Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

ATTITUDE DETERMINATION BY GPS

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1. Introduction

GPS for position and velocity determination as well as for time transfer is in standard use and will be widely applied on an operational basis as soon as this satellite system will be fully deployed in 1993. The next step is now to develop its use for attitude determination, thus adding the measurement capability for another three degrees of freedom. Various articles have been published in recent years dealing with this topic. Also first commercial products have been advertised recently, such as the ASTECH 3D receiver, which is specified to achieve an accuracy of 3 mrad.

In the following the basic concept is reviewed and different methods of implementation are described.

2. Measurement Concepts

Direction finders have been in use in navigation since many decades. They determine the direction of arrival of the wavefront of a radio wave by measuring the orientation of the wavefront or of its magnetic or electric vector. In case of using GPS- satellite signals most of these techniques are not feasible because of the following effects:

- Many satellites should be received and used for position and attitude determination simultaneously. Directive antenna can, therefore, not be used.
- A correlation process must be applied to the received pseudo- random modulation of the GPS- signals to recover the signal carrier frequency before any other signal processing can be performed.

So, it is the carrier phase measurement technique, which characterizes all methods of GPS- related direction measurement techniques. This carrier phase measurement is well known to geodesists, because it is also used for precise geodetic position determination by GPS.

2. Carrier Phase Measurement

It is certainly not necessary to describe the carrier phase measurement technique in detail, as it is generally known. Only some specific aspects are considered in the following:

- The carrier phase technique determines the slant range Ri from the satellite i to the user's position by measuring Ri in multiples of the carrier wavelength.L_1. L_1 is the carrier frequency of the GPS- signal , which is modulated by the civil code (C/A-) code. Its wavelength is about 19 cm. We can subdivide R_i in an integer number of range segments of one wavelength and in some fractional part This fractional part of a wavelength can be measured by correlation techniques with a precision of about 1% of the applied wavelength, i.e. to about 2 to one mm, or in many cases to even a mm or better. The integer number remains unknown in this correlation process, due to its modulo L_1 performance feature. So, the carrier phase measurement procedures are generally ambiguous.

The problem of ambiguity is well known and much effort has been undertaken by geodesists to solve this problem by software. Various solutions are known, which are mainly applicable to static or quasi- stationary measurements. For the dynamic case, however, it becomes increasingly difficult with the increasing degree of dynamic.

Another problem exists: There are many error sources summing up to the total ranging error: Errors of the space segment, errors of the ground segment, and errors of the signal propagation thru the atmospheric medium. It must be assured that these effects deteriorate the angular measurement as little as possible. For the following this is not discussed, as it is also a problem of precise position determination. as well and is treated in the literature. However, as a speciality, it has to be emphasized here that for the angular measurement the multipath effects in close neighbourhood to the user´s antenna system can impose very important degradations.

In the following we assume that by means of the carrier phase measurements to at least 4 GPS-satellites the user has determined its position. So, we can define for each pair of GPS- satellites and the user´s position a plane, consisting of 3 points, for example A_1, S_1, S_2, S identifying the position of a satellite and A the position of an antenna of the users "antenna system", which consists in general of at least 3 antennas for direction finding. The vector between two such antennas A_1,A_2 identifies a "baseline 1", the vector between A_1A_3, which is orthogonal to the first one, defines the "baseline 2".

We consider first the baseline 1. Two angles a1,a2 between this baseline and the lines of sight (l.o.s) to the two satellites are to be measured. If this is possible then we have one vector for the defintion of the platform´s 3-D orientation If we can then perform the same procedure for the second baseline as well, then we have the orientation of the platform defined w.r.t. the instantaneous positions to the two GPS- satellites S_1, S_2. By making use of the other satellites in view we can improve the accuracy.

Various methods are applicable to perform the described task of measuring the incidence angle of the satellite signal towards the baseline. The most important ones will be shortly described in the following.

3. Interferometric Concept

In the followinf we assume that the baseline A_1A_2 is extremely small compared to the slant range of the user to the satellite S_1, which is more than 20.000 km away. The l.o.s. to A_1 and A_2 are, therefore, parallel to each other. The total history of the signals from the GPS- satellite to the antennas A_1,A_2 are identical, except that the length l.o.s.1 is longer than the l.o.s.2. This difference can be expressed by the length of the baseline and the angle a_1 between the l.o.s. and the baseline. It is $B_1 \cos a_1$, where B_1 is the length of that baseline. The corresponding correlation cannot discriminate between range differences which differ some integer numbers of wavelength. The ambiguity w.r.t. 19 cm exists in the corresponding phase measurement.

So, if this difference can be larger than a wavelength, then the ambiguity must be solved. If it is smaller than one wavelength then the angle a_1 is immediately determined. For simplification we assume that this is the case. This is so, if the baseline is at most as large as one wavelength.

The observable defines by this way the l.o.s.1 to be located at the cone around B_1. If we apply the same procedure for the baseline 2, then another cone around B_2 is defined and the intersection of these two cones determines one vector of the user´s platform. If we make the same procedure for the second satellite, then we shall get the second reference line. and the task is solved.

We have, however, to fulfill a few assumptions:

- The phase measurement can only be realized this way, if the receivers of the three antennas apply the same reference clock, which means that special receiver design is necessary. In other words, the set of receivers must be coherent and it must also be assured that they make the phase measurements with the same set of satellites.

- The ambiguity problem must be solved. The assumption we made above that the basline is made very small, solves the ambiguity problem at the expense of less accuracy. The accuracy is inversely proportional to the length of the baseline. A solution would be to use the small baseline for ambiguity and to apply additionally a larger baseline. In view of the cost reduction which can be expected for the receivers of the future, one could certainly afford 5 instead of 3 receiver units. If the additional ones extend the 2 baselines to 5m, or 10 m, or even 20 m, then an increase of the accuracy down to at least the mrad level would be possible, accompanied with robustness of the system.

3. Triple Difference Method

Above we used at least a pair of satellites for determination of the observables. If we take measurements of the same pair twice, i.e. at time t and t+dt, tand if we use the time differences of these phase changes, then we have, what is called in the positioning technique, the tripple difference measurement principle. This observable is free from clock errors of the applied satellites, from popagation errors, and from errors of the receiver clocks, as is well known. This means that one can use independent, i.e. non- coherent receivers. In other words, commercially available receivers can then be applied. The disdvantage of this technique is, however, that longer times of observation are generally required.

4. Rotating Antenna

Another method of attitude measurement by means of GPS is based on the mechanical rotation of a single antenna around some axis z of a local reference system. This technique could be easily applied in helicopters, where the antenna would be located at the rotor. It could also be used on board of ships, where the GPS- antenna could be attached to the rotating radar antenna. Due to this rotation of the antenna w.r.t. the satellites a Doppler frequency is generated, which can be used to determine the direction to the satellite(s): The Doppler rate is maximum, when the motion is parallel to the l.o.s. and it is zero, when it is across the l.o.s.

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Abstract

Various methods for direction finding are possible, a very promising one being the method, which applies first a small baseline interferometer for ambiguity purposes and extends then with additional receivers the method for very precise angle determination.

LAGEBESTIMMUNG MIT GPS

Zusammenfassung

Verschiedene Methoden der Richtungsbestimmung sind möglich, wobei besonders vielversprechend diejenige Methode ist, die eine kleine Baislänge für die Interferometrie anwendet, um die Eindeutigkeit herzustellen und dann eine große Basislänge dann zur hochgenauen Winkelmessung nutzt. Dies erfordert zusätzliche Empfänger.

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