Precision Geolocation

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Agenda

• Introduction
• System Overview
• Implications of Positional Error
• Drive Test Results & Error Analysis
• Best Practices
• Conclusions
• Appendix - Hardware Specifications
Introduction

• Started project to address geopositioning errors

• When the program began, our static, horizontal positional uncertainty (drift) was:
  §~2 to 5 m in rural/suburban areas
  §~5 to 40 m in urban canyon areas;

• Goal is to produce an accurate, precise, cost-effective, and easy-to-use system
Positioning Error Implications
Positioning Error Implications

1st Fresnel Zone

Current positional drift error = ~5cm

Previous positional drift error = ~30 m

\[ r_{(\text{in mts})} = 17.32 \times \sqrt{\frac{d_{(\text{in Km})}}{4f_{(\text{in GHz})}}} \]

\[ r_{(\text{in ft})} = 72.05 \times \sqrt{\frac{d_{(\text{in miles})}}{4f_{(\text{in GHz})}}} \]

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Spectrum Analyzer vs. Precision GPS

Spectrum Analyzer w/ GPS receiver option, drift ~100 ft

PG system w/out correction, drift ~125 ft
Drift comparison: RTX vs. RTK

- PG system w/ corrections (SBAS, RTX, and RTK), drift < 1 ft
- PG system w/ corrections (SBAS and RTX), drift ~2.5 ft
- Positional drift track from spectrum analyzer w/ GPS, drift ~100 ft.
System Architecture

- GPS Antennas
  - Position
  - Heading
- GNSS receiver
- RTK Bridge w/ LTE data connection
- Frequency Standard
  - 10 MHz
- Waveform Generator
- Stereo CMOS cameras
  - 1 PPS
- Inertial Measurement Unit
  - 1 PPS
- Linux Desktop
  - Ethernet
  - USB 3.0 SS
  - USB
PG System Mounted on Drive Test Vehicle

- GNSS position antenna
- Inertial Measurement Unit
- GNSS heading antenna
- Drive test receive antenna
- Visual odometry video cameras
- NTS Engineer Mike Chang
Stereoscopic Landmark Detection
Recent Drive Test Results – Boulder Campus
High Drift Area #4-Street View (Pearl & 16th)
Downtown Salt Lake City – # of Satellites

Number of Satellites in View

5  14
SW occlusion at this point led to low SV visibility and cascading position errors.
Best Practices

• Know your equipment
  • use multiple, redundant correction sources, e.g. Real-Time Kinematic, CenterPoint RTX™, Satellite Based Augmentation System (SBAS and SBAS+), etc.
  • static vs. dynamic, accuracy vs. precision
  • quality matters

• Read the manual
  • NOAA/NGS’ User Guidelines for Single Base Real Time GNSS Positioning is a great reference!

• Keep an eye on the satellite conditions during testing
Best Practices

Extraordinary solar flux or geomagnetic conditions = bad times

Conclusions

• We have achieved a 6,000x increase in positional accuracy (30 m to 5 cm) when conducting static measurements

• A properly-configured GPS system has the biggest impact on positional accuracy

• Comparable civilian systems, e.g. Leica Pegasus 2 start at $600k
  • An identical system at the current level of development can be replicated in less than a year for just under $250,000
Thank you!
Appendix

Hardware Specifications
Hardware Specifications

Trimble BX982 GNSS receiver

- Position and vector antennas based on a 220-channel Maxwell 6 chip:
  - GPS: Simultaneous L1 C/A, L2E, L2C, L5
  - SBAS: Simultaneous L1 C/A, L5
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Code differential GPS positioning accuracy:
  - 0.25 m ± 1 ppm Horizontal
  - 0.50 m ± 1 ppm Vertical
- SBAS accuracy:
  - <5 m 3DRMS
- RTK positioning accuracy (<30 km):
  - Horizontal: ±(8 mm ± 1 ppm) RMS
  - Vertical: ±(15 mm ± 1 ppm) RMS
  - Heading: 2 m baseline <0.09°; 10 m baseline <0.05°

*this functionality is included with our current receiver
**this functionality requires additional equipment and/or subscriptions

- Initialization time
  - Typically, less than 10 seconds, 99.99% reliability
Hardware Specifications

Gladiator Technologies LandMark 01 IMU
- 3 degrees of freedom: Gyro rotation (X,Y,Z in °/s), Acceleration (X, Y, Z in g’s), Temperature (°C)
- 4 kHz
- NON-ITAR Low Noise MEMS IMU 1” Cube
- Gyro Range: 490°/s
- In-Run Gyro Bias: 5°/hour 1σ
- Low Gyro Noise: 0.003°/sec/√Hz
- Accelerometer range: 10 g’s
- Low Accel Noise: 0.09mg/√Hz
- Compensated Misalignment: 1mrad and g-Sensitivity: <0.001°/sec/g 1σ
- External Sync Input: (5kHz)
- Low Power: <240 mW typical
- Power: 3.3 V
- Wide Sensor Bandwidth: 250 Hz
- RS422/RS485 Serial Interface
- Data Rate 2.5kHz (user selectable)
- Fully Temperature Compensated Bias and Scale Factor
- Bandwidth Filtering Capability
Hardware Specifications

Gigabyte BRIX ultra-compact gaming PC

- CPU: Intel Core i7, 8 x 2.5 GHz CPU core
- GPU: NVIDIA GeForce GTX 870M
  - CUDA Cores: 1344
  - Graphics Clock (MHz): 941 + Boost
  - Memory Specs:
    - Memory Clock: Up to 2500 MHz
    - Standard Memory Configuration: GDDR5
    - Memory Interface Width: 192-bit
    - Memory BW: 120.0 Gb/sec
- 256 GB SSD, 15.6 GB RAM
- Ubuntu 16.04 LTS (64 bit)
- Ports:
  - 2 x miniHDMI
  - 1 x Mini DP
  - 4 x USB 3.0SS
  - 1 x RJ-45
  - Headphone and mic jack
Hardware Specifications

Ximea XiQ Cameras

- Model: MQ022CG-CM
- Resolution: 2048x1088
- Pixel size: 5.5 μm
- 10 bit ADC
- Dynamic Range: 60 dB
- 2/3” lens
- Maximum Frame Rate: 170 fps @ 8 bits/pixel
- Sensor types: CMOS, Global shutter sensor
- Acquisition Modes: Continuous, software and hardware trigger, defined fps, exposure defined by trigger, pulse(*1) and burst
- Image data formats: 8, 10 or 12 bit RAW pixel data(*2)
- Color image processing: Host based de-Bayering, sharpening, Gamma, color matrix, true color CMS
- Auto adjustments: Auto white balance, auto gain, auto exposure
- Flat field corrections: Host assisted pixel level shading and lens corrections
- Image Data and Control Interface: USB 3.0 standard Micro B with screw lock threads compliant to USB3 Vision standard
- Synchronization Hardware: trigger input, software trigger, exposure strobe output, busy output