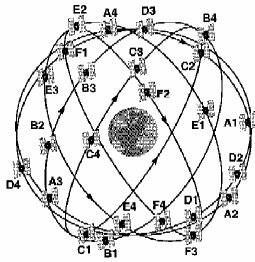071502

Constellation 3D-i

Indoor GPS Technology
For Metrology

ARCSECOND

3D-Intelligence
TECHNOLOGY

GPS

The Global Position System (GPS) has become ubiquitous and is now viewed as the position-utility for the entire world. The power of GPS is not only in its advanced technology but also in the power of its system concept; the satellites operate independently of the users. The satellites (transmitters) output the signals required for a position measurement with great precision. This allows an unlimited number of users to calculate their positions from the received signals and the known positions of the satellites. Again, each user of the system obtains their position independently using a one-way-signal path from the satellite to the receiver.

Constellation^{3Di}

Arc Second® has pioneered and patented its parallel Indoor-GPS™ concept, Constellation^{3Di}™. In Constellation^{3Di}, a transmitter uses infrared light to create one-way position information: the relative azimuth and elevation from the transmitter to the receiver. With the addition of a second transmitter of known location and orientation, users can calculate their position in the Constellation^{3Di} coordinate system. The end result is that as in GPS, a one-way-signal path is created from the transmitters to the receiver. This allows an unlimited number of receivers to continuously and independently calculate their positions whenever two or more transmitters are in view. As will be seen in the discussion below, there are direct parallels between the concepts used in GPS and those used in Constellation^{3Di}.
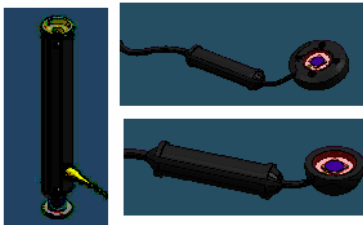
3 or More Transmitters

Wireless Receiver Electronics

Control Center

A family of Detectors

Scale Bar

Invar

Interferometer

Photo provided by API

Figure 1 The Constellation^{3Di} Components

Comparison of GPS and Constellation³ᴰⁱ

Infrastructure

We never see it in GPS, but the entire system is based on a multi-billion dollar infrastructure consisting of over 24 satellites in orbit about 12,000 miles above the earth's surface. These satellites continually transmit the information necessary for remote receivers to calculate their positions.

Satellites   **Transmitters**

Figure 2

In Constellation³ᴰⁱ the satellites are replaced by infrared transmitters which can either be permanently installed in the facility or easily moved between worksites. Whenever the transmitters are on they send out the signals needed by the receiver to independently calculate its position. Therefore, as in GPS, the infrastructure is fixed and unlimited receivers can operate simultaneously.

Creating the Measurement Matrix

In GPS, again hiding behind the scenes, is a critical piece of information: Where are the satellites and has the clock in the receiver drifted? To determine information about the satellites there is a world wide network of ground stations operated by the United States Government. The information is then passed to the receivers on the ground through a special communication channel embedded in the GPS signal. This orbital information, ephemeris, is updated on a continuous basis. In addition, the clocks in the GPS receivers are monitored and adjusted as needed. Receiver clocks are synchronized to the clocks of the GPS satellites by the inclusion of a fourth measurement, from a forth satellite.

The Military Determines the Orbits and Clock Drifts

Setup Determines Transmitter Position and Orientation
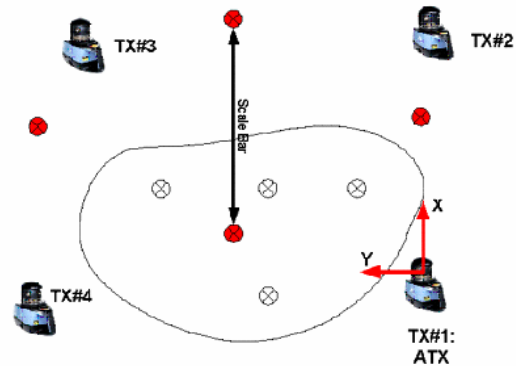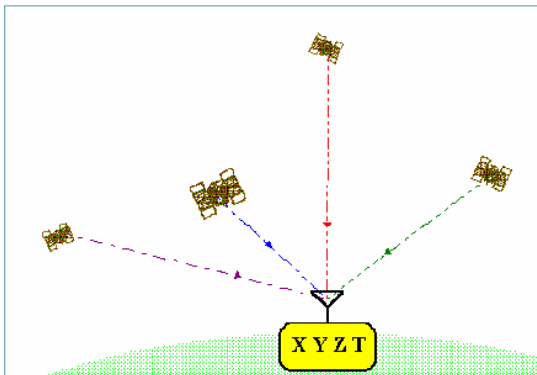
Figure 3

Constellation^{3Di} utilizes a similar concept to determine the location of the transmitters at the local level: setup. During the setup process the relative position and orientation of the transmitters are determined using an advanced bundle algorithm. An additional component of setup is to determine scale, which is the absolute distance between the transmitters. Scale is determined by telling the system the known distance between two receiver locations. Once the transmitter position and orientation information is available it is distributed to all receivers via wired, wireless, and infrared communication channels. For the user, setup is a rapid process and in many installations can even be fully automated.

Simple Measurements

In GPS the receiver must calculate four quantities: x, y, z, and time. The signal from each satellite contains one measurement value; the range from the satellite to the receiver. To calculate four quantities, four or more measurements values are needed leading to the requirement that four satellites must be in view to make the simplest measurement.

Four Satellites yield X,Y,Z, and Time ~10m
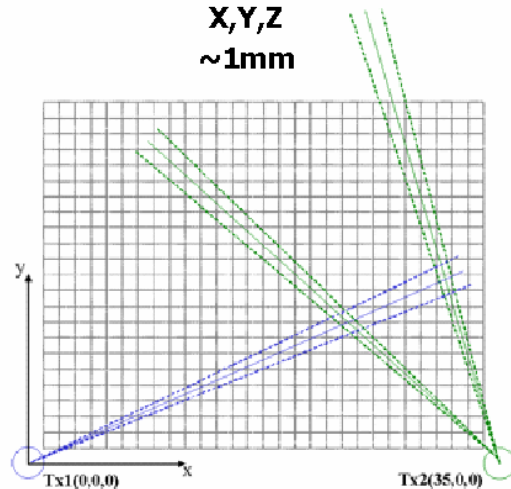
Two Transmitters yield X,Y,Z ~1mm

Figure 4

In Constellation^{3Di} three quantities are calculated: x, y, and z. Each transmitter presents two measurements values to each receiver: the azimuth and the elevation from the transmitter to the receiver. For the simplest position calculation, two transmitters must be in view yielding four measurement values which are used to calculate the three position quantities using triangulation. Figure 4 also shows the error surface for these simple measurements. Note that for two transmitters the error surface is a rhombus and that its size and shapes is different in different parts of the measurement field.

A more complicated measurement

GPS receivers are designed to receive more than four signals at once. There are many receivers on the market which can receive signals from up to 12 satellites simultaneously. Although each additional satellite might not dramatically reduce measurement uncertainty due to degradations in the geometry, each additional set of signals does help the solution. Users of GPS will note that the dilution of precision decreases with the addition of more satellites.
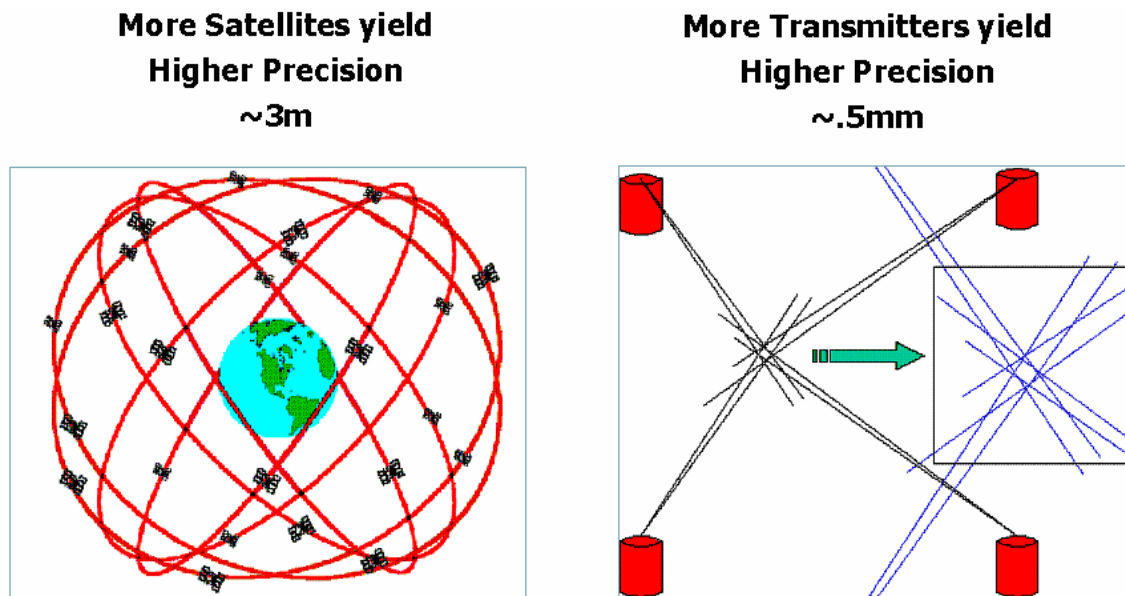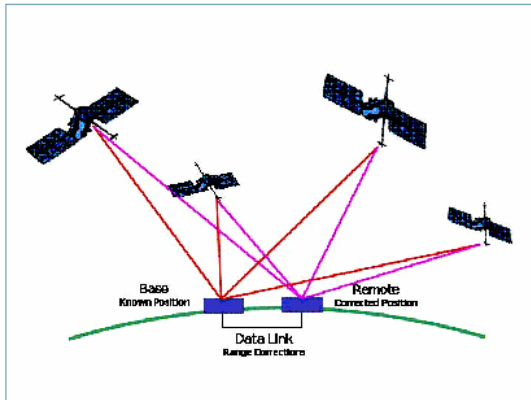

Figure 5

Constellation^{3Di} can also make use of signals from additional transmitters. As Figure 5 shows, the major advantage is that the error surface becomes closer to a circle and its size and shape stay relatively constant in the measurement volume. The Constellation^{3Di} user will see their measurement uncertainty decreasing as the number of transmitters is increased.

Local corrections increase the quality of measurements

The position of the satellites is a critical piece of information for a GPS receiver to accurately calculate its position. The ephemeris data that is transmitted from the satellites is of high quality, but orbits and radio signal propagation velocity through the earth's ionosphere and troposphere change more often then the data can be practically updated. It is possible to deploy large numbers of receivers on the ground with special software installed. These base station

receivers, such as in the Wide Area Augmentation Network, use the knowledge that they are not moving to create better estimates of the satellite's orbit and the effect of propagation velocity variation.

Differential GPS
Local Corrections of Orbits
~1m

Fixed Receivers as Base Stations
Local Correction of TX Info
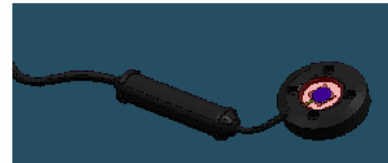**~.1mm**

Figure 6

Likewise in Constellation[3Di] base stations dramatically increase the reliability of the measurements. A single fixed receiver can automatically and immediately determine whether the measurement system has gone out of tolerance. With multiple fixed sensors, the system can perform a background setup and continually correct the measurement field.

Real time cooperation between receivers give this highest quality measurements

The most accurate GPS measurement configuration, differential GPS, uses two receivers acquiring data from the same satellites at the same time. The technique can instantly measure the relative distance from the receivers to each of the satellites. This differencing technique requires a fixed receiver within a few thousand meters of the roving measurement receiver. The dramatic increase in accuracy makes this a common technique in cadastral (land) surveying.

Real Time Kinematic Phase Difference Rx to Rx ~.05m

SV at time 1
Orbit path
SV at time 2
Remote Receiver
Reference Receiver
Remote Position = Reference Position + Difference in X, Y, Z
Derived From Difference in Carrier Cycle Measurements
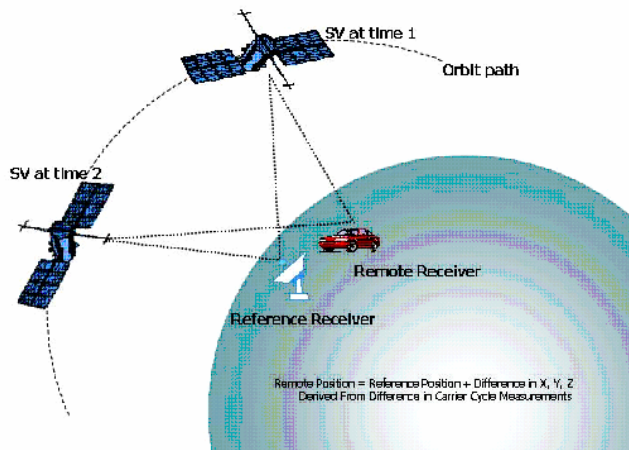
Multiple RX on the Object ~.050mm

Figure 7

In Constellation[3Di], techniques are also available for using multiple receivers to more accurately determine position. These relative techniques are very important when 10s to 100s of sensors are on a fixed body. As in GPS, this is the most accurate technique and allows the precise determination of deformation in a jig or the precise alignment of bodies.

Constellation[3Di] Testing

A major aircraft manufacturer recently funded an effort with Arc Second to determine the feasibility of Constellation[3Di] for aircraft manufacturing. The ultimate goal is to change the way aircraft are built by providing accurate position information to all stakeholders. The vision is to create an increase in productivity by reducing the cost of tooling, inspection, and rework. It was identified early in the program that system accuracy could be a significant barrier to acceptance. Therefore, an important part of the program was to independently document the overall accuracy of the system. The accuracy goal was 0.040 inches of extended uncertainty (k=2) in a 75 ft x 75 ft x 18 ft volume.

> **Test Results**
>
> Extended Uncertainty:
> 2-4 mils in 42 feet

Two types of tests were performed to assess the uncertainty of Constellation[3Di]: (a) testing against a laser interferometer and (b) testing against a set of monuments whose coordinates were determined with a laser tracker.

In the test with the laser interferometer (rated at 1.4 parts-per-million) the linear measurements of the interferometer were compared to the 3D coordinates generated by Constellation[3Di]. In this test the uncertainty allocated to Constellation[3Di] was 2-4 mils[2] or 4-8 parts-per-million. Laser-trackers are typically rated at 10 parts-per million.

In the 3D coordinate test using monuments, a measurement field of dimensions 60 ft x 75 ft x 18 ft was created in a temperature-controlled room using four laser trackers. Analysis showed that the uncertainty in the monument positions was between 10 and 20mils. When the

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[2] All data presented are 2 standard deviation values after two seconds of averaging.. One mil is .001 inches.

data from Constellation[3Di] was compared to the monuments the difference had a 2 sigma standard deviation of 20mils. Under such a circumstance, where measurement results are the same as the uncertainty in the measurement field, it is impossible to say which is better: Constellation[3Di] or a laser-tracker.

What became clear from the tests is that Constellation[3Di]'s absolute uncertainty is directly related to the quality of the scale bar measurement. When a laser tracker provided scale, then the results were on the order of the uncertainty of the laser tracker. When an interferometer provided scale, then the uncertainty was reduced. Therefore Arc Second offers as an accessory an interferometric scale bar. With this option, Constellation[3Di] consistently delivers uncertainties better than 8 parts per million.

Arc Second is now applying these concepts into our "auto-calibration" capability. With auto-calibration, all setup steps are fully automated and logged using fixed receivers, two of which are tied to the interferometric scale bar. The implementation of auto-calibration minimizes downtime and corrects for environmental conditions in the measurement field; continuously and in real-time.

Applications in Aerospace
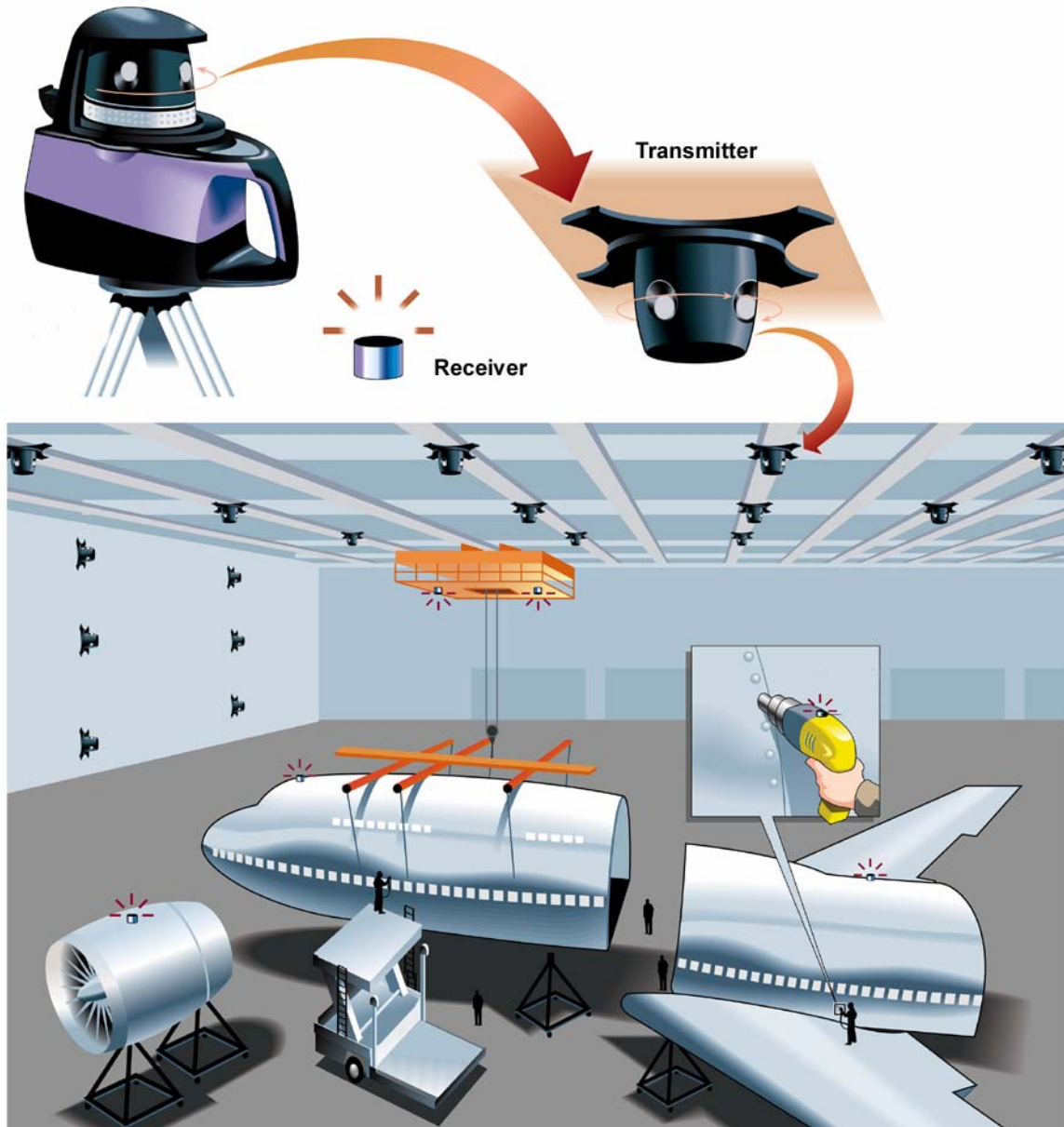
The Constellation$^{3Di™}$ concept is most powerful when viewed as creating a 3D-Enabled Environment™. The existing components can easily be modified to support permanent installations allowing the user to work in a factory coordinate system, no matter where they are in the facility. As shown above, transmitters can be mounted on the ceiling and walls and the receiver can pick the best set of transmitters in view to determine its position.
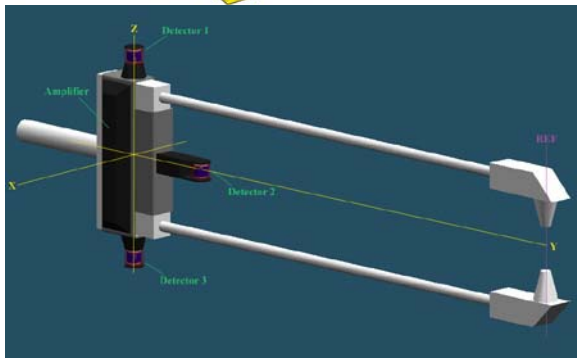
Several important applications for aerospace have already been identified.
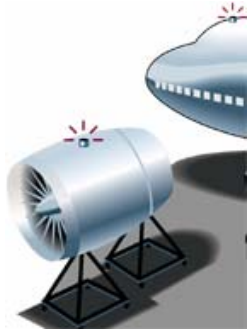
Mating of Large Objects. Once position information is generally available many manufacturing techniques can be simplified. Imagine that the engine and the engine mount are both instrumented so that as the engine is docked to the airframe without the use of special fixtures. Or imagine that both wings and the wing box are instrumented. Not only can the wings be docked to the wing box but they can also be continually monitored for symmetry.

Hand tools that always know their orientation and position with respect to the part being measured. With three attached detectors, the position and orientation of any tool with respect to the part can be determined. This enables hand operations to have the same capabilities and documentation advantages of fixed scanners and milling machines. Imagine that a torque wrench were instrumented. Then as soon as the bolt is tightened a report can be generated documenting which bolt was accessed, when the bolt was installed, and the amount of torque utilized, all automatically. Such documentation minimizes mistakes and rework. Imagine that the NDE tool that is currently utilized to inspect small composite parts was fully instrumented. Then its output can be utilized to create three-dimensional images of the part being inspected. These pictures of the object, created with a hand tool, become the basis for economical, automated inspection documentation.
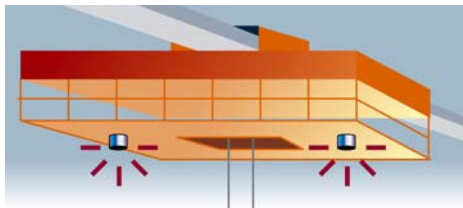
Tracking of Infrastructure. Again, with the wide availability of accurate position information objects about which tracking information has always been desired can now be instrumented with ease. Cranes and crane tracks can be monitored. Scaffolding around a moving production line can be monitored for interference with the aircraft. Inventory can be located in a global coordinate system.
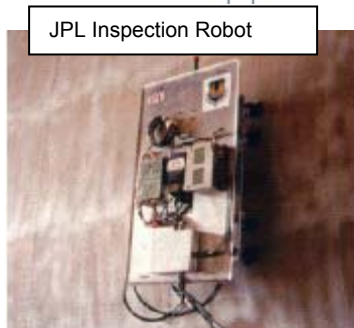
JPL Inspection Robot

Robotic Inspection. Finally, with a ubiquitous factory coordinate system, high tech solutions to old problems are now available. Robots have already been developed that can climb the side of the aircraft. Now they will know where they are on the outside of the aircraft. One could even imagine coordinated robots on the inside and outside riveting the aircraft sections together.

Summary

These applications simply scratch the surface of possibilities. Arc Second believes that as system designers realize the ease with which position information can be added to their systems, the possibilities will explode. Arc Second stands ready to apply its off-the-shelf position technology products and solutions to your problems.

Arc Second's 3D-Intellegence technologies are also available today our licenses. Trimble Navigation, under license from Arc Second, sells LaserStation™ for the construction industry. Sokkia sells Arc Second's Vulcan® system for law enforcement applications.

Additional information is available at:

http://www.arcsecond.com
http://www.Constellation3Di.com
http://www.pocketcad.com
http://www.trimble.com/type_conpositioning.html -- Trimble's LaserStation site

http://www.thehunley.com/Digital%20Imaging/digitalimages.htm -- Our work on the archeology of the Hunley Submarine
http://www.survice.com/SIPages/SI_Download_Briefing.htm -- Survice Engineering's web site demonstrating the efficiency of Infrared GPS vs. other techniques

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