Software Defined-Radio for Satellite and Inertial-Aided Navigation

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Consultants' Network of Silicon Valley

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- ❖Founder, President and CEO of Crossbow Technology, a leader in MEMS-based inertial navigation systems and wireless sensor networks
- ❖15 patents in inertial navigation technology
- ❖BSEE and MSEE from UC Berkeley

Outline

High-Accuracy vs Consumer GNSS/INS Positioning

- Performance
- Cost
- Ecosystem

“New” vs Traditional High-Accuracy Requirements

- Performance
- Algorithms
- Development Environment

Solutions to New High-Accuracy Requirements

- SDR-Based GNSS for a Multi-Constellation & LEO Future
- Array-based IMU
- Open-Source Tools & Technologies
- Cloud Assisted Algorithms & Corrections

Performance

REQUIREMENT	HIGH-END GNSS INS	CONSUMER MOBILE
Position Accuracy	2cm	2-3m
GNSS Loss	<30cm for 10-30 sec via Inertial Measurement Unit	WiFi / Cell Tower Back up to ~100m
GNSS Aiding	RTK or PPP Service	A-GPS Service
Heading	0.05°	5-10°
Heading Method	IMU Gyro-Compass or Dual Antennae GNSS	Magnetometer & Map-Matching
Roll/Pitch	0.02°	1°

Performance Delta ~10^2

Cost

REQUIREMENT	HIGH-ACCURACY GNSS INS	CONSUMER MOBILE
GNSS Receiver Cost	> $500	< $1
IMU (Inertial Measurement Unit)	> $1000	< $1
Antennae	> $200	< $1
CPU & Electronics	$40	Provided by Phone / FREE
IP67 Housing	$200	Provided by Phone / FREE
GNSS Aiding Service	$200 - $500/month	A-GPS Service / FREE

Cost Delta ~10^3

ACEINNA POWERFUL SENSING SOLUTIONS

Consumer Positioning

- **Start-up Friendly**
- **Navigation Easy to Integrate for Developers**
  - Clear Core Mobile SDK
    - Technology "just works" including A-GPS, Wifi/Tower Fall-back
  - Clear Plugins (mapbox etc)
  - Minimal Algorithm Development Required
- **> 10 Apps/GNSS Receiver**
  - Maps, Social, Ride-Share, Recommendation Apps
  - Large $B+ Businesses built on top of GNSS Features in Mobile e.g., Uber

High-Accuracy

- **Unfriendly to Start-up Companies**
- **Navigation Hard to Integrate for Developers**
  - PhD level Algorithm Development
  - Custom Drivers
  - Limited 3rd Party Tools
- **1 App/GNSS Receiver**
  - Aerospace, Construction, Farming
  - Market Dominated by Vertically Integrated Solutions – Trimble Makes Receiver and End-User Application

New High-Accuracy Requirements are Growin

Traditional Apps

- Aerospace
- Construction
- Farming
- Marine

New: AI / IoT

- Self-Driving
- Drones
- Robotics
- Augmented Reality

Major Growth in High-Accuracy Applications due to AI/IoT

AI / IoT App

- **Difficult Urban Canyon & Indoor Environments**
- **Multiple Applications per System**
- **Friendly to Start-up Companies**
- **Majority of Developers from non-GNSS background**
- **GNSS + IMU Integration with CV Oriented Sensors**
  - LIDAR, Camera, Radar
- **Aggressive Cost Targets << $100**
- **Additional Safety Certifications Required (ISO26262)**

Key Solutions

Inertial

- Array Based Approach

GNSS Solution - SDR

- Merge into large GPU

Open-Source Tools & Technologies

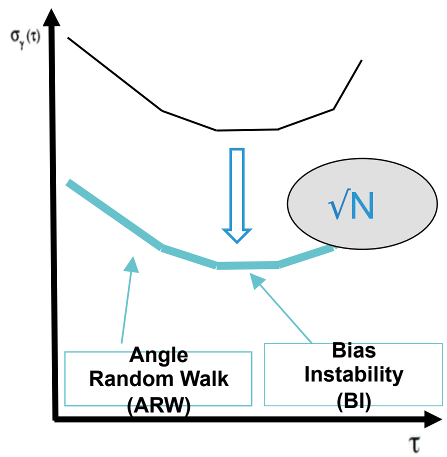
- Simulator
- Open Source Rover SDK

Cloud Assisted Algorithms & Corrections

- LEO Assisted PPP
- Dense Urban RTK Deployment
- 5G

Redundant Inertial Sensor

Performance



ARW and BI improved by 1/√N

Reliability

1 x IMU

Failure Rate： 10^{-6}

N=2

Failure Rate： 10^{-12}

Failure rate reduced exponentially with N

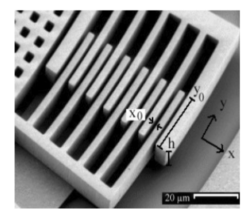
Safety

ISO 26262

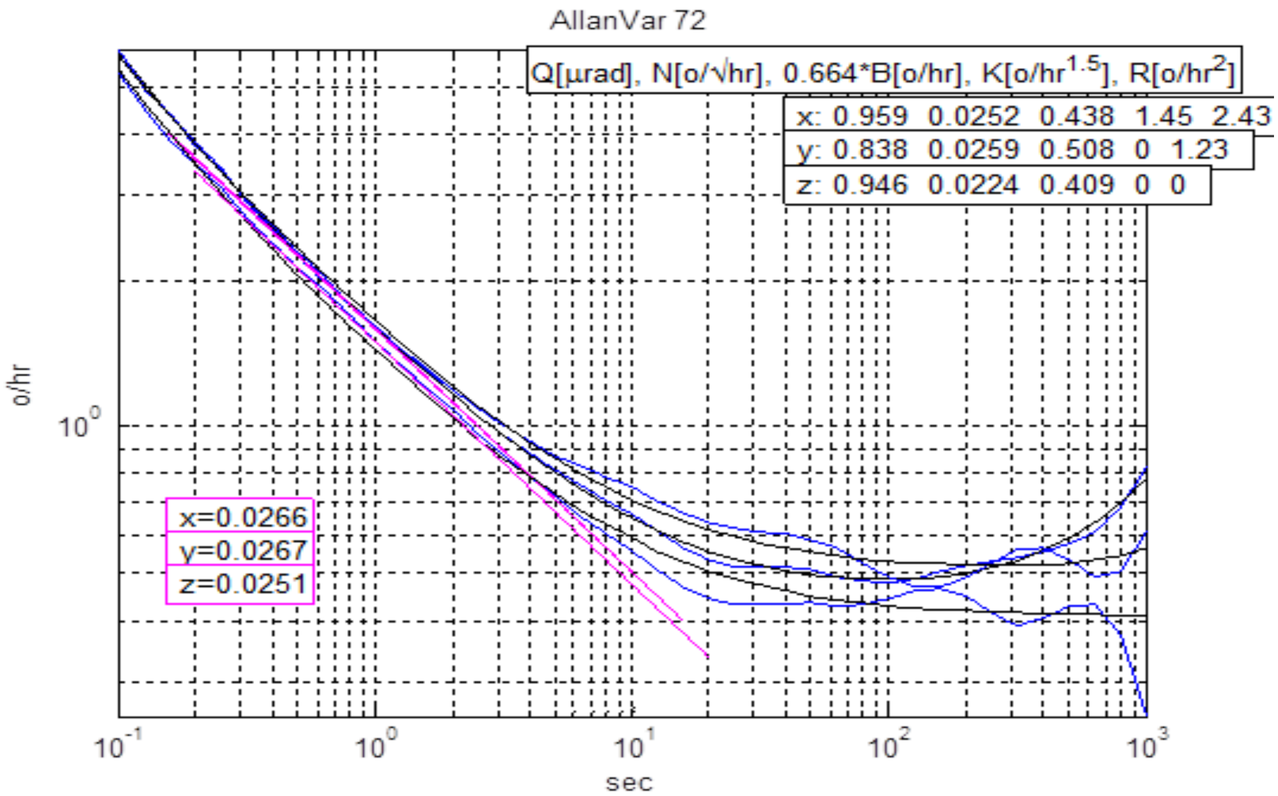
Road Vehicles - Fuctional Safety

Fault Tolerant - Proprietary Voting Scheme selects valid sensor data

ASIL B



0.02°/√Hr and < 0.5°/Hr => FOG Grade Performance



Examples: OpenIMU330,

Package Type	PN/Certification	Description	Applications
BGA 	OpenIMU330BA ASIL-B	BGA-44, SPI/UART, Triple-Redundant 9-axis IMU, 2°/Hr	L3 Cars & Drones
EZ 	OpenIMU400ZA ASIL-B / ASIL-D	SPI/UART, Multiple-Redundant 9-axis IMU, < 1°/Hr	L4 Cars & FOG Applications

GNSS – Integrated Dual-Frequency

L1/L5
E1/E5a

L1/L5
E1/E5a

L1/L5
Or L1/L2

Low-Cost High-Volume Mass-Market IC's are Here

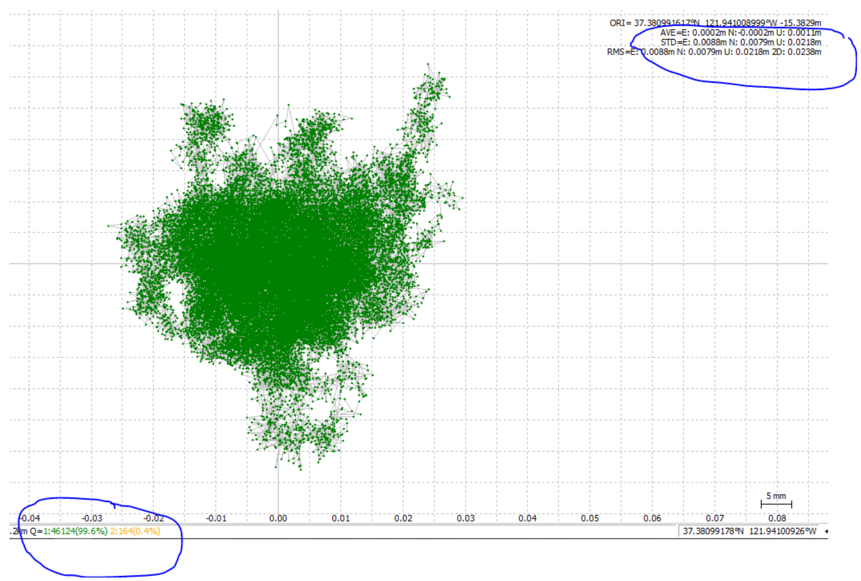
Example:

- **ST Teseo V-based**
  - L1/L2, L1/L5
  - BeiDou，GALILEO, GPS, GLONASS, QZSS
- **Integrated Triple-Redundant IMU (OpenIMU330)**
  - <2°/Hr
- **Open source CPU**
  - Free Tool and Simulation System
- **Ethernet, CAN, SPI, UART**

OpenRTK330 Data with

- **Static data test quality from Aceinna OpenRTK330**
  - 17 hours' static data
  - 21 km baseline

- **In-house RTK engine**
  - 99.6% fix rate
  - 1cm in horizontal
  - 2cm in vertical



OpenRTK330 Dynamic Test

ACEINNA OpenRTK330 vs Mainstream Solution

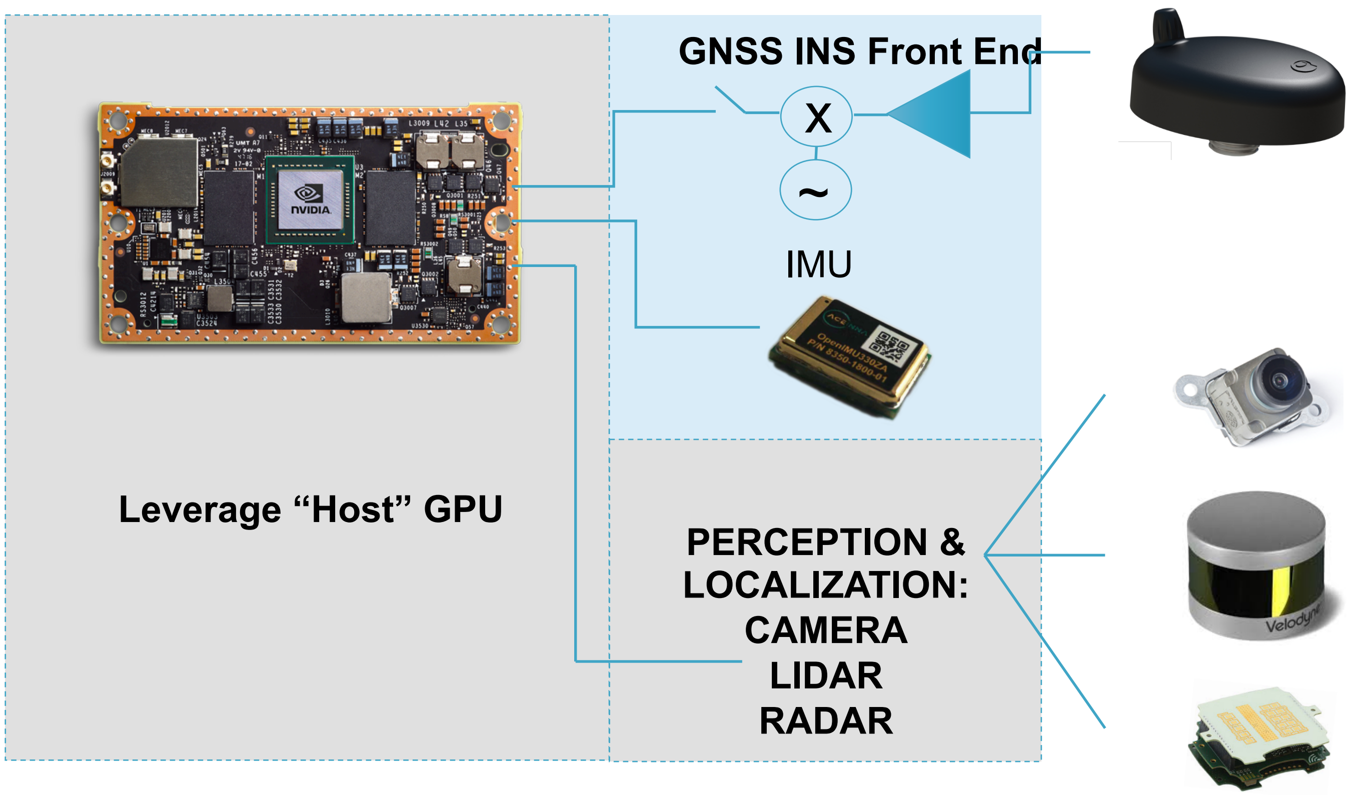
- Car Mounted
- Parking Lot with Trees
- Same Antennae
- RTK Service
- Aceinna's Silicon Valley RTK Trial Network

ACEINNA RTK Engine

- 98.3% Fix Rate

Difference (cm)	68%	95%	99%
Horizontal	2.5	5.2	6.0
Vertical	2.1	4.5	5.1

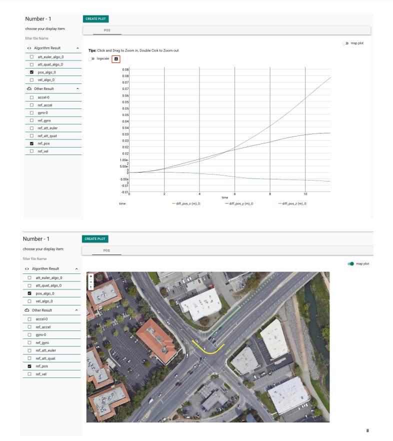

GNSS SDR



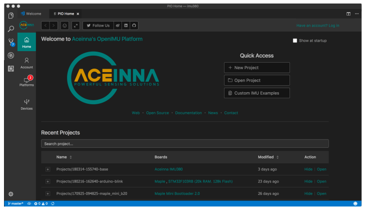
GNSS INS Front End
X
~
IMU
Leverage "Host" GPU
PERCEPTION &
LOCALIZATION:
CAMERA
LIDAR
RADAR

Open Source Tools => Speedy

1. Simulate



2. Embed



3. Test

Open Source Tools, Friendly to Start-up Companies

GOLDEN MOUSETRAP AWARDS
2019 GOLD WINNER

https://developers.aceinna.com

https://github.com/Aceinna

RTK/PPP

Traditional Correction Networks

- Expensive
- Proprietary
- Not-well Suited to Urban
- No Processing in Cloud

Solutions

- PPP data should be FREE
- New LEO Ionospheric data improve PPP
- Cloud Processing + Rover RTCM => Scale RTK
  with minimal fixed infrastructure

Cost Revisited, Cost Delta ~10^2

REQUIREMENT	HIGH-ACCURACY GNSS INS
GNSS Receiver Cost	< $10
IMU (Inertial Measurement Unit)	< $10
Antennae	< $10
CPU & Electronics	Provided by Host
IP67 Housing	Provided by Host
GNSS Aiding Service	TBD but Much Cheaper

Low Cost High Accuracy Solution

CHALLENGE	SOLUTION
RECEIVER COST, ACCURACY	GPU Based SDR GNSS, Low-Cost Dual Frequency Consumer Receivers
IMU COST, ACCURACY	MEMS IMU Array, e.g., OpenIMU330
TIME TO MARKET, EASY TO DEVELOP	Open Source Tools and SDK
COST/QUALITY OF CORRECTION DATA	PPP + LEO Combined with Moving Base RTK

THANK YOU