THE USE OF THE GLOBAL POSITIONING SYSTEM FOR TIME SPACE POSITION INFORMATION ON THE RANGES

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ABSTRACT

The GLobal Positioning System (GPS) is a precision navigation system ideally suited for target position determination. There are basically five GPS alternatives applicable to range applications depending upon target size and dynamics. The Department of Defense has recognized the potential advantages of GPS for range tracking applications. The Air Force is sponsoring the development of a family of GPS hardware for use on the ranges.

INTRODUCTION

The Global Positioning System (GPS) is a precision satellite navigation system developed by the U.S. Air Force. When the system is operational, it will provide precise position (in X, Y, and Z coordinates) plus time to any possessor of user equipment anywhere in the world. In concept, the system is simple, but it tends to be complex in implementation. The principle of operation basically depends on position determination by measuring distance from three known points. For the GPS, these known points are satellites. The global positioning space segment will consist of 18 satellites, with 3 in each of 6 orbital planes.

The GPS control segment is located at Vandenberg Air Force Base, with auxiliary stations at Hawaii and Guam. These stations continuously update the satellite orbital data and time. Each satellite then records and carries its own ephemeris and precise time. All satellites continuously transmit on two L-band frequencies that are identical for all satellites. The data transmitted consists of a 50-bit-per-second telemetry signal that gives the ephemeris of each satellite. In addition, two codes are transmitted: the C/A- and P-codes on the L₁ channel and the P-code on the L₂ channel. The C/A-code is relatively short, repeating every millisecond, while the P-code is high speed (10 MHz), repeating every 7 days. The P-code was intended to be more accurate than the C/A-code and can also be easily
encrypted for security. In practice, the C/A-code alone has been found sufficiently accurate for range tracking applications, particularly when relative or differential tracking is used. The code from each satellite is unique, and the codes from all satellites are code-division-multiplexed, allowing all satellites to transmit continuously on the same frequency.

The navigation technique is as follows: Since the telemetry data tells precisely where each GPS satellite is, all the information needed is precise distance from three of the satellites to obtain a position solution. To do this, the codes are generated locally from four of the satellites in view. The phase of each code is shifted until we lock on to each code. Examining the phase shift needed to lock on to a satellite code shows the code transit time from the satellite to us, assuming that we know our own time precisely. Not knowing our own time precisely, we make the measurement anyway and call it pseudorange. We can then construct four position equations with four unknowns, which are our X, Y, and Z position and time. A Kalman filter is then used to optimize this solution.

A COMPLEX SYSTEM

The GPS is, therefore, a precision navigation system designed primarily for military applications. The receiving systems are also relatively complex, consisting of an L-band receiver, followed by code generators and correlators. Then a complex computer is required to generate a position and time solution. With this general description of a GPS navigation system, it is evident that this is a very complex system.

Because of its precision navigation characteristics, it became evident that GPS would have application to our tracking ranges. The question is how best to apply GPS to the time space position information (TSPI) measurement set. The first reaction might be to fly a complete GPS receiver and telemeter the TSPI to a ground station or record it onboard. This certainly would work, but there are much simpler and more cost-effective solutions for range applications.

THE RANGE TRACKING PROBLEM

First, examine the peculiarities of the range tracking problem:

- Relative position data is sufficient for range applications. That is, absolute target position is generally not required. What is required is precise target position relative to a master ground location. (This is what we now attempt to get from radars.)

- Many of the targets are expendable; so cost of the onboard system becomes important.
• Ideally, a tracking system would function within or outside existing range boundaries.

• The cost of the tracking capability should be minimized.

• An observer desires the target position; the target itself generally does not need to record its own position.

RANGE TRACKING TECHNIQUES

The requirements for range tracking, therefore, differ from the general navigation requirements. For this reason, a distinct family of user equipment must be considered for range applications. First let us examine the various GPS tracking techniques that have been considered for range tracking. The five techniques that have received the most attention are described in the following paragraphs.

Multichannel High-Dynamic GPS Receiver

For large, unexpendable targets such as aircraft or even large, expensive, expendable targets such as intercontinental ballistic missiles, it is practical to consider flying a multichannel high-dynamic GPS receiver. The complete position solution could then be telemetered to a master station or recorded onboard. This approach is planned for aircraft tracking in the future and was considered for the MX program. The missile accuracy evaluator (MAE) program for MX tracking was dropped because of the cost of receiver development at that time.

Pseudorange Determination in the Target

If it is desired to reduce the amount of hardware on the target, but at the same time fly a receiver, a unique approach can be used. That is to perform the pseudorange determination in the target and telemeter the pseudoranges to a master ground station where the position calculation is performed. Although initially proposed to reduce the size of the receiver required in the target, with the advancements in digital circuitry, the computation capability can be performed easily in the target with minimum additional size and weight. Practically, this approach has become outdated.

GPS Receiver Carried on the Target

For very large, dynamic targets, a very simple GPS receiver can be carried on the target. A single-channel receiver can be programmed to cycle among four satellites, determining pseudorange from each of the satellites, one at a time. These pseudoranges can then be
processed in a navigation computer to determine precise position. This is a very practical approach for very slow-moving targets. For example, this approach is used in manpacks. The advantage of this approach is that the GPS receiver can be made extremely small. The target position could be recorded or telemetered to a master station.

**Inertial Navigation System Approach**

If a simple onboard receiver is desired for high dynamic targets, a unique approach is currently being investigated. Here, a single-channel cycling receiver as described previously is combined with a simple inertial navigation system (INS). This scheme takes advantage of the best of both worlds. The disadvantages of a low dynamic receiver are compensated for by the INS, and the disadvantages of a simple INS are compensated for by the GPS receiver. That is, the INS tracks the target position in between satellite samples while the receiver output updates the simple INS to correct for its drift. This approach is currently under study since exact interconnection techniques have not yet been determined. Again, position could be recorded or telemetered to the master station.

**L-Band-to-S-Band Frequency Translator Approach**

The last GPS tracking approach to be discussed is currently utilized by the U.S. Navy’s Trident test program. Here an L-band-to-S-band frequency translator is flown on the target. The signals from the GPS satellites in view are received, converted to S-band, and retransmitted to a master ground station where missile position is determined.

This system has many advantages compared to flying a GPS receiver on the target. In addition to these obvious advantages of smaller size, lighter weight, and lower cost than an onboard receiver, there are significant technical advantages. Because at the master station both an S-band target receiver and an L-band reference receiver are used, the system becomes a differential navigation system with associated accuracy advantages. In addition, a 6-dB signal-to-noise ratio advantage is obtained because a phaselock tracking loop can be utilized for carrier tracking. The other advantage to a translator GPS tracking system is that the complex computational system required can be contained in the ground station, not in the target.

**GPS AS AN ALTERNATIVE RANGE TRACKING SYSTEM**

The preceding discussion indicates that a GPS tracking system may provide an attractive alternative to the present pulse radar tracking systems. The office of the Under Secretary of Defense for Research and Engineering recognizes the potential advantages of a GPS-based range tracking system. A triservice committee was formed in the summer of 1981 under the chairmanship of the Western Space and Missile Center (WSMC). After a 1-1/2-
year study with contractor assistance, the committee reported its findings. It was unanimously agreed that the application of GPS to range tracking offered both cost and technical advantages over existing range tracking techniques.

FUTURE PLANS

As a result of the study, the Office of the Under Secretary of Defense established a Range Applications Joint Program Office (RAJPO). This RAJPO is managed by the Air Force at Eglin Air Force Base and has deputy program managers from the Army and Navy. The purpose of the RAJPO is to develop a family of GPS components required by the range tracking community. They are now planning the development of a low dynamic receiver, a high dynamic receiver, and an instrumentation pod containing a receiver married to an INS and a translator and translator ground system. The development of these components will not be completed for 2 or 3 years but will match the availability of the GPS satellite constellation.

At this time, there are five GPS satellites in orbit. These will provide sufficient coverage for precision position determination for about 2 hours a day anywhere in the world. This coverage will be maintained until 1987 when the rest of the 18 satellites will be launched. By the end of 1987, two-dimensional navigation (three satellites in view) will be in use 24 hours a day anywhere in the world, and by the end of 1988 three-dimensional navigation (four satellites in view) will be provided.