Using GNSS for Robot Positioning

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OUTLINE

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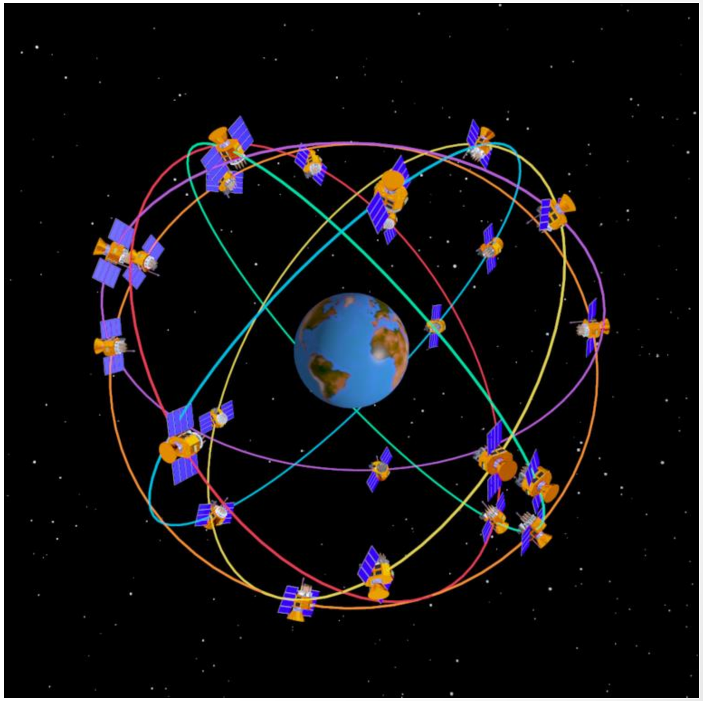
- Traditional techniques revisit (pros and cons).
- How it works (GPS as example).
- Why use GNSS for Robots.
- How accurate is GNSS (GPS as example).
- Some sources of GNSS error.
- Techniques to improve GNSS precision.
- Conclusion.
- Q&A and Feedback.

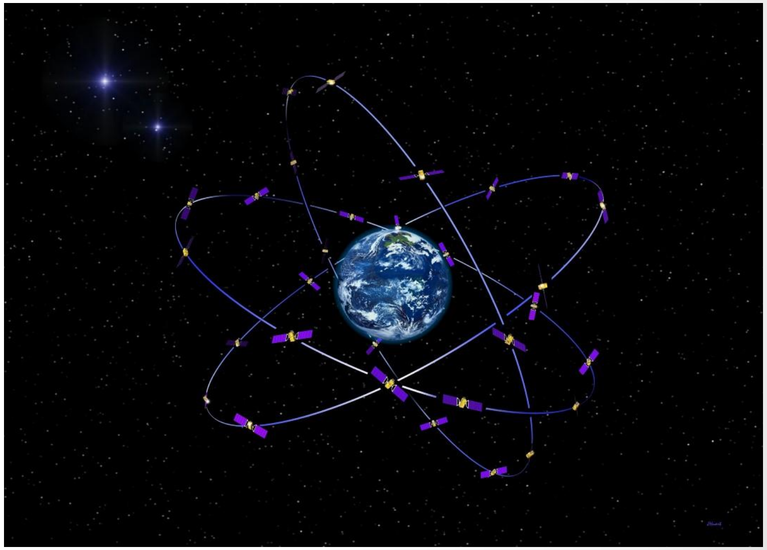
Introduction

- Global Navigation Satellite System - GNSS
  - Constellation of orbiting satellites.
  - Network or ground stations.
  - Coded signals at precise interval
- GPS
  - 24 satellites, 24/7 operation time, 6 orbits planes.
  - Real-time, 3D positioning,
  - Maintained by U.S. D.o.D. (public sector funded)



Other GNSS systems

- GLONASS
  - Russian alternative, 24 satellites, 3 orbit planes.
  - 12 healthy satellites
- GALILEO
  - European's next generation GNSS
  - Funded by both public and private sectors.
  - Chargeable services additional features.



Traditional positioning techniques revisit

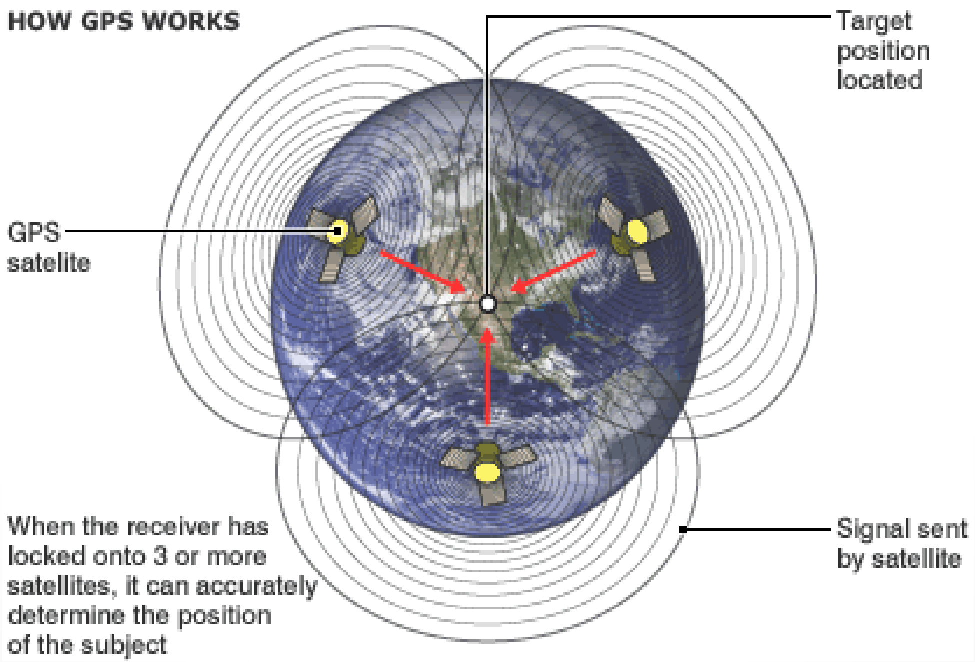
TECHNIQUE	PROS	CONS
Odometry (widely used)	short-term accuracy inexpensive	Drifting (collision) Odometer needs calibration.
Inertial navigation (IN): gyroscopes	Self-contained no external references required	Drifting or unsuitable for long range mission.
Solid-state magnetic compasses	Low power consumption Tolerant to shock and vibration Fast acquisition	Magnetic field can be distorted near power lines or metal structures.

Traditional positioning techniques revisit

TECHNIQUE	PROS	CONS
Active beacons	Reliable high sampling rate	Require installation, operation and maintenance.
Map-mapping	Robots already have map of the mission, responsive to the environment	Scenes changes, moving objects make it difficult to identify the current location.

How GPS system works

- "Clocks in the sky"
  - Each satellite broadcasts a time signal, plus orbit information
  - Receivers calculate pseudoranges to visible satellites
  - Receivers triangulate their position



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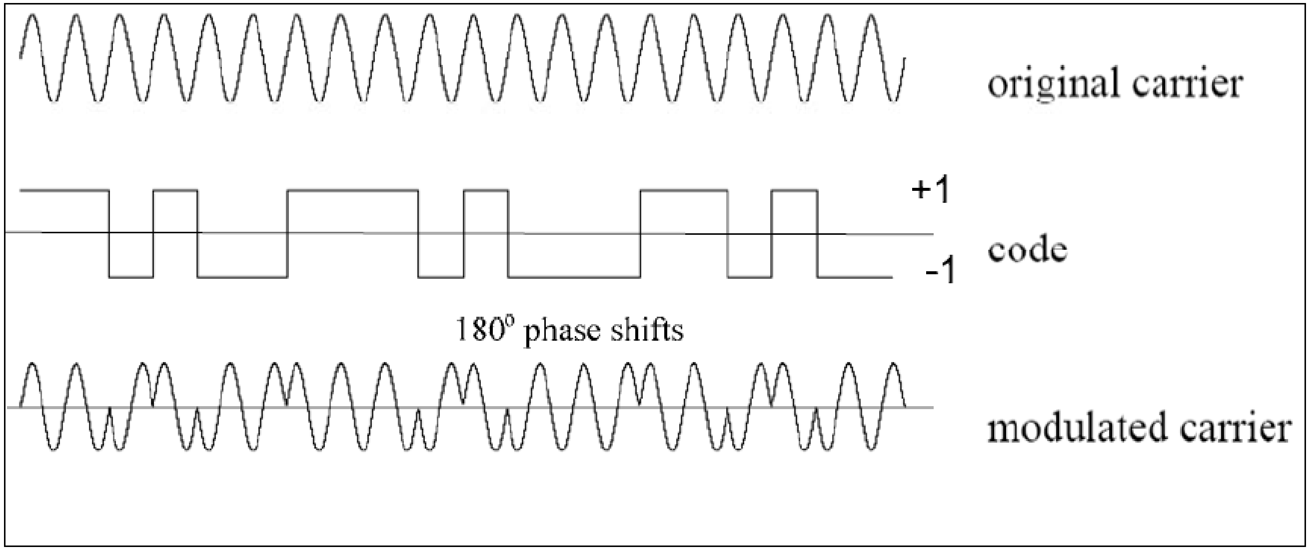
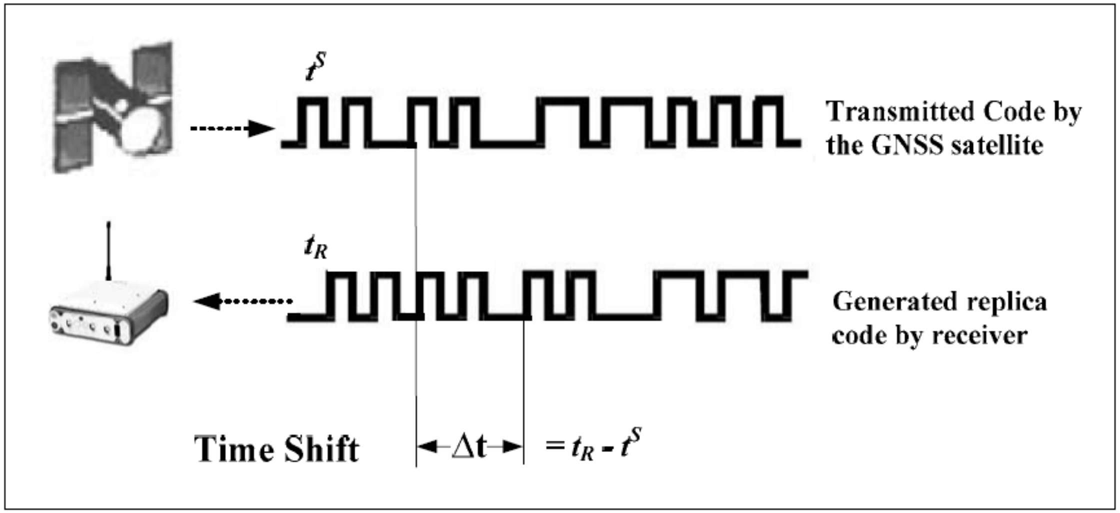
How GPS system works



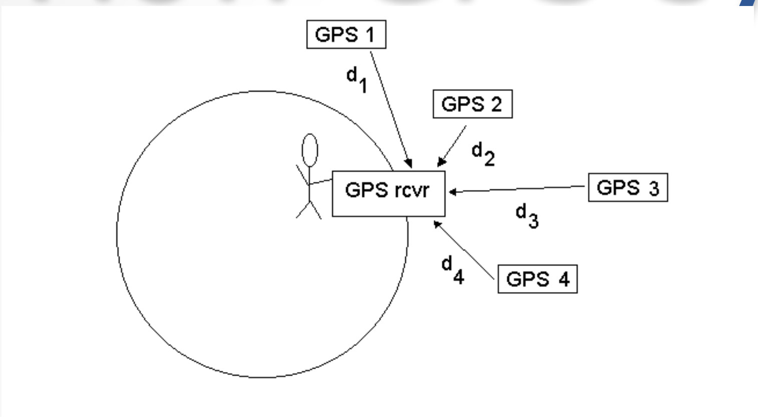
- Based frequency f0 = 10.23 Mhz.
- Two carrier signals L1 and L2 are generated by integer multiplication with f0.
- L1 and L2 are biphase modulated by codes (sequence +1, -1) to provide clock readings and transmit information such as orbital params.

How GPS system works



- The time or phase measurement performed by the receiver is based on the comparison between the received signal at the antenna of the receiver and the generated reference signal by the receiver.
- **Range = velocity * time**

How GPS system works



four equations for four unknowns *x, y, z, t_c*,
(*x, y, z*) are the receiver's coordinates
***t_c* is the time correction for the GPS receiver's clock.**

$$d_1 = c\left(t_{t,1} - t_{r,1} + t_c\right) = \sqrt{\left(x_1 - x\right)^2 + \left(y_1 - y\right)^2 + \sqrt{\left(z_1 - z\right)^2}}$$

$$d_2 = c\left(t_{t,2} - t_{r,2} + t_c\right) = \sqrt{\left(x_2 - x\right)^2 + \left(y_2 - y\right)^2 + \sqrt{\left(z_2 - z\right)^2}}$$

$$d_3 = c\left(t_{t,3} - t_{r,3} + t_c\right) = \sqrt{\left(x_3 - x\right)^2 + \left(y_3 - y\right)^2 + \sqrt{\left(z_3 - z\right)^2}}$$

$$d_4 = c\left(t_{t,4} - t_{r,4} + t_c\right) = \sqrt{\left(x_4 - x\right)^2 + \left(y_4 - y\right)^2 + \sqrt{\left(z_4 - z\right)^2}}$$

Why use GNSS for Robot

- Aerial: In vast space and long distance mission.
- FREE: just GPS receiver, 24-hour and all-weather availability.
- It provides accurate position for over-the-horizon and grounded operations.

MQ1-predator drone

Why use GNSS for Robot

- Offshore exploration, dangerous environment.
- Enhanced vehicle control
  - User aid-system.
  - Autonomous car
- It’s a **consistent**, global co-ordinate system.

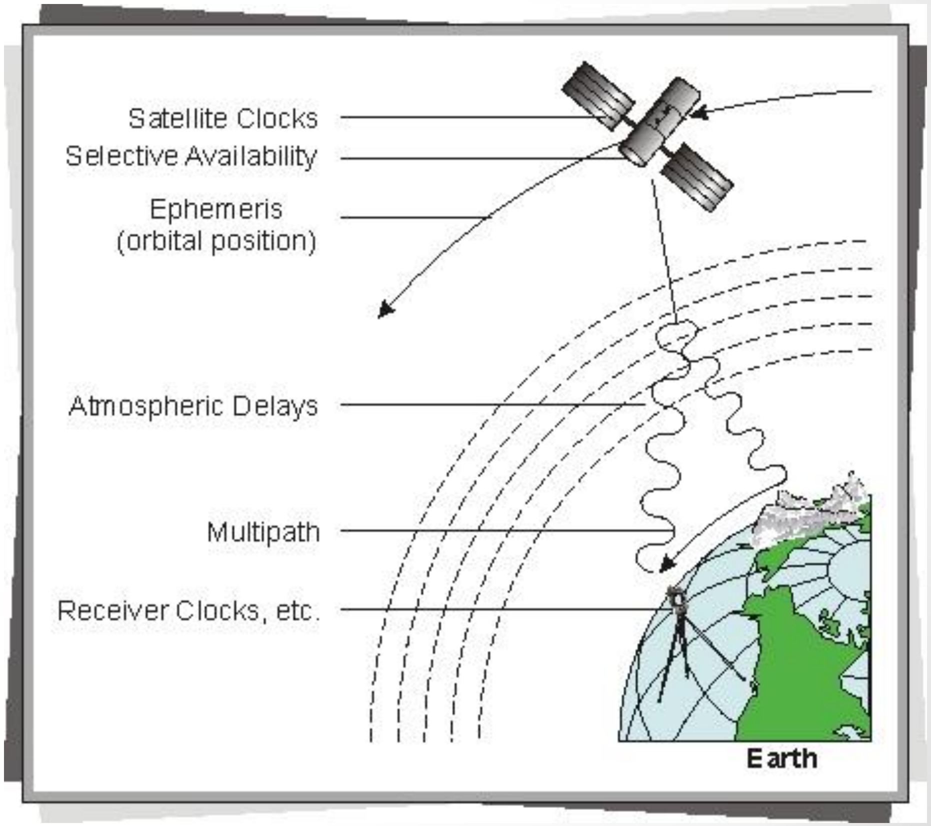
Perry XLX Generation 2 ROVs

How accurate is GNSS (GPS as example)

- Quality of receiver (how much you spend).
  - Base GPS receiver: about 15m
  - Galileo: 1m.
  - SBAS in U.S. E.U. and Japan: 3m
  - Source correction and dual frequency (more than $2,000.0): ~ 10 cm
  - Great correction and $10k receiver: < 1cm
- Number of channels
  - In theory: 3 satellites are enough
  - In practice: at least 4, the more the better.
- Position of the GPS satellites
  - Signal travels in space: error prone (0.001 second ~ 300km inaccuracy).
  - GPS satellites are also accurate to about 10 nano-seconds. (3m at speed of light).

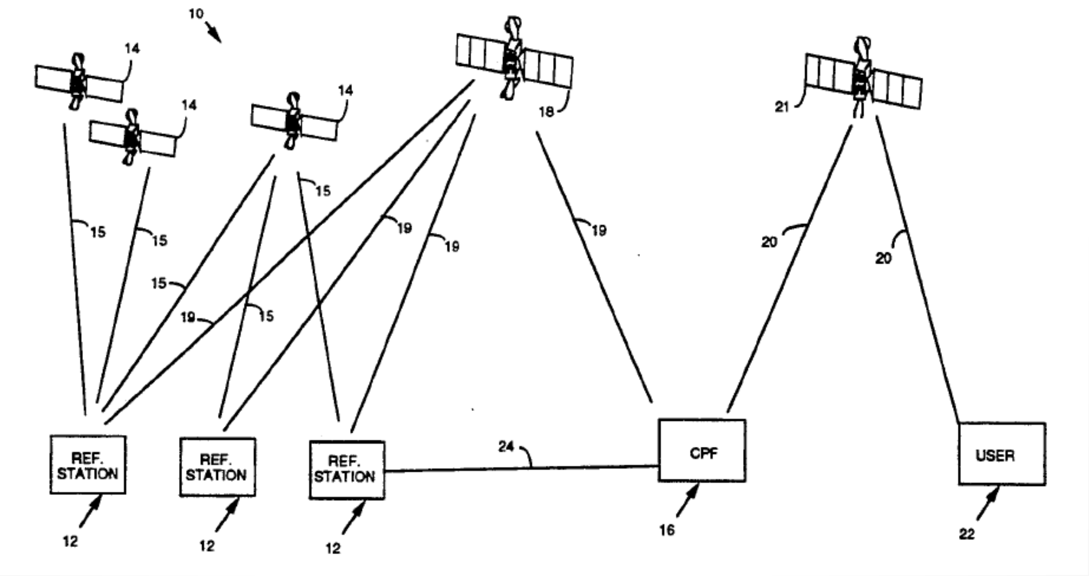
Some sources of GPS error

- Mismatch between ionosphere model and actual conditions
- Multi-pathing
- Dynamic model mismatch to real movement'
- Bugs in code and standards.
- Antenna errors
- Clock errors.
- Orbital errors.



Differential GPS

- Generally, to use more than one receivers and make differential measurement.
- Use ground-based reference stations.
- Ground stations broadcast corrections via radio links.
- User device received both satellite and station signals.



Differential GPS

A: is reference station; B is moving Rover.

$$R_A^1(t_0) = \rho_A^1(t_0) + \Delta\rho_A^1(t_0) + c\delta^1(t_0) - c\delta_A(t_0)$$

$$PRC^1(t_0) = -R_A^1(t_0) + \rho_A^1(t_0)$$
$$= -\Delta\rho_A^1(t_0) - c\delta^1(t_0) + c\delta_A(t_0)$$

Range rate correction due to transmission time between A and B

$$PRC^1(t) = PRC^1(t_0) + RRC^1(t_0)(t - t_0)$$

Pseudo range at B:

$$R_B^1(t) = \rho_B^1(t) + \Delta\rho_B^1(t) + c\delta^1(t) - c\delta_B(t)$$

Differential GPS

Adding the pseudo range at receiver B with PRC correction

$$R_B^1(t)_{corr} = R_B^1(t) + PRC^1(t)$$
$$= \rho_B^1(t) + (\Delta\rho_B^1(t) - \Delta\rho_A^1(t)) - (c\delta_B(t) - c\delta_A(t))$$
$$R_B^1(t)_{corr} = \rho_B^1(t) - c\Delta\delta_{AB}(t)$$

Both orbital error and satellite clock error are eliminated.

Other techniques.

- GNSS Ambiguity Resolution.
- Carrier Phase GNSS.
- Fast Ambiquity Resolution Approach.
- Wide Area Differential GNSS (WADGNSS)

Conclusion

- GNSS are a really promise approach to vast space aerial and large grounded robotics missions.
- Various techniques must be apply to obtain the precise locations.
- High precision come with higher price device, but there are also interesting project like Low-cost Differential GPS for Field Robotics [2] which is really interesting.

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References

1. Vidal AshkenaziDavid ParkMark Dumville, (2000),"Robot positioning and the global navigation satellite system", Industrial Robot: An International Journal, Vol. 27 Iss 6 pp. 419 – 426

2. Ben Nizette, Andrew Tridgell and Changbin Yu, Low-cost Differential GPS for Field Robotics.

3. P.J.G. Teunissen, GNSS Ambiguity Resolution for Attitude Determination: Theory and Method

4. Details of the GPS position calculation https://www.courses.psu.edu/aersp/aersp055_r81/satellites/gps_details.html

5. Understanding the Global Positioning System (GPS) http://www.montana.edu/gps/understd.html

Thank you.

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Your questions and feedbacks are welcome.