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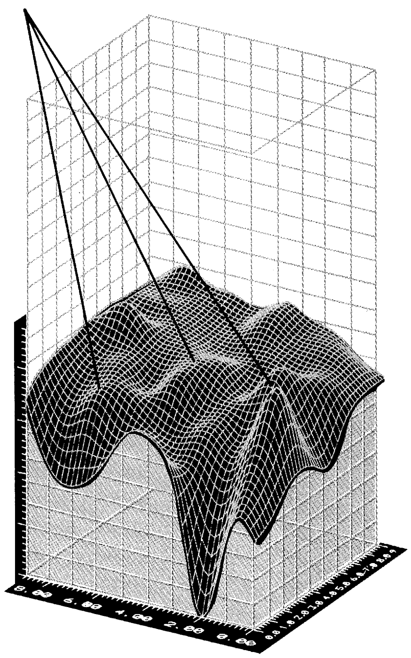

Comparing GPS and GLONASS

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"Innovation" is a regular column in GPS World *commenting on GPS technology, product development, and other issues and needs of the GPS community. This time we look at similarities and differences between GPS and GLONASS and the potential for an integrated system.*

This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. We welcome your comments and suggestions for future columns.

On February 22, 1978, the first GPS prototype satellite was launched into orbit by the United States, starting a new era in satellite navigation. Four and a half years later on October 12, 1982, the first GLONASS satellites were placed in orbit by the Soviet Union. Since then, the two satellite navigation systems have been built up slowly, and both are expected to be fully operational by the mid-1990s. At that time, the world will have two separate and independent tools for navigation and positioning of unprecedented accuracy and reliability.

These navigation systems did not come for free. They required commitments to multibillion dollar research, development, and deployment programs. Certainly, the "cold war" environment helped to ensure the availability of these funds. Public money probably would not have been made available to install a navigation system just for merchant fleets and pleasure boats.

Although technical details concerning GPS were freely available from official sources right from the start of the system development, the same was not true for GLONASS. An initial understanding of GLONASS in the West came only as a result of the pioneering work of Dr. Peter Daly and others at the University of Leeds.

Lately, the global political climate has changed dramatically and now provides a more friendly and cooperative atmosphere. As a by-product, technical data related to GPS and GLONASS are officially being exchanged between the United States and the Soviet Union. The electronics industry is being encouraged to develop combined GPS/GLONASS receivers, and research groups are exploring the benefits and problems to be expected when this "peace dividend" becomes available.

In this column, I will look at the two systems' technical similarities and differences from a user's point of view. Based on this evaluation, I will summarize the anticipated changes in user operation that would result from combining GPS and GLONASS.

COMPARING SYSTEMS

After full implementation, GPS and GLONASS will be used primarily for global, all-weather, continuous, real-time positioning and for marine, air, and land navigation. Basically, the users of these systems simultaneously measure ranges to several satellites, and receive a broadcast data message containing information on the satellites' positions. If these positions are known, in an earth-centered, earth-fixed (ECEF) coordinate system the users' positions can be computed either in Cartesian geocentric coordinates or, equivalently, in geographic coordinates.

The ECEF-referenced satellite positions computed from the received data message depend on the configuration of the satellite orbits and the way the orbital data are represented in the message. The range-measuring procedure inside a GPS or GLONASS receiver depends on the structure of the microwave signal transmitted by the satellites. Therefore it is useful to compare GPS and GLONASS satellite orbit configuration and description, and the corresponding microwave signal structures, in order to understand the potential benefits of and problems with combining the two systems. Because both systems serve more or less the same purpose, similarities in their design should not come as a surprise.

Satellite orbits. GPS satellites are launched, one at a time, with Delta 2 rocket boosters from Cape Canaveral Air Force Station in Florida. The schedule calls for about five deployments per year until the constellation is complete. As of now, nine operational satellites (Block II) have been placed in orbit, and an additional six GPS prototype satellites (Block I) remain usable.

GLONASS satellites are launched atop Proton D-1-e heavy boosters from Tyura-tam, located east of the Aral Sea in the Soviet Republic of Kazakhstan, at an average of two launches per year. Each Proton booster can carry up to three GLONASS satellites at a time, and a total of 46 GLONASS satellites have been put in orbit so far. Some of these have failed in the meantime, and others have apparently never been turned on. Presently, the active GLONASS constellation consists of eight satellites.

After full implementation, both systems will consist of 24 satellites. However, the orbital arrangement of the satellites will not be the same, as can be seen from Table 1. Four GPS satellites will be unevenly distributed in each of six orbital planes. These planes are inclined to the equator by 55 degrees, and are separated from each other by 60 degrees in longitude. Nominally, the satellites' orbits are circular with a radius of about 26,560 kilometers. Kepler's third law relates the orbital radius to the orbital period, the time needed by the satellite to travel a full circle in its plane. It turns out that the GPS orbital period is exactly one half of a sidereal day. (A sidereal day is the rotation period of the earth, and is equal to a calendar day minus four minutes.) Therefore, after one sidereal day the geometric relationship between fixed spots on the earth and the satellites repeats. For an observer on the earth, all GPS satellites reappear in the same part of the sky day after day, always four minutes earlier each day.

The GLONASS constellation consists of three orbital planes with eight satellites evenly distributed in each plane. The planes have a nominal inclination of 64.8 degrees and are spaced by 120 degrees in longitude. The orbital height is about 1,060 kilometers lower than that of the GPS satellites. Accordingly, the shorter orbital radius yields a shorter orbital period of 8/17 of a sidereal day such that, after eight sidereal days, the GLONASS satellites have completed exactly 17 orbital revolutions. For an observer on the earth, a particular satellite will reappear at the same place in the sky after eight sidereal days. Because each orbital plane contains eight equally spaced satellites, one of the satellites will be at the same spot in the sky at the same sidereal time each day.

Although the orbit configuration is different for GPS and GLONASS, the two systems will provide quite similar coverage when fully deployed. At least 6 and up to 11 satellites will be visible at any place on earth from either system at any time. The geometric strength of the satellite configuration as expressed by the *position dilution of precision* (PDOP) should be similar as well. In summary, no obvious advantage exists for the GPS or GLONASS satellite configuration from a user's point of view.

Satellite signals. Because both GPS and GLONASS are basically one-way ranging systems serving the same purpose, they exhibit a very similar radio-signal structure. The satellites broadcast two carrier signals, L1 and L2, in the L-band of the radio frequency spectrum. These signals are modulated by two binary codes, the C/A-code and the P-code, and by the data message. (The purpose of these codes, the type of modulation, and the choice of frequencies for GPS was the topic of the Innovation column in the May/June 1990 issue of *GPS World*. Therefore, the following comparison and Table 2 serve primarily to highlight the differences between GPS and GLONASS signals.)

All GPS satellites transmit the two carrier signals at the same L-band frequencies and modulate them with satellite-specific C/A-codes and P-codes. The GPS user equipment receives the sum of the signals broadcast by all visible satellites. A particular signal can be tracked with a radio frequency channel in the GPS receiver by looking for the satellite's unique code modulation, thereby rejecting all signals with a different code. This procedure of separating the total incoming signal into the components transmitted by different satellites is called *code division multiple access* (CDMA).

In contrast, all GLONASS satellites transmit carrier signals in different L-band channels, that is, at different frequencies. A GLONASS receiver separates the total incoming signal from all visible satellites by assigning different frequencies to its tracking channels. This procedure is called *frequency division multiple access* (FDMA). Because FDMA does not need to distinguish satellites by their unique signal modulation, all GLONASS satellites broadcast the same codes.

In both systems, the C/A-code is modulated onto the L1 carrier only, whereas the P-code appears on both L1 and L2. Accordingly, C/A-code receivers can use only the L1 signal for ranging, and P-code receivers can measure ranges on both frequencies to correct for ionospheric refraction. (Again, see the May/June 1990 Innovation column).

In both systems, the frequency of the C/A-code is 10 times lower than the P-code frequency. As a general rule, higher signal frequencies yield a better range-measuring accuracy than lower frequencies. Thus, both GPS and GLONASS have a precise mode of operation with the P-code and a less accurate mode using the C/A-code. As can be seen from Table 2, the GLONASS code frequencies are about half the corresponding GPS values. This indicates a slightly lower ranging accuracy for GLONASS.

Each satellite in both systems transmits, at a rate of 50 bits per second, a data stream containing a wealth of information regarding the status of the individual broadcasting satellite and the whole satellite configuration. Of primary importance from a user's point of view are two particular subsets of the message, the data describing the satellite's clock error and the data representing the satellite's position, called the satellite ephemeris. Receivers need both data types to make proper computations with the range measurements.

The GPS clock data are transmitted in terms of clock offset, clock frequency offset, and clock frequency rate, and allow the calculation of the difference between the individual GPS satellite's time and the GPS system time. The latter is related to *Coordinated Universal Time* as kept by the U.S. Naval Observatory, *UTC (USNO)*. In contrast, the broadcast GLONASS clock and clock frequency offset yield the difference between the individual GLONASS satellite's time and the GLONASS system time, which is related to UTC as kept in the Soviet Union *UTC (SU)*.

The satellite ephemerides broadcast by the GPS satellites contain the parameters of the satellite orbit in terms of a linearly varying ellipse, plus small correction terms accounting for irregularities in the orbit. The ephemeris data are updated every hour.

Table 1. Nominal satellite orbits

	GPS	GLONASS
Orbital planes	6, spaced by 60°	3, spaced by 120°
Satellites per orbital plane	4, unevenly spaced	8, evenly spaced
Orbital plane inclination	55°	64.8°
Orbital radius	26,560 km	25,510 km
Orbital period	1/2 of a sidereal day ≈11 hours 58 minutes	8/17 of a sidereal day ≈11 hours 16 minutes
Repeat ground track	every sidereal day	every 8 sidereal days

Table 2. Nominal satellite signal characteristics

	GPS	GLONASS
Carrier signals	L1: 1,575.42 MHz L2: 1,227.60 MHz	L1: (1,602 + k × 9/16) MHz L2: (1,246 + k × 7/16) MHz k = Channel number
Codes	different for each satellite C/A-code on L1 P-code on L1 and L2	same for all satellites C/A-code on L1 P-code on L1 and L2
Code frequency	C/A-code: 1.023 MHz P-code: 10.23 MHz	C/A-code: 0.511 MHz P-code: 5.11 MHz
Clock data	clock offset, frequency offset, frequency rate	clock and frequency offset
Orbital data	modified Keplerian orbital elements every hour	satellite position, velocity, and acceleration every half hour

From these, the user can compute ECEF coordinates of the satellite for a particular measurement time using well-known equations. The resulting ECEF coordinates are referenced to the *World Geodetic System 1984 (WGS84)*.

GLONASS has a different way of transmitting satellite orbit information. For every half-hour epoch, each satellite directly broadcasts its three-dimensional ECEF position, velocity, and acceleration. For a measurement time somewhere between these half-hour epochs, the user interpolates the satellite's coordinates using position, velocity, and acceleration data from the half-hour marks before and after the measurement time. The resulting ECEF coordinates are referenced to the *Soviet Geocentric System 1985 (SGS85)*.

COMBINING SYSTEMS

Both GPS and GLONASS have been designed to be self-sufficient military navigation systems and, as such, they really do not need each other. However, as more and more user groups have become aware of the potential of these systems, GPS and GLONASS now are seen as all-purpose positioning and navigation systems for use in diverse applications. The requirements of some of these user groups are not quite satisfied by either system. In particular, civil aviation users have argued that neither system alone can provide the necessary integrity and reliability for a sole means of navigation. Therefore, over the past couple of years initiatives have arisen to assess the potential benefits and problems of a combined system comprising both GPS and GLONASS.

Problems. Combining GPS and GLONASS means primarily the building of a receiver that can simultaneously track GPS and GLONASS signals. Ranges measured on these signals must be combined with GPS and GLONASS clock and orbital data to compute the receiver's position. Each of these steps has its own little problems.

As discussed above, GPS and GLONASS have different ways of accessing and tracking the satellite signals. A receiver useful in a combined satellite system must be able to simultaneously track the GPS signals in CDMA mode and the GLONASS signals in FDMA mode. It cannot be simply a GPS receiver with a few more channels. Consequently, the designs for combined receivers published so far show basically separate GPS and GLONASS receiver modules driven by the same local frequency oscillator, all packed into one casing.

The range measurements to either GPS satellites or to GLONASS satellites are combined with the broadcast satellite ephemeris information to yield the position of the receiver and the receiver time with respect to the satellite system time. As discussed earlier, GPS and GLONASS have different coordinate and time systems. With GPS satellites alone, the computed receiver position is referenced to the coordinate system WGS84, and the computed receiver time is referenced to UTC (USNO). With GLONASS satellites alone, the receiver position is computed in SGS85, and the receiver time is UTC (SU).

So, what do we get from a combined receiver? If nothing is done about the differences in coordinate systems and, especially, about the time system differences, we simply may get garbage. There are two ways to overcome this problem. One can establish the relation between WGS84 and SGS85 and include the transformation parameters to convert from one system to the other into the receiver software. These parameters then can be used to either transform GPS satellite positions into SGS85, or to transform GLONASS satellite positions into WGS84. The difference between the two time systems can either be handled in a similar fashion, or alternatively the offset between GPS and GLONASS time can be determined as part of the position solution.

These problems could be more easily resolved at the system control level. If the ephemerides for both satellite systems would be computed in the same reference coordinate system, and if both systems were timed with respect to the same superior time reference frame, the aforementioned difficulties would not exist, and the user would not have to worry about getting rid of them.

Benefits. The most obvious advantage of a combined system is the availability of twice as many satellites. Of the total of 48 satellites, at least 12 will be visible anywhere at any time. The resulting redundancy in range measurements allows the real-time detection and identification of faulty signals by *receiver autonomous integrity monitoring* (RAIM) as described in "A Multi-Sensor Approach to Assuring GPS Integrity," by Alison Brown, in the March/April 1990 issue of *GPS World*.

There is also another twist to the integrity issue. GPS and GLONASS are independent systems being run by independent organizations. From the measurements of a combined receiver, the user can calculate separate GPS-based positions and GLONASS-based positions. Any major discrepancy between these solutions, or an anomalous behavior in one of the two solutions, can indicate a problem with one of the two systems as a whole. In such cases it may prove better to rely temporarily on just the one "normally operating" system.

In land navigation, integrity monitoring is not as high a priority as in civil aviation navigation. On the other hand, vehicles sometimes have to be navigated over land under severe shadowing conditions, especially in mountainous and urban areas. In these cases, GPS or GLONASS alone may not provide enough coverage for a position solution. Studies have shown that a combined system will yield a robust navigation solution even if the satellite visibility is more or less completely obstructed on one side of the sky.

Another potential benefit of a combined system is improved accuracy. A typical example relates to selective availability (SA) in GPS. Under SA, the GPS positioning accuracy is severely degraded. No plans for selective availability have been announced for GLONASS. If SA remains implemented in GPS, GLONASS-derived positions will be more accurate than GPS-derived positions. To get the best out of a combined receiver, the user would base the positioning on GLONASS measurements only, and use GPS measurements just to ensure the signal integrity.

The last benefit we are going to discuss here is economical in nature, and is anticipated in surveying. Surveyors use GPS carrier phase measurements in a differential static mode of operation to determine the three-dimensional baseline vector between survey markers with centimeter accuracy. This accuracy is obtainable if measurements are accumulated over several tens of minutes. The required measurement time could be dramatically reduced if the number of satellites is doubled via a combined system.

We should also mention that the International Maritime Satellite Organization (INMARSAT) plans to include transmitters of GPS-like signals in their next generation of satellites (INMARSAT-3). The INMARSAT-3 network will consist of four geostationary satellites. The signals broadcast by these satellites will allow measurements similar to those from GPS or GLONASS and may also transmit additional information on the status of all GPS and GLONASS satellites.

Prototype receivers capable of tracking satellite signals from both systems are now in operation and may be available as commercial products in the near future. We should anticipate these developments as further major steps toward improved safety in navigation on land, at sea, and in the air. ■