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EXACTLY POSITIONING DETERMINATION USING GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

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Abstract

The goal of this article is to emphasize the possibility to determine the exactly position of an object anywhere in the word and in real time, using Global Navigation Satellite System (GNSS). It is made a short description of the SATNAV existing systems (GPS and GLONASS) and the newest system that belongs to the European Communities (Galileo). In the end of this article we present a Java application helping us to determine the exact position of the object.

1 How GNSS Works

The GNSS goal is to permit land, sea, and airborne users to determine their three dimensional position - east-west, north-south, and vertical (longitude, latitude, and altitude) -, velocity, and time, 24 hours a day in any kind of weather, anywhere in the world. Some receivers have the ability to store attribute information in addition to position information. Examples of attribute information are the condition of a street sign, the name of a road, or the condition of a fire hydrant. Position and attribute information can be stored in a Geographic Information System (GIS) to help users to manage their assets more efficiently.

Signals from three overhead satellites provide this information. Each satellite sends a signal that codes where the satellite is and the time of emission of the signal. The receiver clock times the reception of each signal, then subtracts the emission time to determine the time lapse and hence how far the signal has traveled (at the speed of light).

Key Words: GNSS, GPS, GLONASS, Galileo, navigation, positioning determination

This is the distance the satellite was from user when it emitted the signal. In effect, three spheres are constructed from these distances, one sphere centered on each satellite. The object is located at the single point at which the three spheres intersect.

The clock of hand-held receiver is not nearly as accurate as the atomic clocks carried in the satellites. For this reason, the signal from a fourth overhead satellite is employed to check the accuracy of the clock in your hand-held receiver. This fourth signal enables the hand-held receiver to process GNSS signals as though it contained an atomic clock.

Position accuracy depends on the receiver's ability to accurately calculate the time it takes for each satellite signal to travel to earth. This is where the problem lies. There are primarily five sources of errors which can affect the receiver's calculation. These errors consist of:

1. ionosphere and troposphere delays on the radio signal,
2. signal multi-path,
3. receiver clock biases,
4. orbital errors, also known as ephemeris errors of the satellite's exact location,
5. the intentional degradation of the satellite signal.

GNSS includes three components:

- Constellation of satellites (space segment);
- Ground-based control facilities (control segment);
- User equipment (user segment).

GNSS has a wide array of applications:

- in the civil sector: traffic (ships, planes, cars, etc.), agriculture, telecommunications, and natural resources exploration,
- in the scientific sector: expeditions, cartography, continental drift, meteorology, etc.,
- in the military sector: weapons guidance systems.

Depending on the distance from the Earth, it is possible to make a comparison between satellite orbits.

Low-Earth-Orbit (LEO)	Medium-Earth-Orbit (MEO)	Inclined Geosynchronous Orbit (IGSO)
- 1000 – 2000 km	- 12000 – 20000 km	- 36000 km
- 1.5 –2 h orbit	- 6 – 15h orbit	- 24 h orbit
- micro or mini-satellites	- GPS, GLONASS & Galileo	- fixed regional coverage
- 40 < #of SV < 100	- 24-30 satellites	- 21 – 24 satellites for global system
- low launch cost	- proven technology	- 9 – 12 satellites for regional system
- multiple launch capability	- medium power consumption	- regional control possible
- low power for bidirectional COM link	- regional control possible with restrictions	- good visibility under high elevation (mask) angles
- fast acquisition technology required		- high launch cost
- no regional control possible		- bidirectional COM link requires more power

2 USNO NAVSTAR Global Positioning System (GPS)

GPS is a satellite-based global navigation system created and operated by the United States Department of Defense (DOD). Originally intended solely to enhance military defense capabilities, GPS capabilities have expanded to provide highly accurate position and timing information for many civilian applications.

The first navigational satellite was launched in 1978, and now the system consists of 24 satellites (in six orbital paths circle the earth twice each day at an inclination angle of approximately 55 degrees to the equator) and associated ground support facilities.

This constellation of satellites continuously transmits coded positional and timing information at high frequencies in the 1500 Megahertz range. GPS receivers with antennas located in a position to clearly view the satellites pick up these signals and use the coded information to calculate a position in an earth coordinate system.

While GPS is clearly the most accurate worldwide all-weather navigation system yet developed, it still can exhibit significant errors. GPS receivers determine position by calculating the time it takes for the radio signals transmitted from each satellite to reach earth. Radio waves travel at the speed of light. Time is determined using an ingenious code matching technique within the GPS receiver. With time determined, and the fact that the satellite's position is reported in each coded navigation message, by using a little trigonometry the receiver can determine its location on earth.

The United States has launched an extensive modernization program to provide even better service to GPS users. The first step was the discontinuation of Selective Availability, the process whereby the civil signals were intentionally degraded, in May 2000. This improved the accuracy of the GPS civil service (from 100 meters 95% of the time and up to 300 meters 5% of the time) to 10-20 meters. The next step involves new satellites that will broadcast two new civil signals: one of which will be introduced in 2003, the other in 2005. The added signals will increase the robustness of the civil service and improve accuracy to 3-5 meters. Additional upgrades are being planned for the next generation of satellites, known as GPS III.

Part of this modernization will be the availability of a second civil signal on the existing L2-frequency and a third civil signal on the new L5-frequency of 1176.45 MHz. Civil GPS users nowadays have access only to the L1-frequency's C/A code, although receiver manufacturers have developed a number of techniques to also access the L2-frequency. This is important since it allows for the elimination of ionosphere effects, which are frequency-dependent and may amount to several tens of meters, depending on solar activity.

3 Global Orbiting Navigation Satellite System (GLONASS)

Similar to the NAVSTAR Global Positioning System (GPS) deployed by the United States of America is the system Global Navigation Satellite System (GLONASS)developed by the Russian Federation. The first satellite in the Russian GLONASS system was launched in 1982, and now the system also contains 24 satellites but only utilizes 3 orbital planes.

The GLONASS system is managed for the Russian Federation Government by the Russian Space Forces, system operator, providing significant benefits to the civil user's community through a variety of applications. The GLONASS system has two types of navigation signal: standard precision navigation signal (SP) and high precision navigation signal (HP). SP positioning and timing services are available to all GLONASS civil users on a continuous, worldwide basis and provide the capability to obtain horizontal positioning accuracy within 57-70 meters (99.7% probability), vertical positioning accuracy within 70 meters (99.7% probability), velocity vector components measuring accuracy within 15 cm/s (99.7% probability) and timing accuracy within 1 μs (99.7% probability). These characteristics may be significantly increased using differential mode of navigation and special methods of measurements (e.g. carrier phase etc.).

The visibility of GLONASS satellites is better than the one of GPS for northern latitudes greater than 50 degrees.

4 Global Navigation Satellite System GALILEO

Nowadays there are two world wide satellite systems - American GPS and Russian GLONASS, but a new system - Galileo will be developed by the European Space Agency (ESA) and the European Commission.

The U.S. is interested in cooperating with the EU to ensure that Galileo is interoperable with the U.S. Global Positioning System (GPS) and benefits users worldwide.

Reliable and accurate positions are required for general marine navigation and specialized applications such as buoy tending. The GPS signals are often masked by obstructions, which results in degraded geometry and accuracy at best, and unavailable or unreliable positions at worst. Once Galileo is implemented by the European Union, the use of a combined GPS + Galileo receiver will result in an increase of twice the number of satellites available above the horizon. The availability and reliability improvements attained, by augmenting GPS with Galileo and constraints under isotropic masking conditions and within a constricted waterway / urban canyon is illustrated through software simulations. These results clearly demonstrate the advantage of augmenting GPS with Galileo for marine navigation, especially under moderate to extreme masking conditions.

First, ESA will launch an experimental satellite at the end of 2004 on board a Soyuz or Zenith spacecraft. Galileo satellites have magneto-torques and reaction wheels to help maintain them in the correct orbit, but they do not have engines to maneuver themselves into the right orbit in the first place. Next, at the end of 2007, ESA will launch the first four operational satellites using two separate launchers. The first two satellites will be placed in the first orbital plane and the second in the second orbital plane. These four satellites, plus part of the ground segment, will then be used to validate the Galileo system as a whole, using advanced system simulators. In early 2008, the next two satellites will be launched into the third orbital plane also on board a Soyuz or Zenith launcher. Galileo should be operational by the end of 2008, when modernized GPS with 18 satellites transmitting at L1 and L2 will have reached initial operational capability (IOC).

In the following table, it is made a compare between all three systems that were described below.

Nevertheless, in this explanation it is assumed that they propagate in spheres and in the purely theoretical, two-dimensional case as circles.

Two-dimensional example with receiver clock error

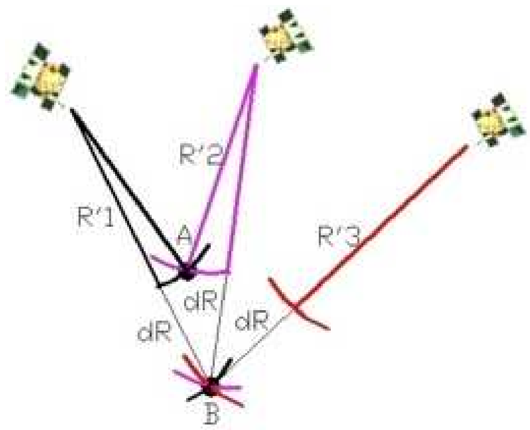
The position is determined as the point of intersection of two signals that have gone the same distance because they have traveled the same time. The traveling time is measured falsely because of the clock error of the receiver.

CARACTERISTICS	GPS	GLONASS	GALILEO
Number of Satellites	24	24	30 (27 operational, 3 spare)
Number of Orbital Planes	6	3	3
Orbit inclination	55°	64.8°	56°
Orbit altitude (Km)	20180	19130	23616
Period of revolution (hh:mm:ss)	11:58:00	11:15:40	14:04:00
Separation of the Orbital Planes	60°	120°	120°
Launch vehicle	Delta 2-7925	Proton K/DM-2	Ariane V, Proton, Soyuz etc.
Carrier frequency (Mhz)	L1: 1575.42 L2: 1227.60	L1: 1602+0.5625n L2: 1246+0.4375n where "n" is frequency channel number (n=0,1,2...)	E2-L1-E1: 1560-1595 E5: 1164-1214 E6: 1260-1300
Coordinates system	WGS84	PZ90	WGS84

This error is a constant offset to the very precise cesium clock of the satellite. This unknown offset produces an additional distance (can be positive or negative) because the signal is propagating according to $dR = c \times dt$ (c is the speed of light). The intersection point varies, depending on dR.

With a third satellite there will be only one solution where all circles (with radii $R_1' + dR$, $R_2' + dR$, $R_3' + dR$) intersect. The former variable dR is now fixed.

If it is no receiver clock error, the solution is point A, else the solution will be point B that is determined by the third satellite.



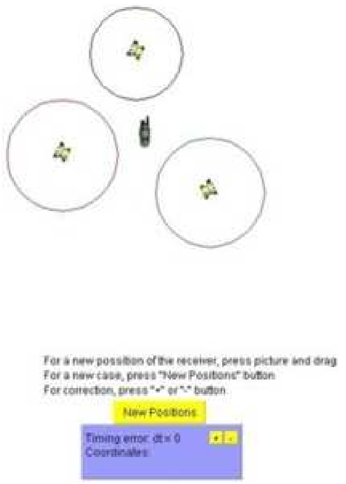
To determinate exactly the correct position of the object (the two unknown coordinates), it is necessary a number of three satellites applying the following mathematical relations:

$$
\begin{aligned}
(x - x_1)^2 + (y - y_1)^2 &= (R_1' + dR)^2 \\
(x - x_2)^2 + (y - y_2)^2 &= (R_2' + dR)^2 \\
(x - x_3)^2 + (y - y_3)^2 &= (R_3' + dR)^2
\end{aligned}
$$

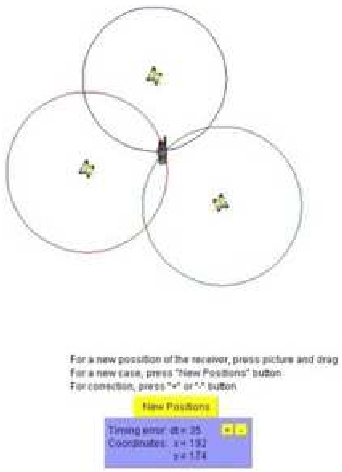
The following application was made in Java language and tries to find the correct position of the receiver.

The Java applet consists of three circles - which can be redrawn in a new position by pressing "New Positions" button - and also one receiver - that can be moved in several positions by clicking on the picture and dragging.

The right position of the receiver will be given by the intersection point of all three circles. This point can be obtained by pressing "Timing error" button + or -.



Before correction



After correction

```
double distance(int i, int j, int k, int r)
    {
    return Math.sqrt((i - k) * (i - k) + (j - r) * (j - r));
    }
    public position()
    {
    rad = (new double[] {
    distance(rec[0], rec[1], cx[0], cy[0]), distance(rec[0], rec[1], cx[1], cy[1]), distance(rec[0], rec[1], cx[2], cy[2])
    });
```

nrrand = 0.29999999999999999D;
devmax = Math.min(Math.min(rad[0], rad[1]), rad[2]);
radh = (new double[] {
rad[0] - devmax * nrrand, rad[1] - devmax * nrrand, rad[2] - devmax * nrrand
});

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