Guidance, Navigation and Control

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AA420 Space Design

Outline

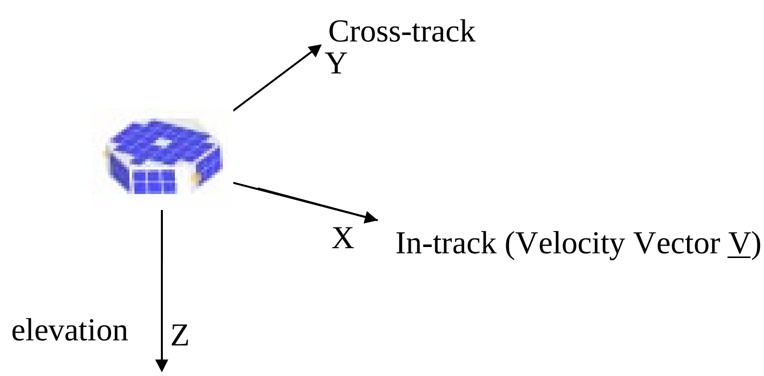
- Driving Issues and Requirements
  - Modes of Operation
  - Disturbance environment and other factors
- Active Options
  - actuators (thrusters)
  - inertial sensors (GPS, TDRS, etc.)
  - relative sensors (GPS/cross-link, stereo imaging, laser range finding)
- Design Approach

- References:
  - Sections 11.7 of Larson and Wertz

Guidance, Navigation and Control

- Objective is to measure and control the inertial (with respect to an external reference frame) or relative position of the spacecraft position (in three axes)

Basic Reference Frame



Modes of Operation

- Control requirements differ during different operations
- Usually, accuracy is required in terms of
  - inertial position
  - relative position (short range or long range)
- Modes of Operation
  - Altitude/orbital maintenance (drag make-up)
  - Orbital transfers
  - Formation Flying (relative)
  - Rendezvous (relative)

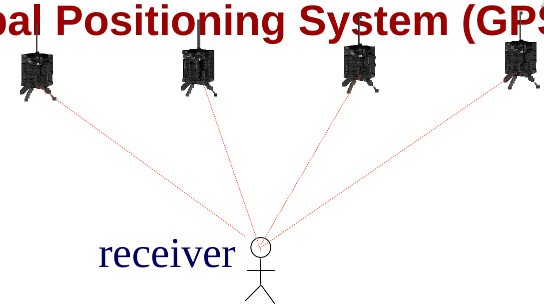
Disturbance Environment

- External disturbances
  - Atmospheric drag
  - Solar radiation and pressure
- Other factors:
  - Mass/Inertia
  - Power
  - Safety
  - Cost

Guidance/Navigation Sensing

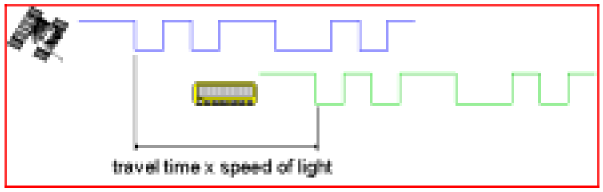
System	Accuracy	Advantage	Disadvantage
Ground tracking	1-3 km in LEO	Traditional approach Methods and tool well established	Accuracy depends on ground-station coverage Can be operations intensive
TDRS tracking	50 m	Standard method for NASA High accuracy Same hardware for tracking/data links	Not autonomous Available mostly for NASA missions Requires TDRS tracking antenna
GPS	15-100 m	High accuracy Provides time signals as well as position	Semi-autonomous Depends on long-term maintenance and structure of GPS LEO only Must initialize some units
MANS	100-400 m in LEO	Fully autonomous Uses attitude-sensing hardware Provides orbit, attitude, ground look-point, sun vector	First flight test in 1993 Initialization and convergence speeds depend on geometry
Space Sextant	250 m	Could be fully autonomous	Flight-tested prototype only-not current production product Relatively heavy and high power

Global Positioning System (GPS)



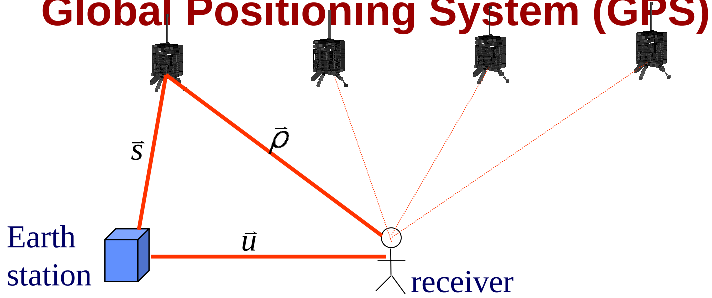
- A network of 24 satellites in 1/2 GEO (12 hr orbit) with the objective of giving a world-wide navigation reference
- Funded by the U.S. Department of Defense to allow precise navigation on the Earth's surface.
- Coverage only in central core of Earth (no poles) - need more satellites!
- GPS receivers retrieve signals from four satellites to find the receiver position (at the same time or sequentially)
- http://www.qualityeng.co.uk/gpstutor/gpstutor.htm

How it works



- The pseudorange measurement is the basic GPS observable that all types of receiver can make.
- The process works something like this......
  - At a certain instant in time, codes (the C/A codes, for example) are generated within the satellite and the receiver.
  - The satellite's code is then transmitted and is picked up by the receiver.
  - The receiver then compares the state of the incoming code with its own code - the difference is the time of flight
- However, the inaccuracy of the receiver clock must be subtracted out

Global Positioning System (GPS)



- Satellites each have a distinct signal that they are constantly sending out
- Requires four satellites (or more) four equations, four unknowns

$$\vec{\rho} = (\vec{s} - \vec{u}) + ct_u$$

(six reduces time errors more)

$\vec{\rho} = (\Delta t \times c) =$ pseudorange (known)

$\vec{s} =$ satellite position (known)

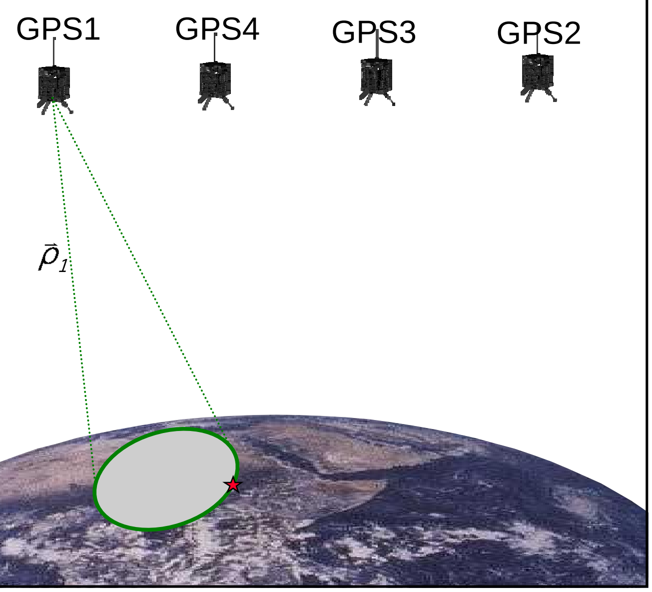
$\vec{u} =$ receiver position (unknown)

$c =$ speed of light (known)

$t_u =$ time difference between receive (unknown) and satellite time

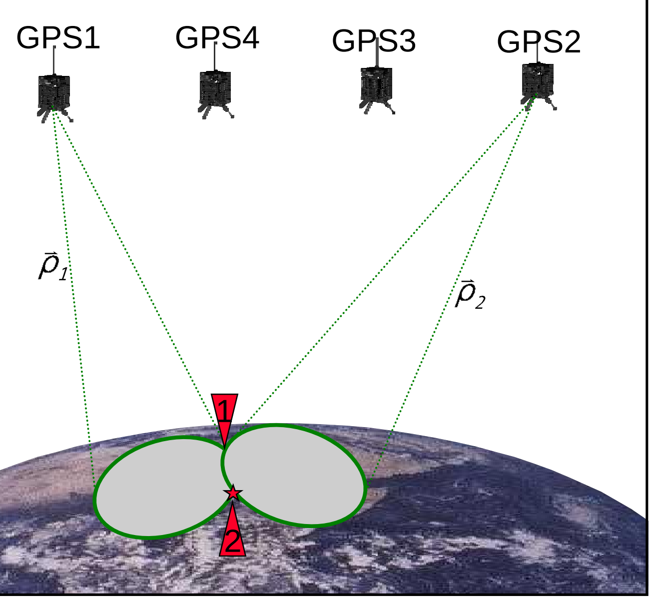
GPS Pictorially 1

GPS1 allows the receiver position "★" to be known somewhere on the outer line of an ellipse (i.e. the pseudo-range distance)



GPS Pictorially 2

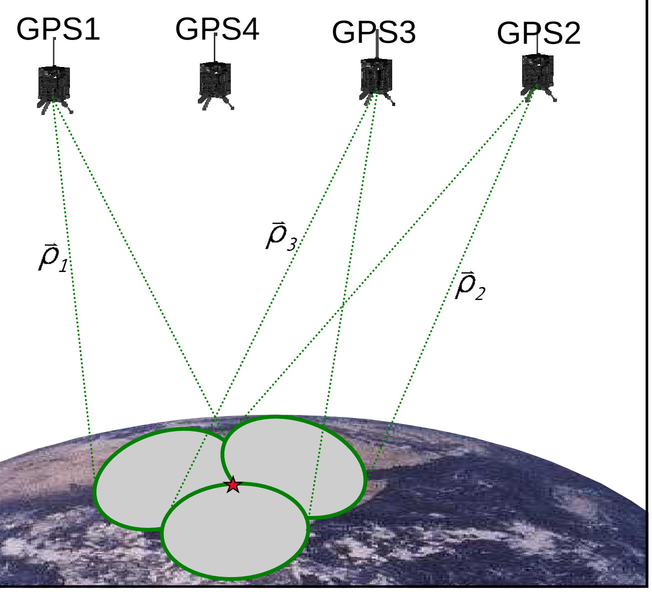
GPS2 allows the receiver position "★" to be known to two points "1" and "2"



GPS Pictorially 3

GPS3 allows the receiver position "★" to be known

GPS4 adds a fourth ellipse and increases the accuracy because of receiver time inaccuracies - this is the normal operating point for GPS receivers



GPS Satellites

- Payloads:
  - Communication package to broadcast time and position information to users
  - two cesium and two rubidium atomic clocks - would lose/gain 1 second every 160,000 years
- Unmanned ground station support:
  - Hawaii
  - Ascension Island in the Atlantic Ocean
  - Diego Garcia the Indian Ocean
  - Kwajalein in the Pacific Ocean
  - Falcon AFB Colorado (master)

GPS Signals

- GPS satellites transmit two L-Band carrier signals
  - L1 at 1575.42 MHz (wavelength of 19 cm)
  - L2 at 1227.60 MHz (wavelength of 24 cm)
- The reasoning behind transmitting using two different frequencies is so that errors introduced by ionospheric refraction can be eliminated.
- The frequencies are generated from the fundamental satellite clock frequency of 10.23 MHz
- Two binary codes are modulated onto the carriers:
  - C/A (coarse acquisition) code
  - P (precise) code
- Satellite coordinates are also modulated onto the carriers

GPS Signals

- The C/A (coarse acquisition) code is a pseudo random binary code (states of 0 and 1) consisting of 1,023 elements, or chips, that repeats itself every millisecond (300 km)
- The term pseudo random is used since the code is apparently random although it has been generated by means of a known process, hence the repeatability.
- The P (precise) code is a long binary code that would repeat only every 38 weeks

Extensions to GPS

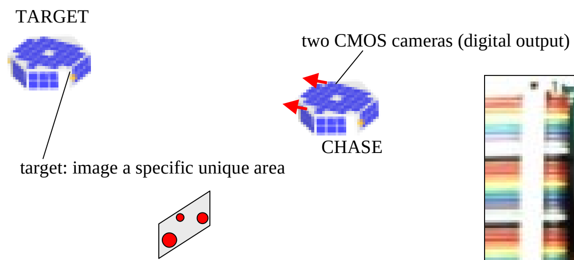
- An extension GPS is differential GPS (DGPS) which also incorporates real-time corrections for the errors inherent in the measurements
- Carrier Phase Measurement utilizes the phase difference for the incoming signals to get very precise measurements
  - Since the two carriers have short wavelengths (19 and 24 cm for L1 and L2 respectively), the whole number of complete wavelengths (integer ambiguities) between the satellite and receiver must first be determined.
  - This is usually carried out by post processing using linear combinations of the two frequencies and differencing techniques
  - can achieve centimeter accuracy

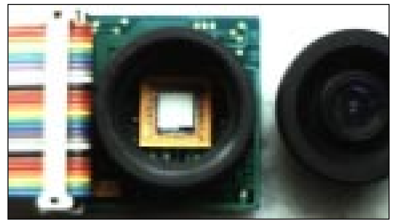
- Can use two receivers to get attitude data

Others

- Microcosm Autonomous Navigation System (MANS): Observes Sun, Earth, and Moon from single sensor to give attitude, orbit, sun angle information
  - Can use any other attitude sensors on most spacecraft
- Space Sextant: measures the angle between spacecraft and a star and the limb of the moon to give both orbit and attitude information.
  - Uses precise telescope measurements i.e. heavy!

Relative Range Sensor using CMOS Technology

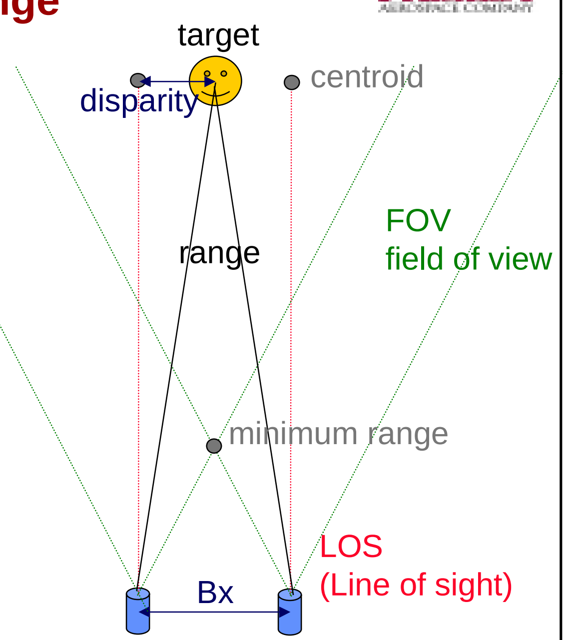




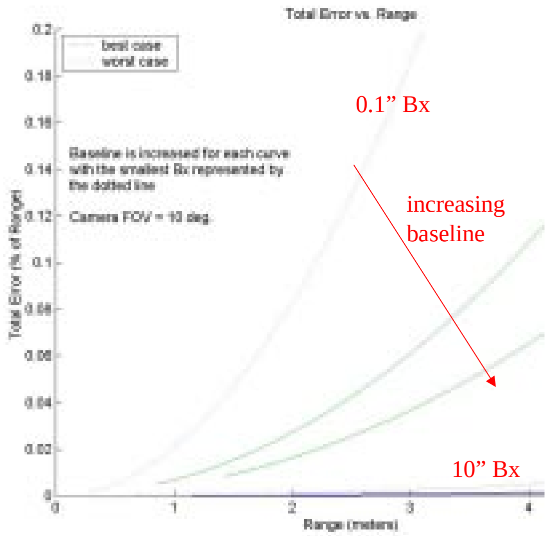
Manufacturer	IMEC Company
Model	Fuga 15d Matrix Sensor
Mass	60 g
Power Consumption	50 mW
Dimensions	45 x 45 x 40 mm

Stereo Range Sensor

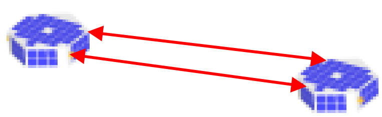
- Disparity (difference in image centroid between cameras) measured in pixels is used to find range
- Errors in stereo range system are a function of
  - range
  - baseline (Bx)
  - field of view (FOV)
  - resolution (pixels)
  - noise



CMOS Range Sensor Accuracy



Laser Range Finder



- Time of flight laser range finder
  - distance based on the time of flight for a laser beam to go from one satellite to another
  - time measured, and distance calculated based on speed of light
- Requires very accurate pointing, although one can spread the beam
- Focus of space based optical interferometry (Space Technology 1)
- Good for laser comm satellites because beams are already there!

Design Approach

1. Define all operational modes for all mission modes
2. For each mode, derive requirements on range (min and max)
3. Quantify the disturbance environment (forces) for each mode
4. Select type of spacecraft control (especially sensors and Ibit) based on system and control mode requirements, disturbance environment
5. Select and size GNR hardware
6. Define guidance, navigation, rendezvous and control algorithms