noise, which is basically a thermal noise and has power of -204 dBW. In addition to thermal noise, we add surrounding electromagnetic noise caused by surroundings. Additional noise power varies from 1 dBW in countryside to 40 dBW in industrial area. Cutoff SNR for satellite is 5 dBW, lower than this margin satellite is considered as unreliable and not taken into position fix.

Free electrons in the ionosphere cause GPS signal to travel slower. This phenomenon affects time calculation and thus directly affects position error. We compute slant path through ionosphere and delay on this path based on total electron content [2]:

$$E_{iono} = 0.162 \cdot (1 + 2.74 \cdot 10^{-6} \cdot (96 - e_{sat})^3) \cdot TEC\,, \tag{3}$$

where *TEC* is total electron content, e_{sat} is elevation angle in degrees. Average error for ionosphere is 5 m.

In addition, we use mapping of Niel tropospheric delay model [3]. This allowed us to insignificantly increase precision of our model introducing average error of 0.5 m.

To add error at each frame, we use normally distributed random values with standard deviation of sum of tropospheric and ionospheric errors. Each random value is multiplied by DOP calculated for geometry of visible satellites.

To test the model, we built virtual map of Odessa region and placed sensor on the terrain. Real sensor was installed on the same spot in Odessa. We took 3600 measurements from real sensor (1 hour, 1 measurement per second). Then we configured model for the same environment conditions and loaded RINEX file for this time. We simulated another 3600 measurements and checked errors distribution (mean and standard deviation). Difference between real and simulated sensors is **3.256%**.

The model of GPS sensor in simulated environment was presented, its accuracy reached **96.744%** compared to live sensor. This model takes into account geometric, atmospheric and ionospheric effects. In addition, test environment and live setup was built for testing and parameters estimation.

SOURCES

1. Samuel P. Mason. Atmospheric Effects on Radio Frequency (RF) Wave Propagation In A Humid, Near-Surface Environment. – California: Naval Postgraduate school, 2010

2. Robert Giffard. Estimation of GPS Ionospheric Delay Using L1 Code and Carrier Phase Observables. // 31st Annual Precise Time and Time Interval Meeting. – USA, Palo Alto. – 1999. – P. 407 – 418.

3. Niell, A. Global mapping functions for the atmosphere delay at radio wavelengths. // Journal of Geophysical Research. - 1998. – № 101. P. 3223 – 3246.

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