# THE GLOBAL POSITIONING SYSTEM AND ITS APPLICATION TO PHOTOGRAMMETRY

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## BACKGROUND

The Global Positioning System (GPS) is a worldwide, all weather, satellite navigation system currently under development by the United States Department of Defense. The different signals provided to the user by each GPS satellite permit the measurement of range from the receiver's unknown position to the known satellite position. When four satellites are simultaneously viewed by the user, four simultaneous ranges to four known positions can be measured. From these four measurements the user's position in three dimensions and time (4 variables) can be determined using conventional trilateration techniques.

The GPS satellites transmit on two frequencies in order to permit correction for ionospheric refraction. These two L-band frequencies are conveniently referred to as $L_1$ and $L_2$. The $L_1$ signal carries two different pseudorandom code modulations while the $L_2$ carries only one of these code modulations. Both of these codes carry the satellite message with a data rate of 50 bits per second.

The codes transmitted by the satellite are a pseudorandom sequence of one's and zero's. The two codes carried by the $L_1$ frequency are referred to as the C/A and P-codes while the $L_2$ frequency only carries the P-code. Each GPS satellite transmits a different pair of codes to permit the user to discriminate among the signals transmitted by the satellites. The P-code has a switching rate of 10.23 MHz and lasts for many weeks but is artifically truncated to seven days. The C/A code switches at 1.023 MHz but lasts for only 1 millisecond. The C/A code is used to assist in the acquisition of the P-code. Since these codes are pseudorandom, they have a very narrow (± 1 code chip) triangular time correlation function with respect to a replica of the code generated by the receiving set.

Because of these narrow correlation peaks, very accurate time of arrival measurements on the received codes can be made. These time of arrival measurements can be translated into ranges to the satellite if time of transmission and the velocity of propagation are known. Since these terms are known, the measurement of code phase (time of arrival) is the basic range measurement made by the user equipment.

In addition to these range measurements, an extremely accurate range change measurement can be made by using the carrier frequency. Since both the satellite and the user vehicle are moving, the carrier signal received by the user has a Doppler offset. This Doppler offset is proportional to the relative radial velocity between the user equipment and the satellite.

By integrating this Doppler offset (integrated velocity is distance), the change in the range to the satellite over the integration time interval can be measured extremely accurately; i.e., this measurement can be made to a fraction of a carrier cycle which has a wavelength of less than 20 cm at $L_1$.

As stated previously, the ability to navigate requires that the user know the position of the satellite from which these range measurements are being made. This position is determined from the data message transmitted by the satellite. The message contains an accurate satellite ephemeris which can be used to calculate the position of the satellite for any instant in time. The time marks used for this calculation are the code epochs, since the time of arrival of these epochs forms the basis for both the range and range change measurement times.

It is important to remember that the reason for the development of GPS is to enhance U.S. military effectiveness. The military GPS program is currently in Phase II of a 3 phase development program. The concept validation phase, Phase I, demonstrated with clarity how military effectiveness can be improved by using a highly precise navigation system such as GPS. Conventional, unguided bombs can reach their targets with great accuracy when dropped from aircraft under GPS control. Other military activities, such as rendezvous and coordination of land, sea and air forces, are also greatly enhanced by GPS. The massive funding required for the development of such a navigation system could only be justified on the grounds of enhanced military effectiveness.

Even though GPS is a military system, civilian applications of GPS have always been presumed. Fortunately, public interest in the U.S. does play a role in shaping national policy and civilian applications of GPS has excited the interest of many Congressmen and U.S. Companies interested in building user equipment. As a result, there is more discussion about civil use of GPS than any other previous military navigation system at this early stage of development.

## STATUS

The present research and development satellite constellation was initially launched to assist the DoD with the concept validation process. It is currently being used by the DoD to test the Phase II user equipment. The DoD plans to maintain 4 to 6 of these R & D satellites in orbit for testing purposes until the production satellites begin to become available. The DoD emphasizes the policy that these current satellites are for DoD's testing purposes only and they do not guarantee the availability, accuracy or reliability of these satellites. This policy warns that although the signals may be used, such use must be at the risk of the user.

It should be noted that the full accuracy of GPS is available to any user from these R & D satellites since the P-code as well as both $L_1$ and $L_2$ frequencies are readily available. However, with only five satellites very limited coverage is available. Typical satellite availability is shown in Figure 1. The future GPS satellite constellation differs significantly from the current constellation. On the positive side, the future constellation will provide the user with a minimum of four satellites simultaneously in view to provide the four measurements required to navigate in 3-dimensions continuously. On the negative side, civilian accuracy will be limited severely when compared with what is available from the current constellation. The DoD policy is to limit civilian accuracy to a level consistent with national security interests, now defined as 100 meters 2 drms (95%).

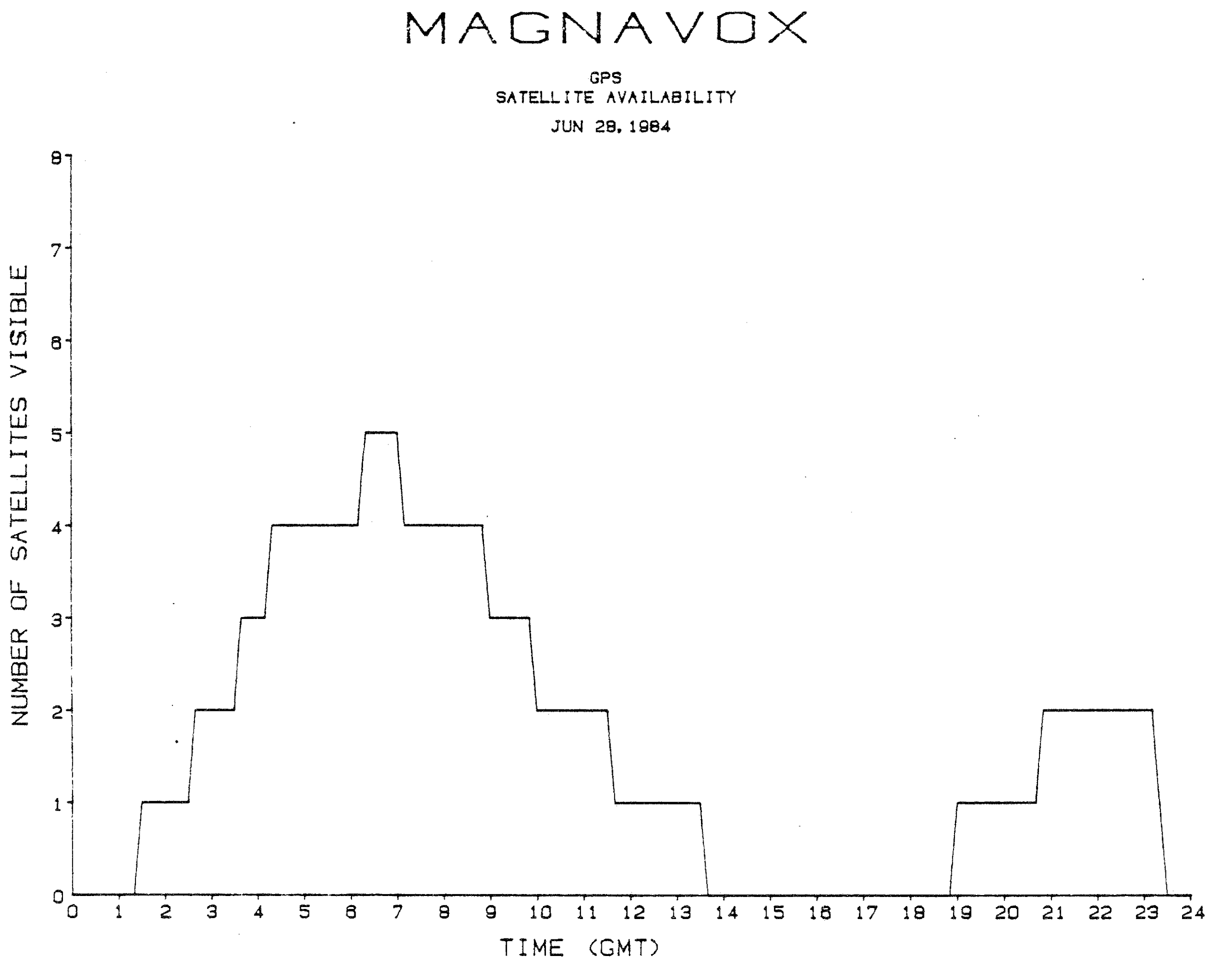



FIGURE 1: GPS SATELLITE AVAILABILITY IN RIO DE JANEIRO

The future GPS constellation will contain three satellites in each of six orbit planes. In addition to these 18 satellites there will be 3 additional satellites placed in orbit as active spares for a total of 21 planned satellites. Since these production satellites are much larger and heavier than the prototype satellites, they are planned to be launched by the Space Shuttle. Figure 2 attempts to predict the number of satellites that will be available in future years. Launches are scheduled to begin in 1986 so that by 1988 there will be 12 satellites in orbit providing worldwide 2-dimensional coverage. By the middle of 1989 all 18 satellites should have been launched, providing worldwide 3-dimensional coverage before the end of the decade.

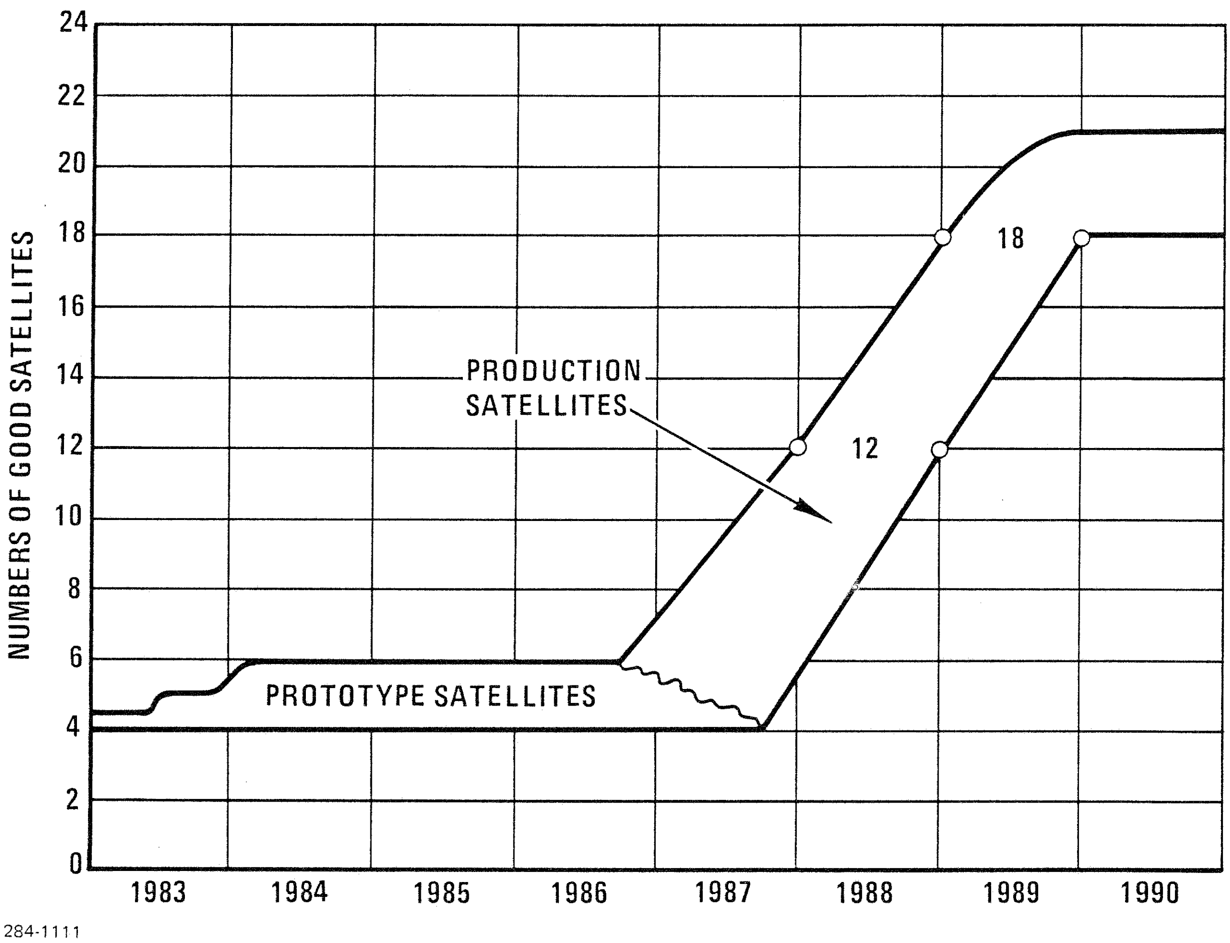
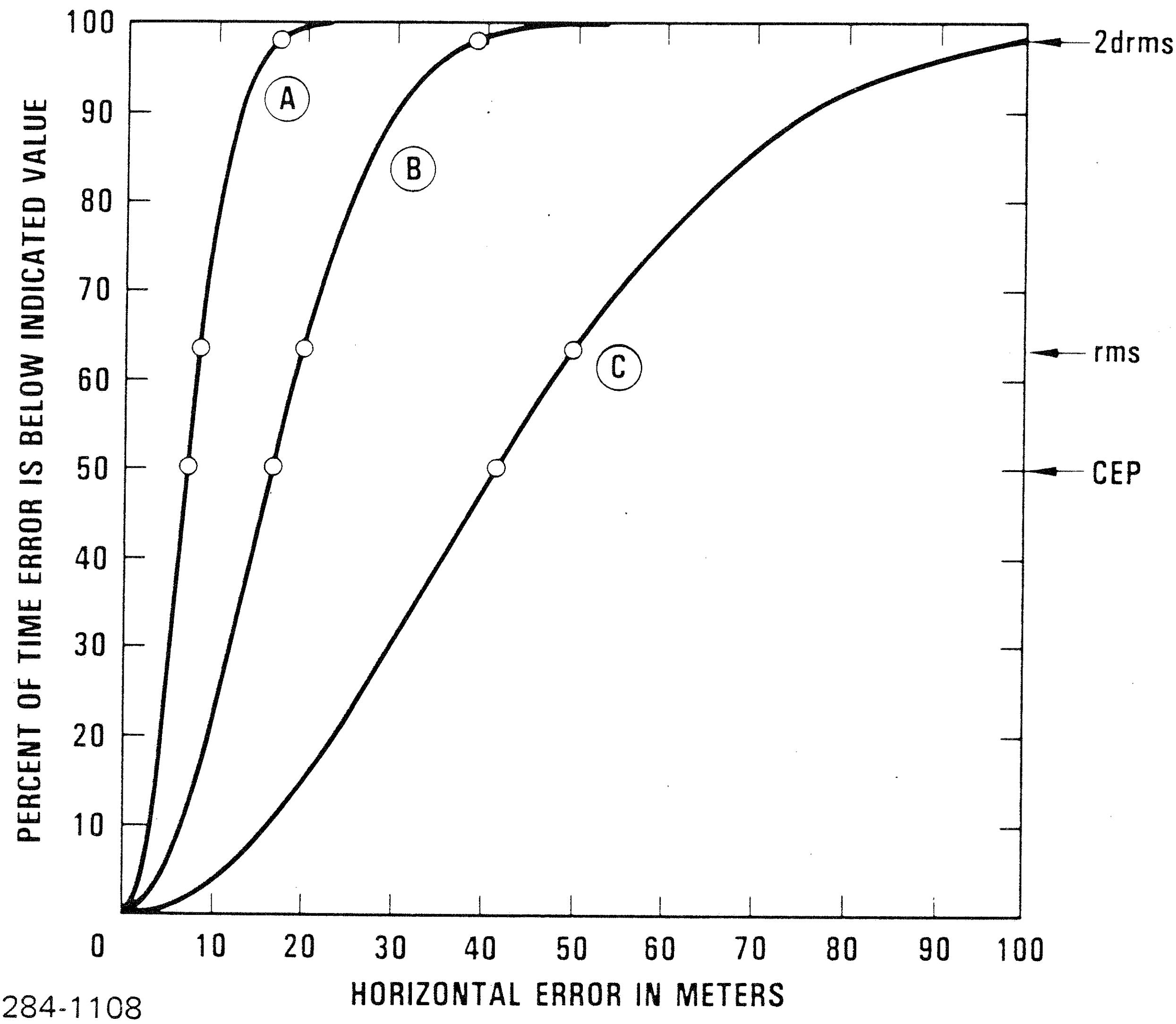



FIGURE 2: FUTURE SATELLITE CONSTELLATION

There will be three classes of accuracy provided to the GPS user by the future constellation. Figure 3 shows these three classes as A, B, and C. Curve A shows the accuracy provided by the full function classified military set. This set will have full access to both GPS frequencies as well as the P-code. Curve B shows the accuracy provided by a low cost classified set which has access to the signal perturbation algorithm giving it the ultimate accuracy of an $L_1$ C/A only receiver. Curve C shows the accuracy provided to the unclassified civilian set demonstrating the 100 meter 2 drms accuracy limit established by the DoD as consistent with national security considerations. It is expected that in time civil users will be given access to full system accuracy .

## DIFFERENTIAL GPS

Since the majority of the error sources which give rise to the accuracy limitations of GPS are highly correlated over a local spatial area, the concept of differential GPS is a natural technique to enhance accuracy. To achieve this enhanced accuracy, a differential GPS monitor would be installed at a known location. This monitor would track all satellites that are visible and compute corrections to the ranges that it measures to force agreement with its known position. These range




A CLASSIFIED, MULTI-CHANNEL, TWO-FREQUENCY, P-CODE RECEIVER
B CLASSIFIED, SINGLE-CHANNEL, ONE-FREQUENCY, C/A CODE RECEIVER
C UNCLASSIFIED, CIVILIAN RECEIVER

FIGURE 3: GPS ACCURACY

corrections then can be employed by other users to enhance accuracy in one of two ways. The monitor station could transmit, in near real time, the range corrections to the users in the local area. In this way, these users could achieve navigational accuracies of approximately 5 meters. An additional extension to this real time differential GPS system would be the use of a pseudolite for the transmission of the range correction information. In this application a pseudolite would be a transmitter which broadcasts a signal which, to a GPS receiver, looks very much like another GPS satellite. The pseudolite transmission would carry a pseudorandom code synchronized to GPS time. In this way the receiver would not only receive the range correction information from the monitor but would also be able to measure an additional range to a known position. Furthermore, this range measurement would be from a location below the aircraft, unlike the measurements from the satellites. For this reason, the pseudolite adds geometric strength to the real time navigation result of the GPS receiver aboard the aircraft.

The ground based, fixed location monitor could also record the raw GPS measurements, including range as well as range change measurements. The user could then post-process these measurements along with like measurements made at the unknown position to achieve even greater accuracies. This latter technique would be used for applications such as land survey where accuracies of approximately 1 cm per kilometer of separation distance can be achieved.

As stated previously, the P-code and hence the $L_2$ frequency will not be available to the civilian user. Because of this signal denial, the region over which any differential technique is useful is limited to that area over which the ionospheric refraction of the $L_1$ signal is highly correlated. As the distance from the monitor to the user increases, this ionospheric refraction correlation diminishes and therefore the advantages of differential GPS diminish.

## PROPOSED PHOTOGRAMMETRIC NAVIGATION SYSTEM

Using a combination of the two differential techniques described above, a proposed Photogrammetric Navigation System based upon GPS can be developed. The first differential technique employing a pseudolite would enhance real time navigation. The second differential technique described uses post-processing to achieve highly precise positioning results for non-moving platforms. This technique can also be employed with data recorded by moving platforms if the noise in the measurements caused by the dynamics of the moving platform can be reduced. The mechanism for achieving this noise reduction is the use of a highly precise dead-reckoning system to aid the GPS receiver which is mounted in the moving platform.

For the photogrammetric application, a fixed site GPS monitor receiver is located in the area which is to be mapped. This monitor will record the GPS measurements including range and range change measurements, for all satellites in view. This monitor would also compute real time corrections for the GPS measurements and transmit them using the aforementioned pseudolite technique. The system mounted aboard the aircraft is shown in Figure 4 in block diagram form. This airborne GPS receiver is tightly coupled to an Inertial Navigation System from which it receives instantaneous velocities. These velocities are used to aid the receiver in tracking the carrier signals received from the GPS satellites. In this way, the GPS receiver can navigate the aircraft using the extremely precise range change information extracted from the carrier along with the real time corrections received from the pseudolites. As the inertial system aids the GPS receiver with velocities, the GPS receiver can reset the inertial system with highly accurate position information. This allows for very precise real time navigation.

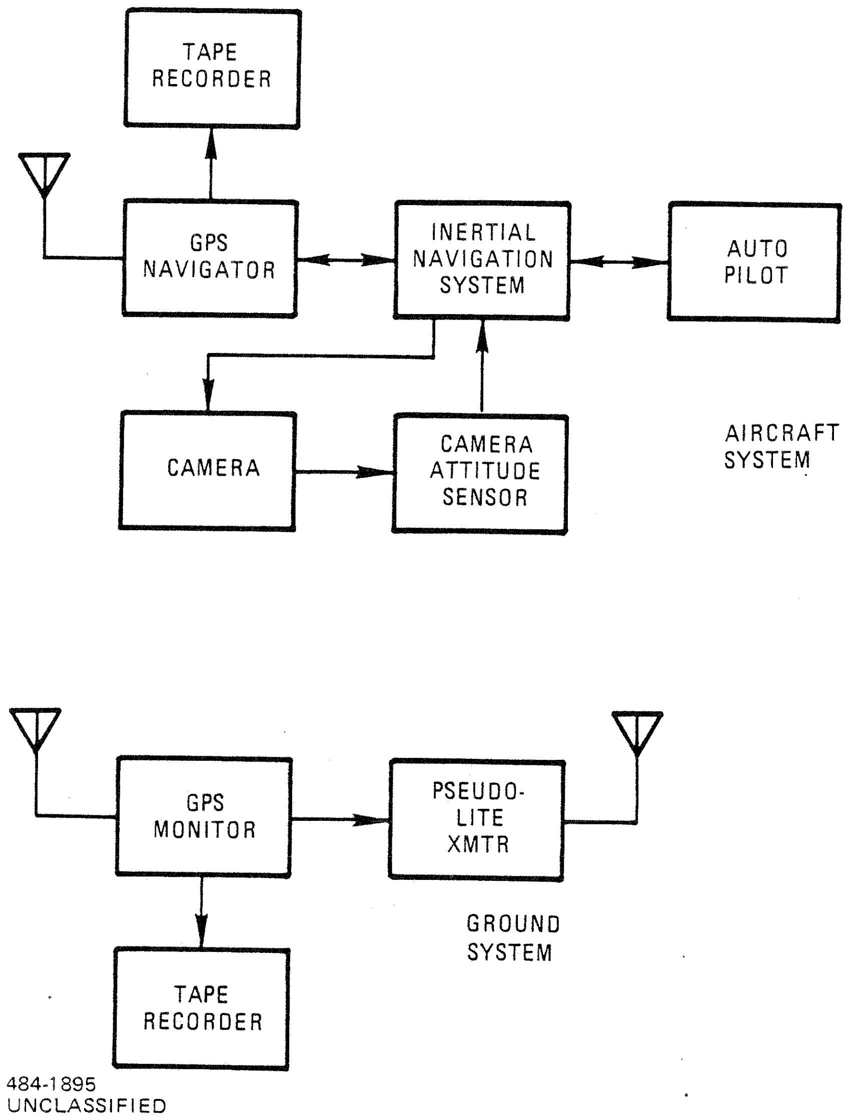



FIGURE 4: PHOTOGRAMMETRIC NAVIGATION SYSTEM BLOCK DIAGRAM

Even greater precision can be obtained after the fact by post-processing. This processing uses the raw data measured by the airborne set in conjunction with the raw data recorded by the ground based monitor. In addition to the GPS range and range change measurements, other data must also be recorded. This additional data includes the position calculated by the inertial navigation system at each of the photographs and the position calculated by the GPS receiver at the same time. This data allows for an after-the-fact calibration of the inertial system errors. The recorded data would then be post-processed by a smoothing filter to develop a highly precise track of the aircraft as it was taking the photographs.

To complete this Photogrammetric Navigation System, two additional extensions should be added. The first extension is that of camera control, whereby the navigation system instructs the camera to expose the film at programmed positions. The connection of the inertial system to the autopilot of the aircraft would then fully automate the photography process with the initialization of the desired route and photograph separation.

Finally, the camera attitude must also be known to complete this automatic system. This can be accomplished by coupling the camera to the inertial system by either precise synchros or by an optical system which measures the attitude of the camera with respect to the local g vector. This attitude would then also be recorded at the times when the photographs are taken.

From the recorded data very precise 3-dimensional camera position and attitude can be developed at each of the photographs during the post-processing. This information should permit the construction of the final map without ground control. In addition, locations where ground control is difficult, such as coast lines, can be mapped accurately using this system.

In summary, a navigation system which tightly couples a differential GPS navigator with an accurate inertial navigation system can provide extremely accurate real time navigation for photogrammetry. This real time navigation system can be coupled to the aircraft's autopilot and camera to fully automate the photogrammetric process. The post-processing of data recorded by the navigator and a ground based monitor could eliminate the need for ground control in the photogrammetric mission.

References: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Acknowledgement:


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