Localization for the Next Generation of Autonomous Vehicles
Autonomy is arriving
- Autonomy is arriving
- Autonomous vehicles need centimeter positioning to navigate
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- Autonomous vehicles need centimeter positioning to navigate
- GPS is the only way to acquire absolute location, but it is inaccurate
- An advanced centimeter-accurate GPS is required for autonomy
Only GNSS/Inertial provide absolute positioning, time, velocity and heading.
5 KEY SENSORS

- Lack of Lane Markings
- Inclement Weather
- Lane Ambiguity
- Lack of Features
5 LEVELS OF AUTONOMY

0. No Automation
1. Driver Assistance
2. Partial Automation
3. Conditional Automation
4. High Automation
5. Full Automation
AUTONOMY REQUIRES

- HIGH PRECISION
AUTONOMY REQUIRES

- HIGH PRECISION
- AVAILABILITY
AUTONOMY REQUIRES
- HIGH PRECISION
- AVAILABILITY
- INTEGRITY
AUTONOMY REQUIRES

- HIGH PRECISION
- AVAILABILITY
- INTEGRITY
- LOW COST
How does GPS work?
Solving for position

\[ p_2 \]
Solving for position
Solving for position
Solving for position

\[ p_2 \]

\[ p_3 \]

\[ t? \]
How can we measure the distance to the satellite?
distance ↔ time

\[ d = ct \]
Sources of error
HIGH-PRECISION GPS

IONOSPHERE
TROPOSPHERE
ORBITS
CLOCK
ENVIRONMENT

Standard Precision
~3 METERS

High-Precision
~1 CENTIMETER
Real Time Kinematic

↓

1) Differential
2) Carrier-phase
ionosphere

Diagram showing common and difference aspects.
Measurement Precision
Measurement Precision

"Float" Kalman Filter Covariance
Measurement Precision

"Float" Kalman Filter Covariance

\[
\lambda \rightarrow \mathbf{Z}
\]

\[
\begin{align*}
N_1' & \rightarrow N_2' \\
N_1 & \rightarrow N_2
\end{align*}
\]
Introducing Piksi™ Multi

Fast RTK convergence times measured in seconds, not minutes

Breakthrough price of $595

Improve results with centimeter-accurate positioning

GPS L1/ L2 Hardware-ready for GLONASS, BeiDou, Galileo

Open platform featuring powerful FPGA & dual core processor

Small form factor compatible with common GNSS modules

UART, CAN, USB & Ethernet interfaces

Designed for rapid prototyping & ease of use
Introducing Duro™

Meet Duro

Duro is a ruggedized version of the Piksi Multi RTK GNSS receiver. Built to be tough, Duro is ideal for agricultural, robotics, maritime and outdoor industrial applications. Duro is designed for integration into existing equipment. This easy-to-deploy GNSS sensor is protected against weather, moisture, vibration, dust, water immersion and the unexpected that can occur in outdoor long-term deployments.

- Centimeter-accurate positioning
- Military-grade, rugged enclosure
- Easy to deploy, ready out of the box
- Weatherproof design, sealed connectors
Appendix
Measuring the code phase

\[ \text{shift} = 0 \]
\[ \sum = 8 \]

\[ \text{shift} = 1 \]
\[ \sum = -4 \]
Measuring the code phase

Received
Locally Generated
Result

\[\begin{array}{ccccccc}
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
\end{array}\]

shift = 0
sum = 8

Received
Locally Generated
Result

\[\begin{array}{ccccccc}
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
& & & & & & \\
\end{array}\]

shift = 1
sum = -4
Doppler shift
Acquisition
Acquisition

Doppler shift

code phase
Acquisition

correlation peak
Tracking
Tracking

Received

Early

Prompt

Late

E-L = 0

E-L > 0

E-L < 0

Code phase

n-1  n-1/2  n  n+1/2  n+1

Code phase

n-1/2  n  n+1/2

Code phase

n-1/2  n  n+1/2
Signal structure

- Code @ 1.023 MHz
- Nav Data @ 50 Hz
- Code ⊗ Nav
- Carrier @ 1.57542 GHz
- Carrier × (Code ⊗ Nav)
Analog Frontend

\[
\cos \theta \cos \phi = \frac{\cos(\theta - \phi) + \cos(\theta + \phi)}{2}
\]
Gold codes

length = $2^n - 1$

Auto correlation

Cross-correlation
Receiving from multiple satellites

\[ \text{sat A code } \ast \text{ sat A code} \]

\[ \text{sat A code } \ast \text{ sat B code} \]