Precise Positioning Enabled by ST GNSS Receiver and ST IMU

Stuart Ferguson

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Technology Tour 2019

Dallas-Richardson, TX | March 7

Agenda

Time	Presentation	Speaker
1.00 pm	**Precise Positioning Enabled by ST GNSS Receiver and ST IMU**	Stuart Ferguson
1.40 pm	Conclusion	

Topics

- Analog MEMS and Sensors Portfolio
- Introducing: New, High Accuracy IMU ASM330LHH
- Teseo GNSS Evolution: ST Positioning Roadmap
- DRAW – Dead Reckoning Automotive Way
  - Based on Teseo III
  - SW implementing GNSS & sensors fusion
  - ASM330LHH IMU
- Building on the ASM330LHH to create High Performance Modules

Analog MEMS and Sensors Portfolio

Sensors	Motion MEMS	Environmental Sensors	Acoustic	ToF Proximity & Ranging	3D Sensing	Sensing
Analog	Operational Amplifiers & Comparators	Voltage References	Rad Hard Analog	Standard Interfaces	Touch Analog Front End	Conditioning
Analog	Power Line Communication	Power over Ethernet	IO-Link	Bluetooth	Sub-1 GHz	Connectivity
Analog	Motor Drivers & Gate Drivers	Industrial ASICs	Galvanic Isolated ICs	Intelligent Power switches	Micro-actuators	Actuation
Analog	AC-DC & DC-DC Regulators	Wireless & Wired Chargers	LED Drivers	Power Management for Portable	AMOLED Display Power	Power & Energy Management
Analog	Digital Power	Linear Regulators & LDOs	Battery Management	PMIC for Data Storage	Custom Analog	Power & Energy Management

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Sensors and Actuators

ST is the only company to offer the full range of Sensors & Micro-actuators

Motion

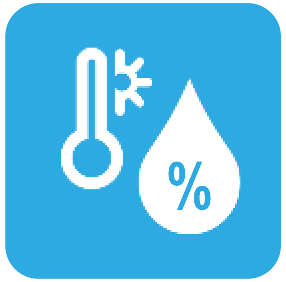
Gyroscope

Accelerometer

Magnetometer

6 & 9-axis inertial module

Optical image stabilization



Environment

Temperature

Humidity

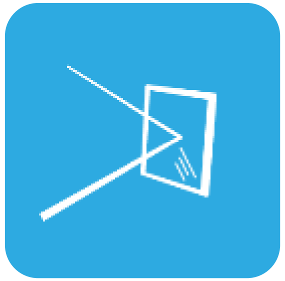
Pressure

VOC (Volatile Organic Compound)

Interactivity

MEMS microphone

Touchscreen controllers



Micro-Actuators

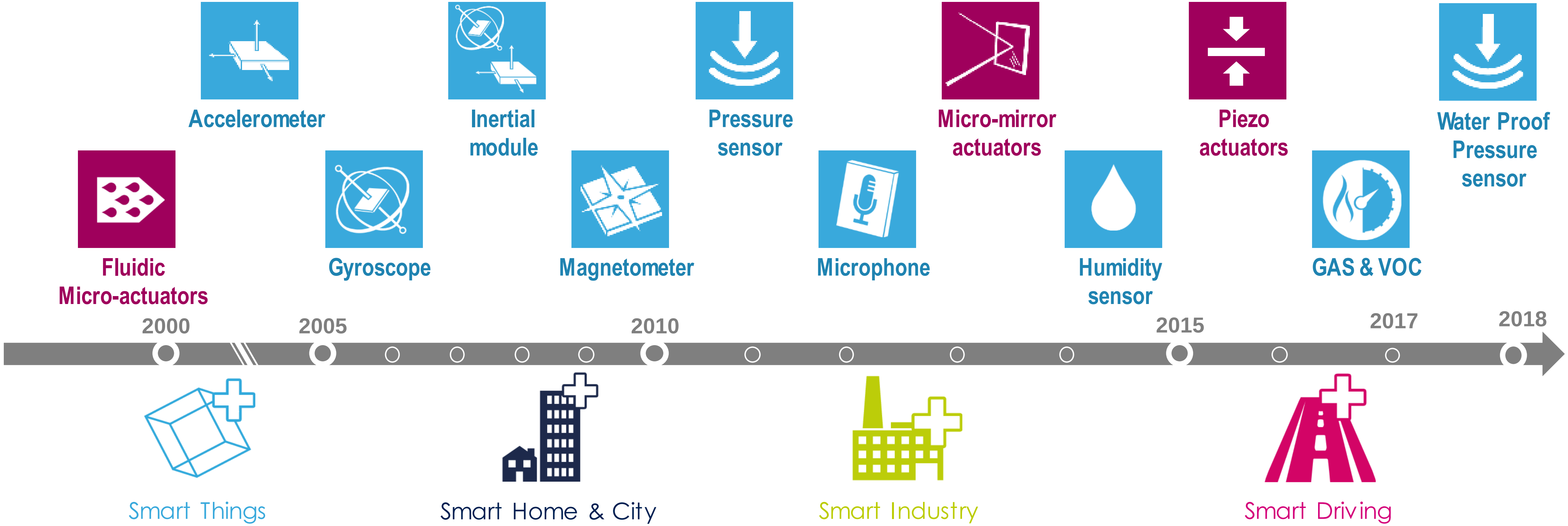
Micro-mirrors

Thin-film Piezo-electric MEMS

Optical

FlightSense™ Time-of-Flight Ranging sensors

20 Years of MEMS at ST



Smart Driving

Making driving safer, greener and more connected

Sensors & Actuators

Inertial measurement units for **safety** applications

Microphones and accelerometers for **Active Noise Cancellation**

Motion MEMS for **dead reckoning**

Micro-mirrors projection for **LiDAR** and **adaptive headlights**

Sensors for Smart Driving

NON-SAFETY Applications

- Navigational assistance
- Anti-theft systems
- Telematics (eCall, …)
- Infotainment

AIS328DQ accelerometer
A3G4250D gyroscope
AIS3624DQ accelerometer

ASM330LHH 6-axis combo
Audio BW Accelerometer*

New

PASSIVE SAFETY Applications

- Airbag peripheral sensors
- Airbag on-board sensors

AIS1200PS accelerometer
AIS1120SX accelerometer
AIS2120SX accelerometer

ACTIVE SAFETY Applications

- Vehicle dynamics
- Electronic stability
- Active suspensions
- Hill-start assist
- Roll stability control

Under Development
(ASIL - ISO26262)

ST Combo family (from 3DOF to 5DOF* sensors)

New

AUTONOMOUS DRIVING

- ADAS
- Assisted / autonomous driving (bring the car to safety in case of emergency)

Under development
(ASIL - ISO26262)

Highly Automated Driving* (HAD)

*Under development

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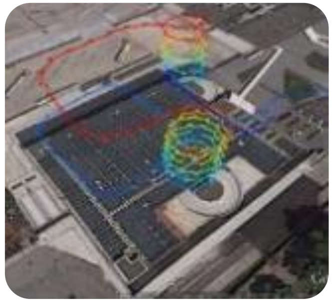
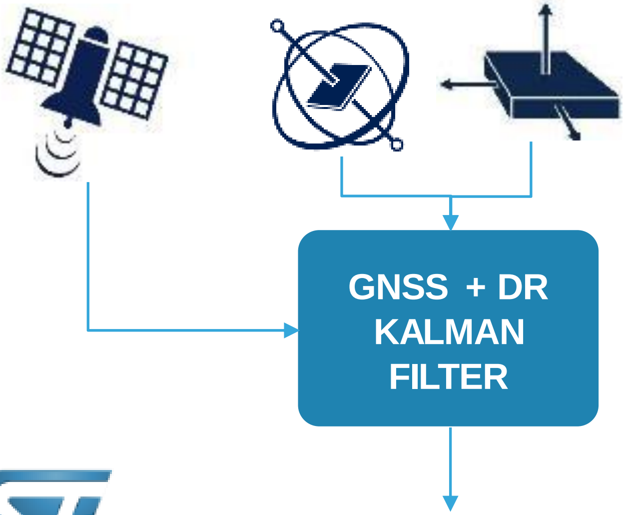
Smart Driving

Focus Applications

Navigation



6DOF IMU as GNSS assistant for Inertial Navigation System



Precise Positioning

TBOX

On Board Diagnostic

Driving Style

Insurance Boxes

Shock detection

Anti-theft

Inclination

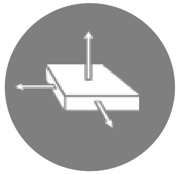
eCall

Voice

PKE

Low power Accelerometer for Passive Key entry

Accelerometer



User Interaction
Detect walking type

Battery saving
Detect no move

SECURITY
Detect no move

ASM330LHH High Accuracy IMU

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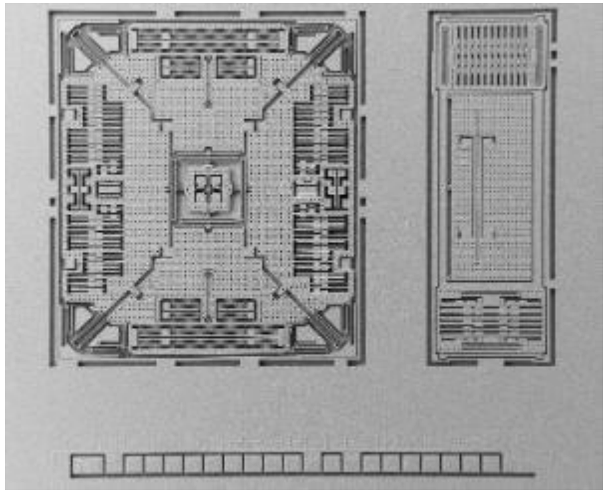
Motion MEMS - Three key elements

Micron-sized **Transducer** using specific Micro-Machining process



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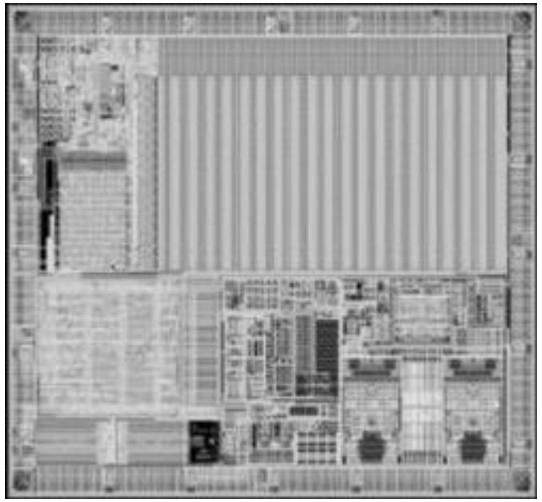
Dedicated **ASIC** with embedded smart functionality



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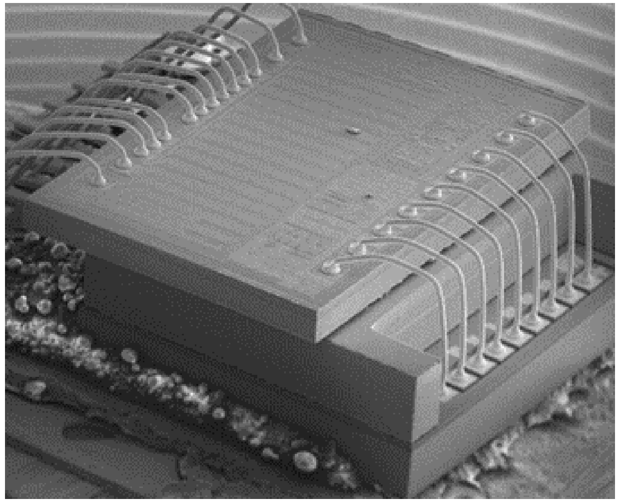
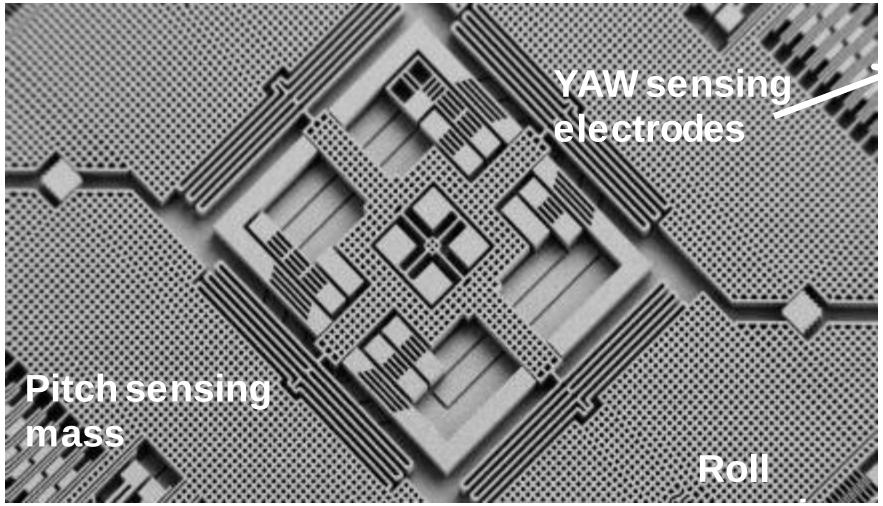
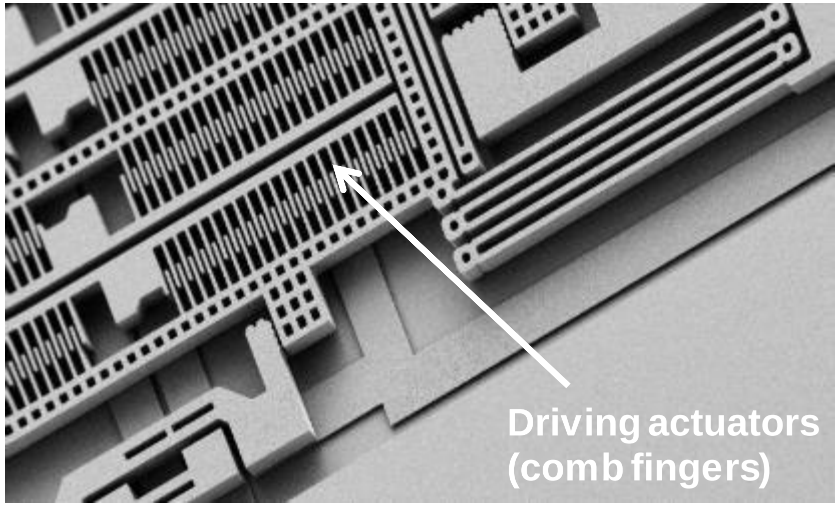
Dedicated **Package** and **Calibration** features

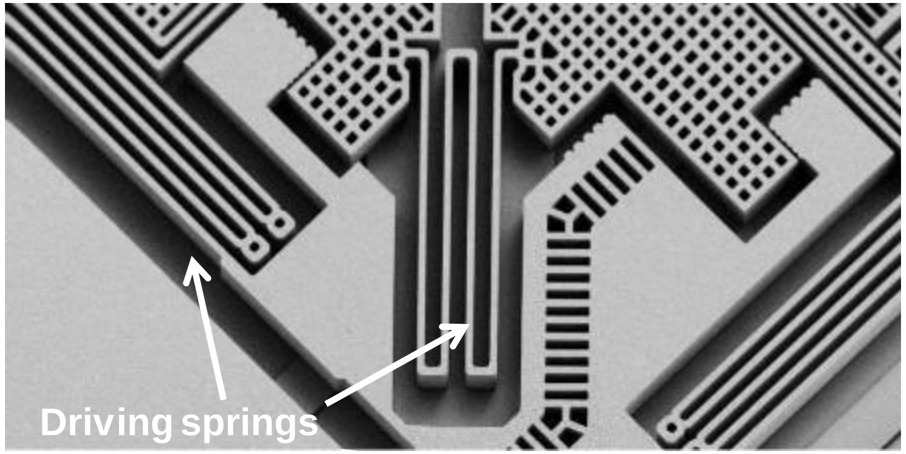


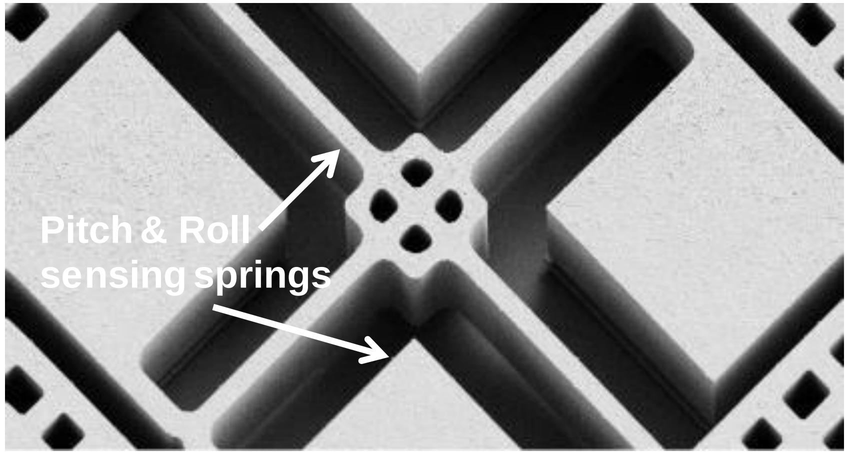
Gyroscope

Reference Images









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ASM330LHH for Accurate Navigation

Smart Driving

Temperature Features

Extended Temp. Range: up to **+105°C**

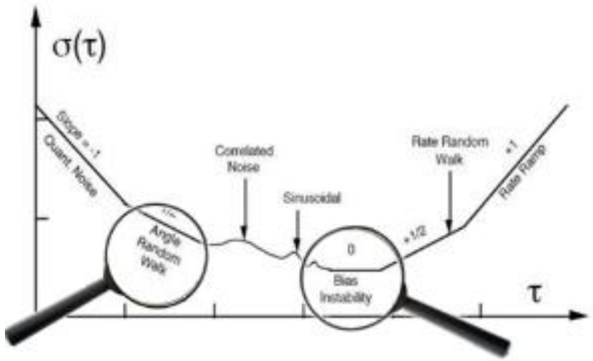
High Resolution: **256 LSB/°C**

Stability Features

Typ. Angular Random Walk (ARW): **0.21 deg/√h**

Typ. Bias Instability (BI): **3°/hr (High accuracy)**

Stability: **Over time & Temperature**



Extended Temperature Range

Improved Stability

Best in Class Accuracy

Smart Driving

ASM330LHH

6-axes IMU
Automotive grade

2.5x3x0.86 mm

ES Available
MP Q1'19

Accurate Navigation

Accuracy 1st

#axes	6 (3 XL + 3 GYR)
Accelerometer range	2/4/8/16 g
Gyroscope range	125 dps to 4000 dps
Supply Voltage	Up to 3.6V
Typ current	1.3 mA (6 axis)
Output i/f	SPI/I2C
FIFO	3kb
Accelerometer noise density	60 ug/√Hz
Gyroscope noise density	5 mdps/√Hz

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New: Advantages of ASM330LHH

- **Qualification:**
  - AEC-Q100 Grade 2
    - Operation from -40ºC to +105ºC

AEC-Q100 compliant

PPAP available

- **FE Golden Flow:**
  - Dedicated defectiveness control plan & specific parametric test associated to reliability performance
  - EWS Test based on Automotive standards including temp test
  - Final Test to guarantee automotive DPPM level:
    - Temperature verification **at extremes of operation**
    - Extended Quality Control
    - Reliability monitoring on assembly lot basis

Proper Process Control

AEC-Q001
AEC-Q002

- **Continuity and stability of supply**

AEC - Q100 - REV-H
September 11, 2014

Automotive Electronics Council
Component Technical Committee

In addition, not shown in the flow charts, the expected end of life failure rate may be an important
criterion. Regarding failure rates, the following points should be considered:
□ No fails in 231 devices (77 devices from 3 lots) are applied as pass criteria for the major
environmental stress tests. This represents an LTPD (Lot Tolerance Percent Defective) = 1, meaning a maximum of 1% failures at 90% confidence level.
□ This sample size is sufficient to identify intrinsic design, construction, and/or material
issues affecting performance.
□ This sample size is NOT sufficient or intended for process control or PPM evaluation.
Manufacturing variation failures (low ppm issues) are achieved through proper process
controls and/or screens such as described in AEC-Q001 and AEC-Q002.
□ Three lots are used as a minimal assurance of some process variation between lots. A monitoring process has to be installed to keep process variations under control.
□ Sample sizes are limited by part and test facility costs, qualification test duration and limitations in batch size per test.

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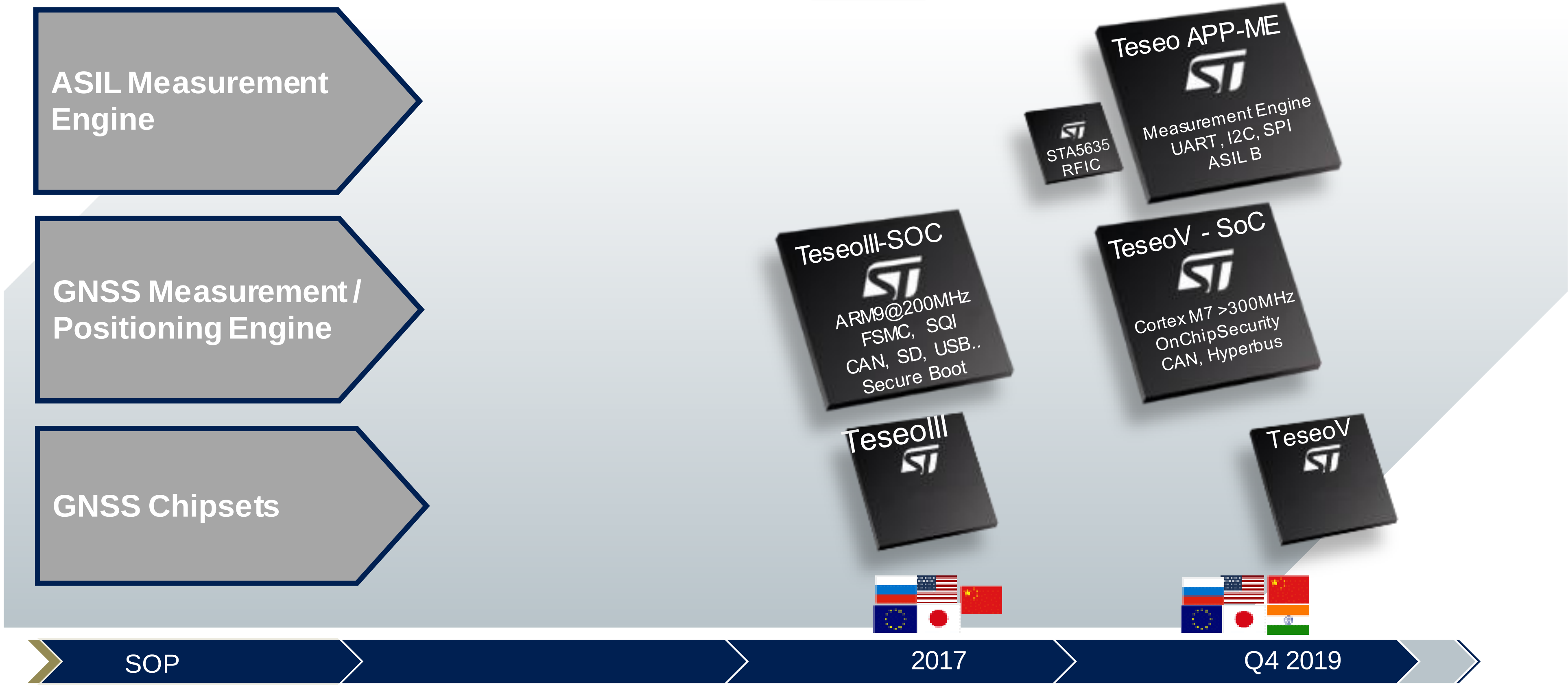
Teseo GNSS Solution & Roadmap

Contact: Mike Slade
michael.slade@st.com

ST Positioning Roadmap

L1 Only

High Precision Multi band L1-L2 or L1-L5



Software		
TESEO GNSS	BeiDou	IRNSS L2 L5
TESEO-DR	3D DRAW	2D TeseoUP TC-IMU
TESEO-PPP	L1 Carrier Phase	RTK RTPPP

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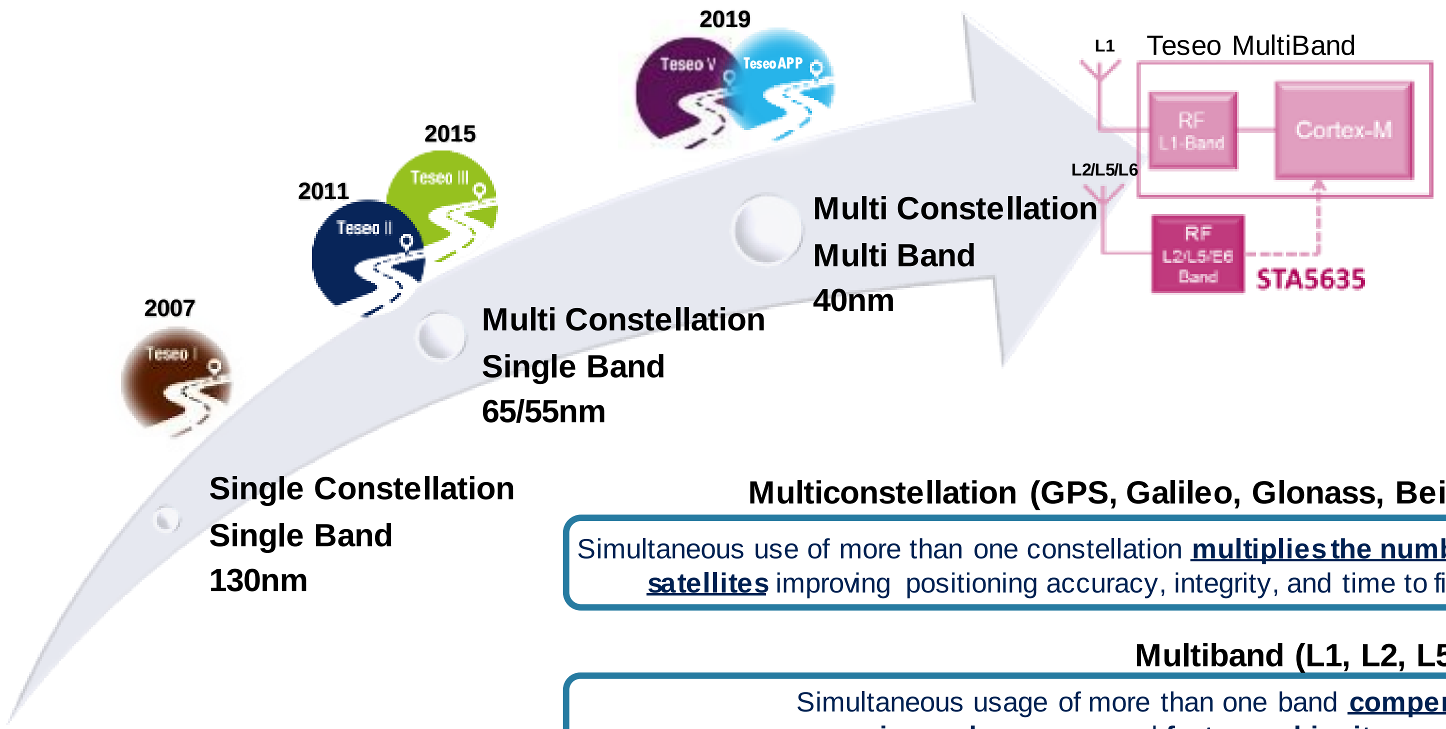
Teseo Evolution

Towards reliable precise positioning



Multiconstellation (GPS, Galileo, Glonass, Beidou,)

Simultaneous use of more than one constellation **multiplies the number of satellites** improving positioning accuracy, integrity, and time to first fix

Multiband (L1, L2, L5, E6)

Simultaneous usage of more than one band **compensates ionosphere error** and **faster ambiguity resolution**

- **TeseoI II III Mass Production:**
  - **100% first cut functional silicon**
  - **TeseoV designed with same LPRFCMOS technology and libraries**

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Teseo DRAW™

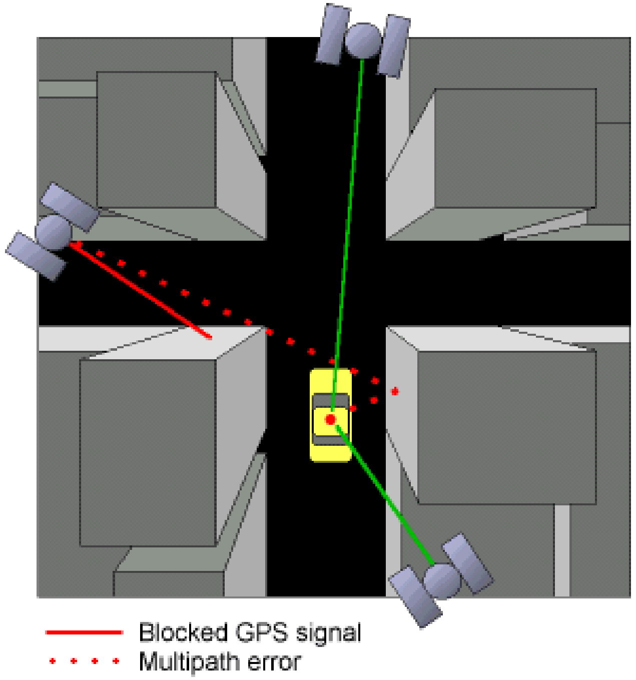
Automotive & Discrete Group

GNSS & Navigation System & Application

DRAW – Dead Reckoning Automotive Way

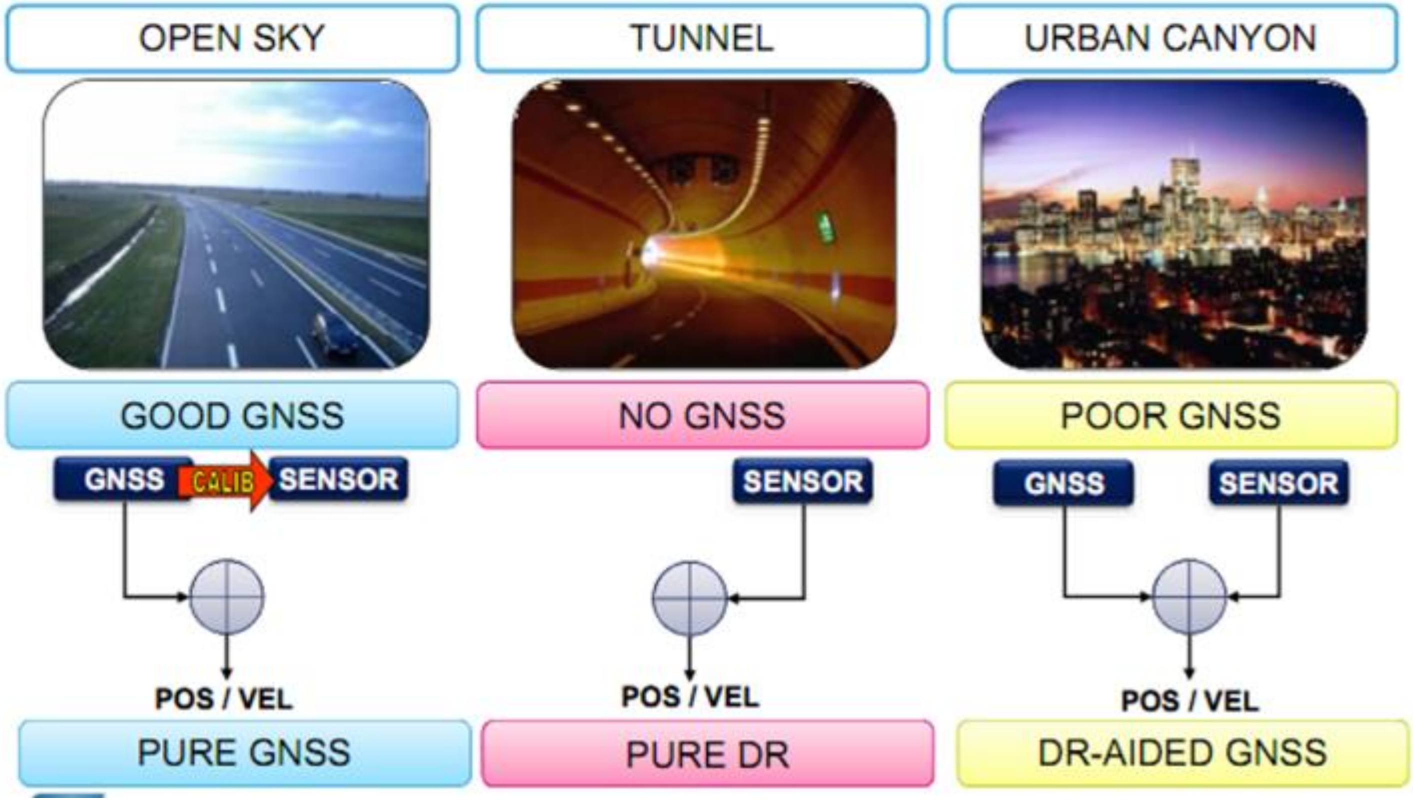
- SW implementing GNSS & sensors fusion

- Provides the user with accurate position, heading, height and speed measurements providing a fusion of GNSS and sensors when GNSS
  - Is not available (e.g. tunnels, indoor, obscured areas)
  - Is available but not accurate (reflective environments, partially obscured areas).



Navigation systems

Car navigation is based on advanced GNSS chipset



Inertial sensors enable dead-reckoning (DR) algorithms

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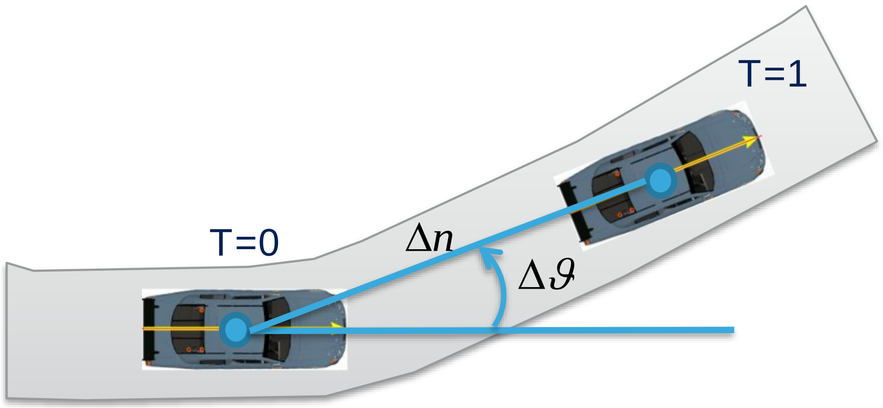
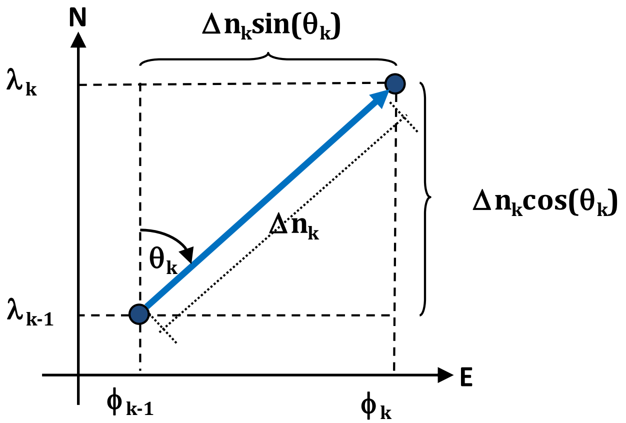
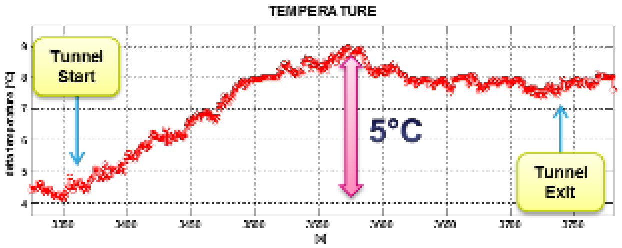


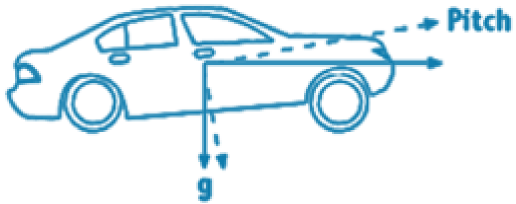


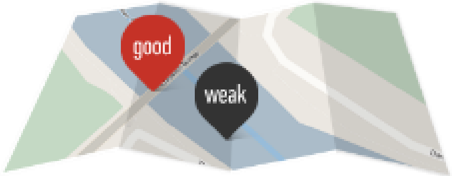
- Dead Reckoning calculates user position and velocity integrating the contribution of two sensors' families:
- Distance Sensors
  - Classic odometer, ABS wheel ticks, wheel speeds, CAN Speed PID
- Yaw Rate Sensors
  - MEMS Gyroscope, Differential Wheel Pulses, Differential Wheel Speeds

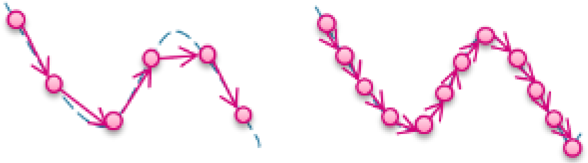
Value-Added Features

- Automatic Temperature Compensation (ATC)
  - Autonomously compensates IMU in presence of thermal changes, guaranteeing long-term accuracy
- Automatic Free Mount (AFM)
  - Autonomously compensates PCB tilt angle, guaranteeing performance independently by the way it is mounted in vehicle
- Map Matching Feedback (MMFB)
  - Map data from customer application can be fed back to DR for improved navigation accuracy
- 3D DR (3DR)
  - Provides accurate position variation in vertical direction even in absence of GNSS signal
- **Low Latency Interface (LLI)**
  - Real time PVT output up to 20 Hz, with minimum latency and jitter
- Sensor Over Uart (SoU)
  - Sensor data can be fed via UART through proprietary ASCII protocol



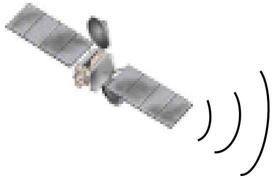






GNSS Positioning

Dead Reckoning and Sensor Fusion



GNSS HW → *GNSS data* → **GNSS + DR KALMAN FILTER** → *Fix Data* →

Latitude
Longitude
Height
Speed
Heading

sensor data ↑

DR CONFIG

CLASSIC FREE-MOUNT	**CLASSIC**	**CAN BASED**
- 3AXES GYRO + ODO + ACCELEROMETER	- 1AXIS GYRO + ODO	- STABILITY GYRO + ODO - DWP FRONT OR REAR

sensor data ↑

DR SENSORS

CAN BUS (ABS, SPEED, ESP GYRO*)	**ACCEL***	**GYRO***	**ANALOG ODOMETER**	**PRESSURE* SENSOR**

*Part of ST Micro's current offering

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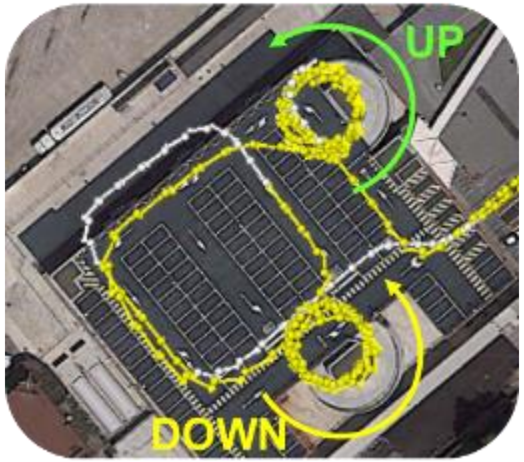
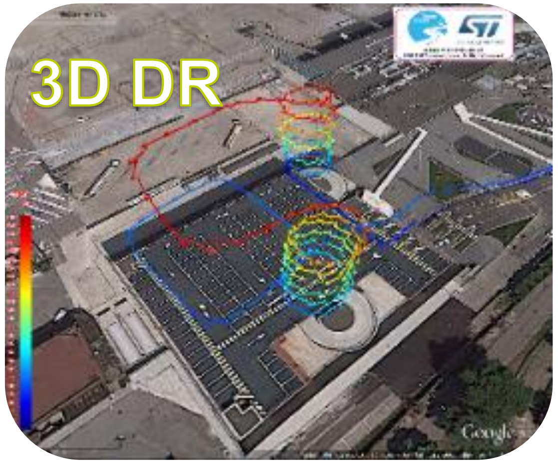
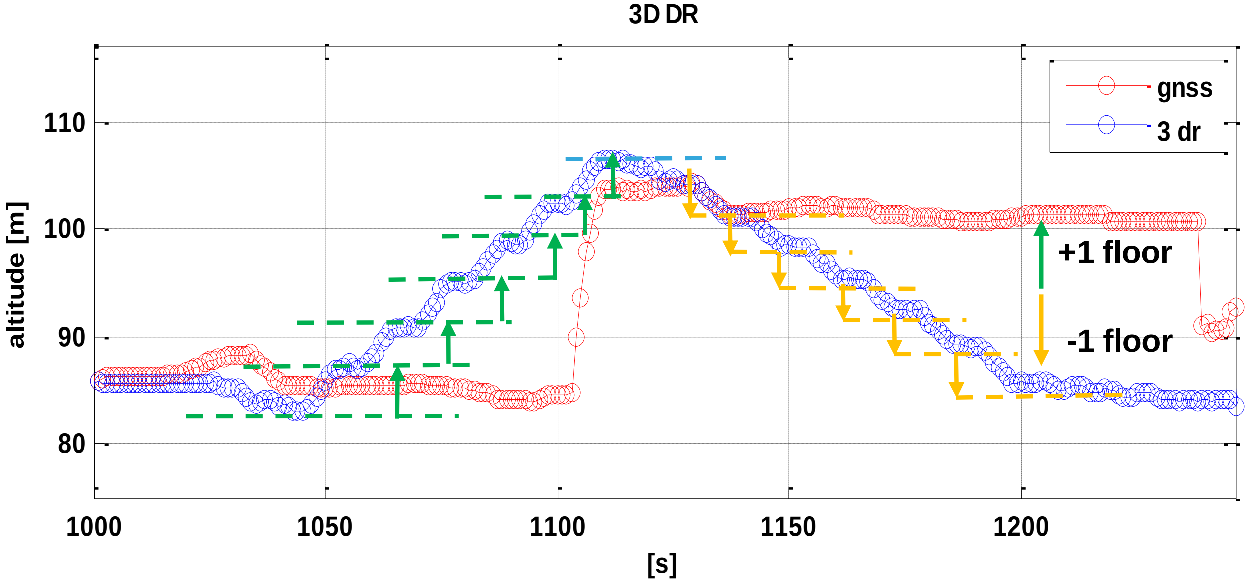
3D DR Multilevel Parking



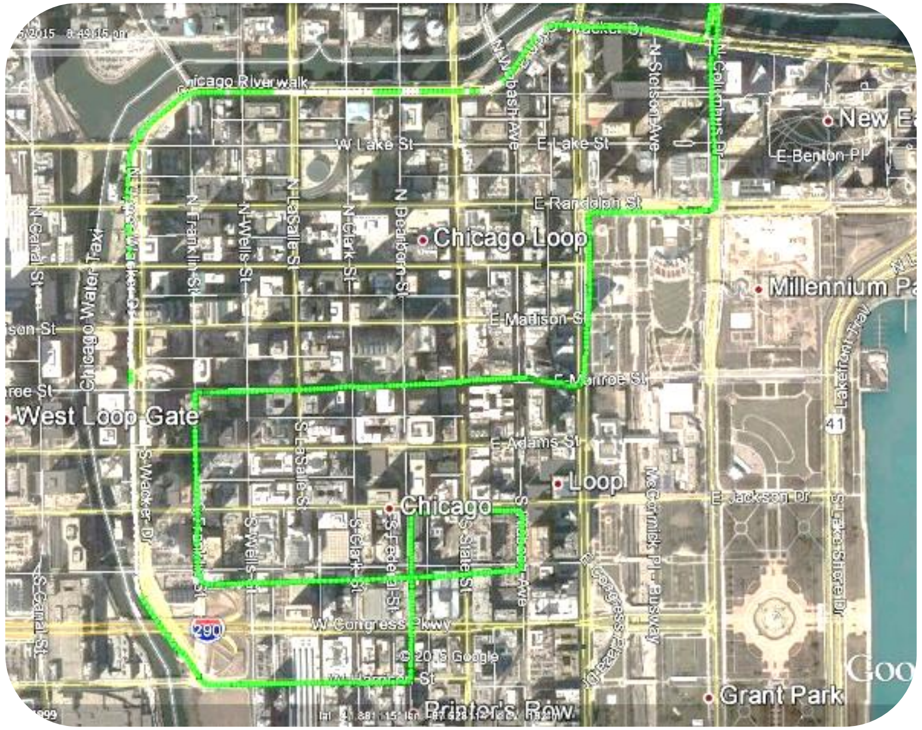




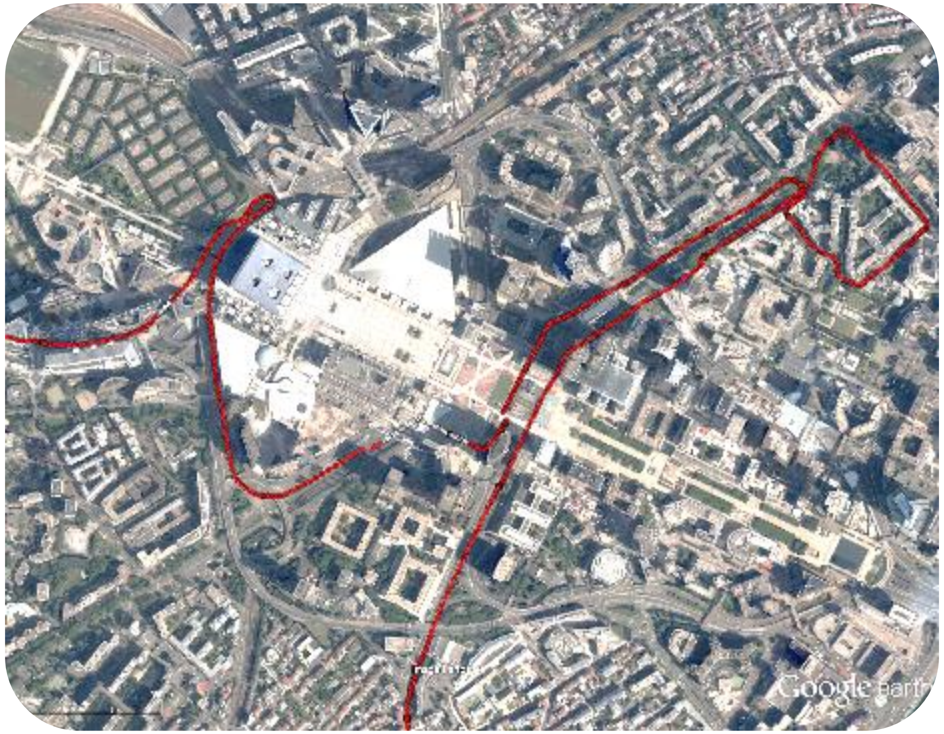
(using ST 3D MEMs Gyro & Accelerometer)

Urban Canyon Scenarios

Chicago – Lower Wacker



Paris – La Defense



Use Case: ASM330LHH
Gyro Effect On Land Vehicle Positioning Accuracy

ASM330LHH vs Competitor

Test Data Provided Courtesy of:

ADG – Infotainment BU System And Application

Nicola Palella – Leonardo Colombo

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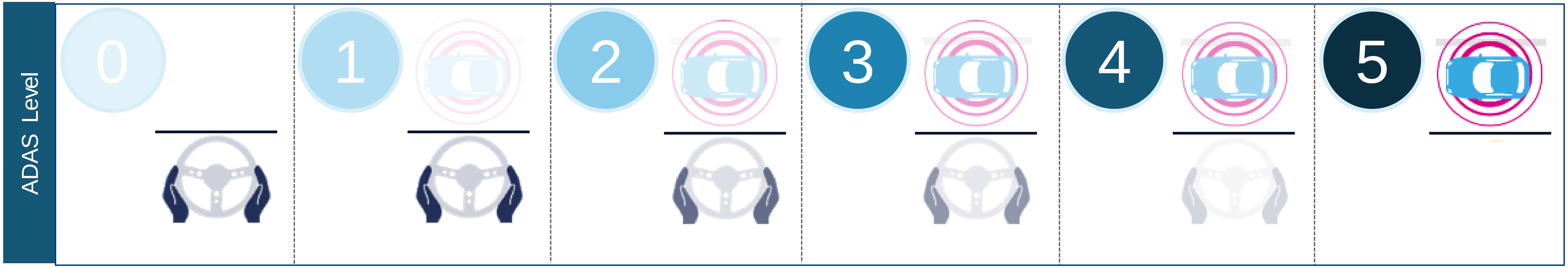
Vehicle Positioning accuracy



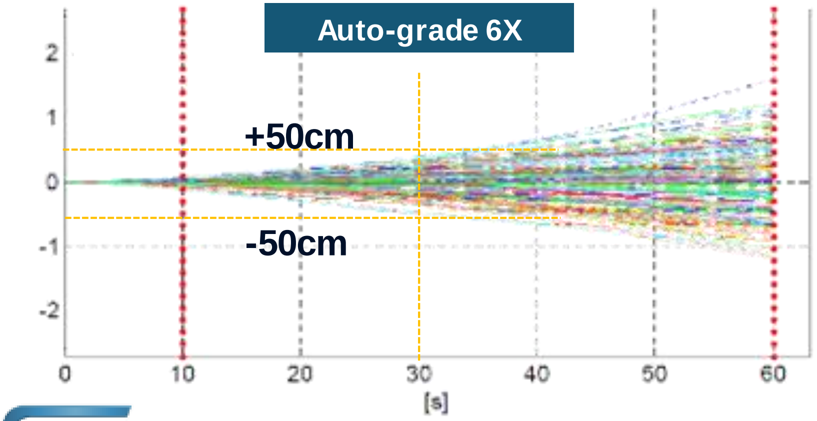
Spec

AVAR (BI, ARW)

50cm/30sec

10cm/30sec

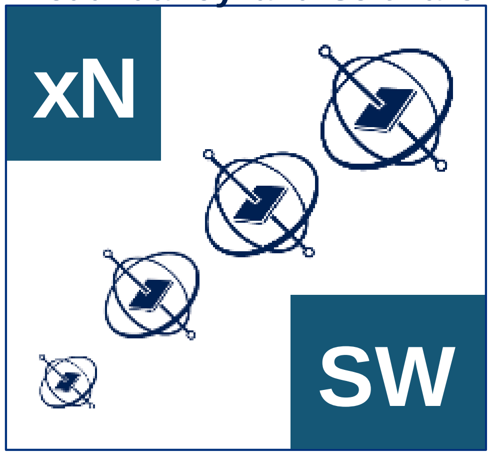
ASIL level



Paths

L0→L3

IMU modules Redundancy and software



Advanced specification and functional safety

ADAS: Advanced Driver Assistance System
ASIL: Automotive Safety Integrity Level

Understanding IMU Sensor Errors

(Gyroscope)

- Gyroscope measures angular rate $\omega(t)$
  - Gyro error $\Delta\omega$ causes an angle error $\Delta\theta = \int \Delta\omega(t) \bullet dt$

- There are several types of gyro error:
  - Zero-g bias can be minimized through calibration and compensation
    - Limit is bias instability (BI_g)
    - $\Delta\theta = BI_g \bullet T$
  - Noise: zero mean but integral will "walk" (1σ = ARW)
    - $\Delta\theta = ARW \bullet T^{0.5}$ (1σ)
  - Non-linearity and scale factor error in transfer function $\Delta\omega_{NL}$
    - $\Delta\theta = \int \Delta\omega_{NL}(t) \bullet dt \cong \Delta\omega_{NL} \bullet T$ (worst case)

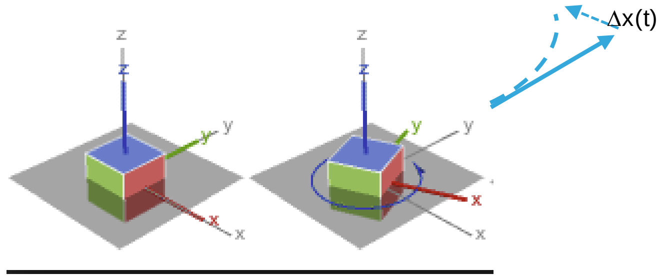
- Angle (heading / attitude) errors grow with $T^{(0.5\sim1)}$

- How do angle errors translate to position errors?

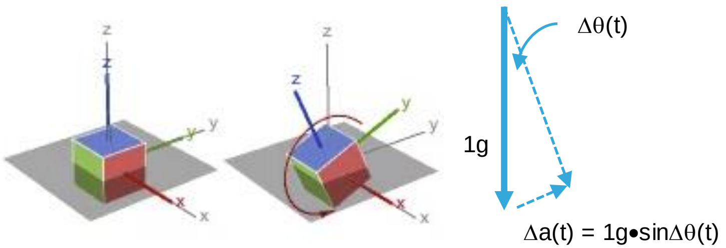
Understanding IMU Sensor Errors

(How angle errors translate to position errors)

- Yaw gyro error $\Delta\omega$ causes heading error $\Delta\theta(t)$ which grows with time
  - $\Delta\theta(t) = \int \Delta\omega(t) \bullet dt$ (grows ~ $T^{(0.5\sim1)}$)
  - $\Delta x(t) = \int \sin\Delta\theta(t) \bullet v(t) \bullet dt$
    $\cong \int \Delta\theta(t) \bullet V \bullet dt$ [for small $\Delta\theta$]
  - Position error *grows with ~ $V \bullet T^{(1.5\sim2)}$*



- X/Y gyro error causes roll/pitch error which grows with time
  - Has the effect of moving angle of perceived gravity vector
    - $\Delta\theta(t)$ grows with $T^{(0.5\sim1)}$
  - Creates an acceleration component in the X/Y plane, which is then double integrated to create a position error
    - $\Delta a(t) = 1g \bullet \sin\Delta\theta(t) \cong 1g \bullet \Delta\theta(t)$ [for small $\Delta\theta$]
    - $\Delta x(t) = \iint \Delta a(t) \bullet dt^2 \cong \iint 1g \bullet \Delta\theta(t) \bullet dt^2$
  - Position error *grows with ~$T^{(2.5\sim3)}$!*



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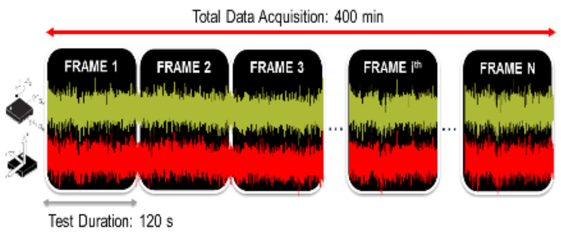
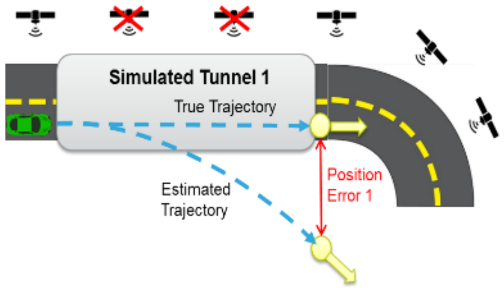
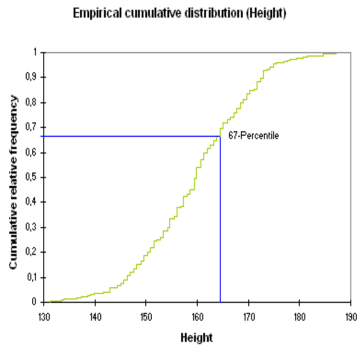
Analysis of noise based errors

Angle Random Walk (ARW) and Bias Instability (BI)







Data Acquisition

Acquisition duration: 400 minutes

IMU signal is acquired through EVBT3-DRAW device

Dataset divided in 200 frames, each one 2 minutes long

Frame Processing

Trajectory modelled: straight tunnel travelled @15 m/s

Known trajectory → known truth

Single test occurrence consists of:
1 min calibration (primary system available) +
1 min pure inertial navigation

Error Statistics

#200+ simulated occurrences for statistical confidence

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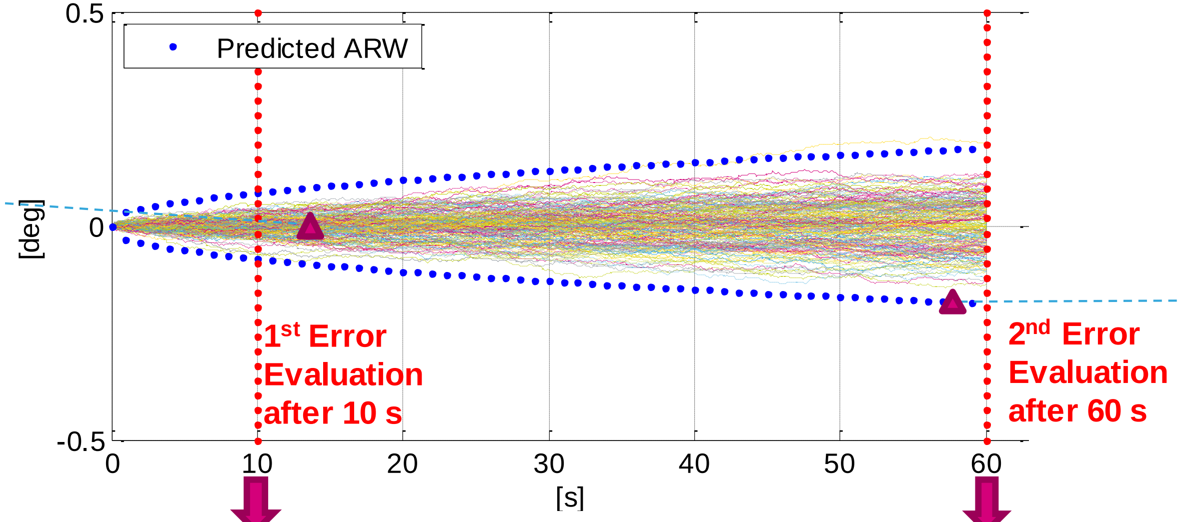
Plots Explained

- The following slide show the result for heading error [deg] and position cross-track error [m]

Each line represents the evolution of heading error vs time during each independent test iteration



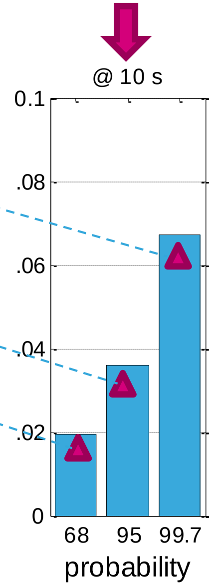
Blue-dotted line represents the typical amount of error noise (ARW), based on datasheet nominal density

Test lines falling out of ARW space are typically due to bias instability

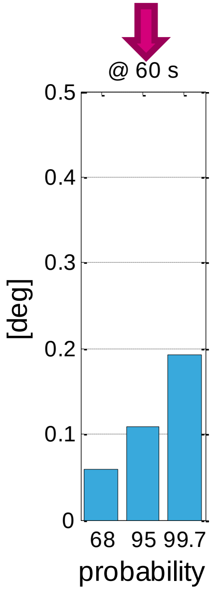
Error 3 σ

Error 2 σ

Error 1 σ

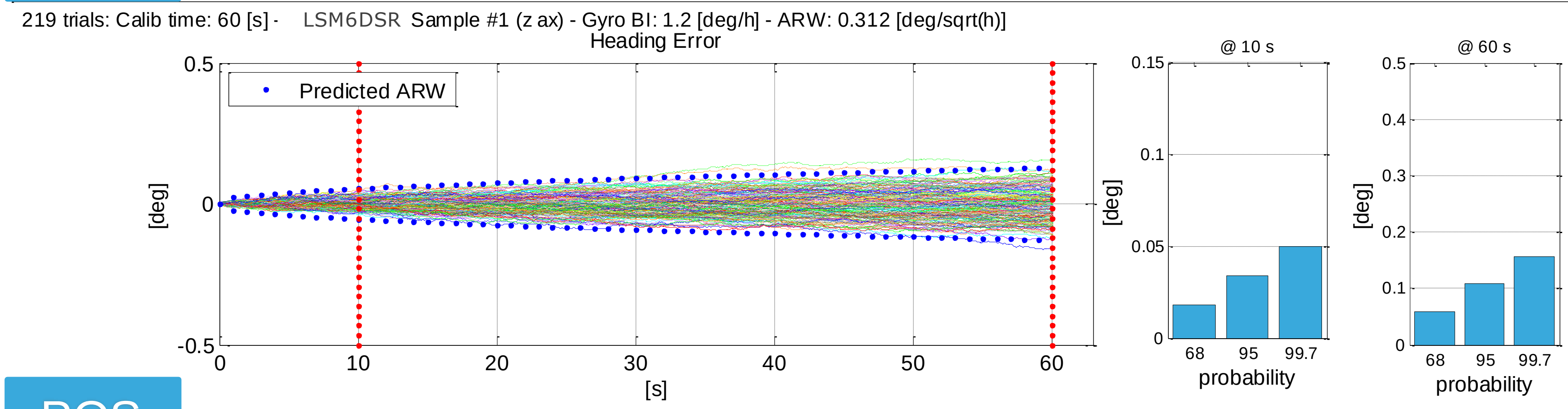


Errors are calculated 1/2/3 σ errors are calculated after 10 and 60 s

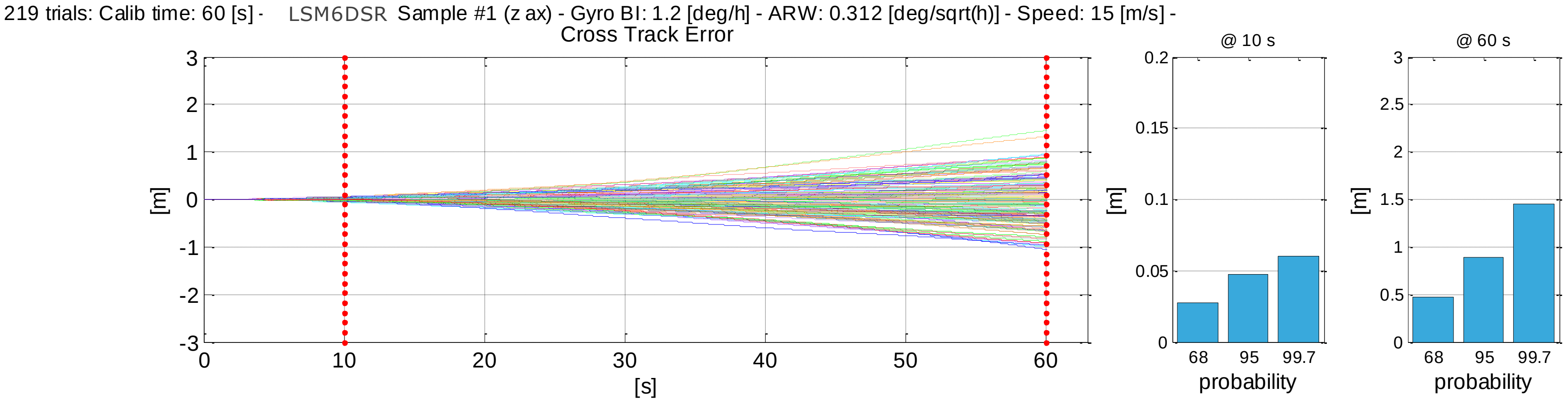


ASM330LHH Results

HEAD

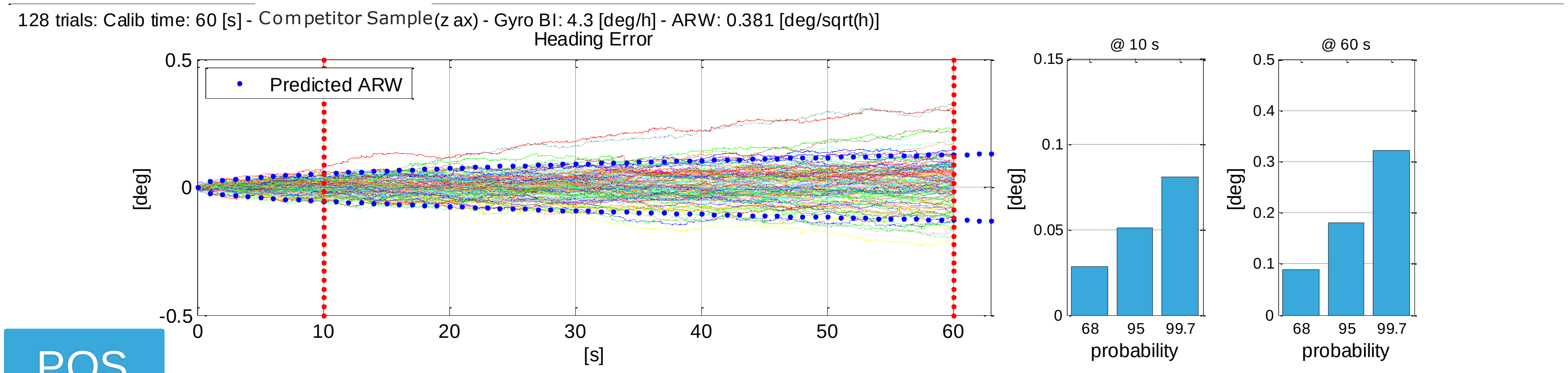


POS

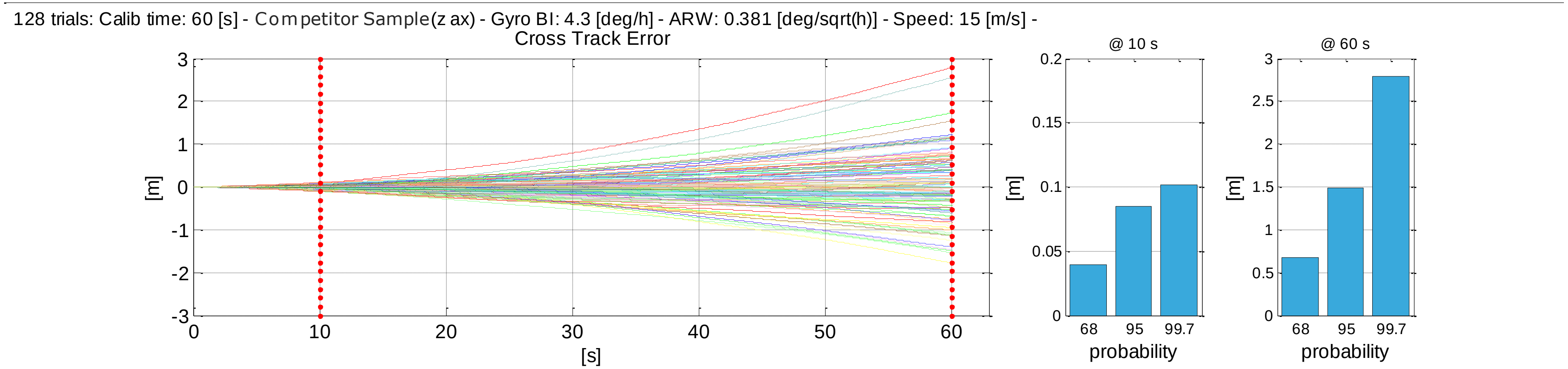


Competitor Results

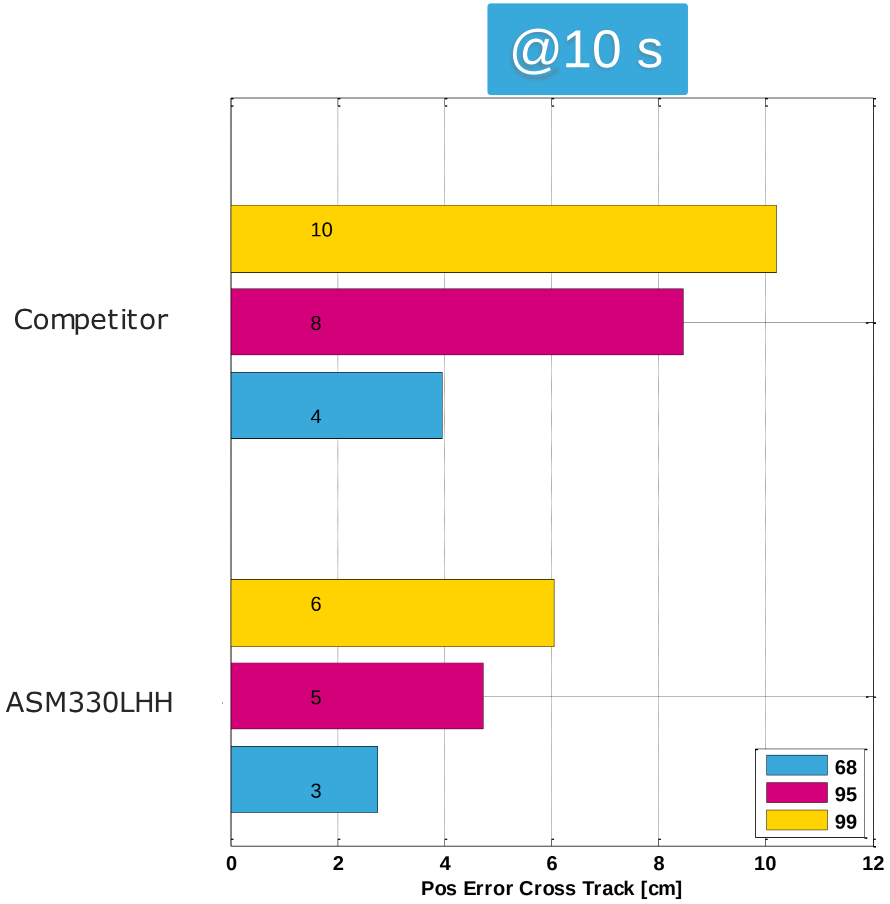
HEAD

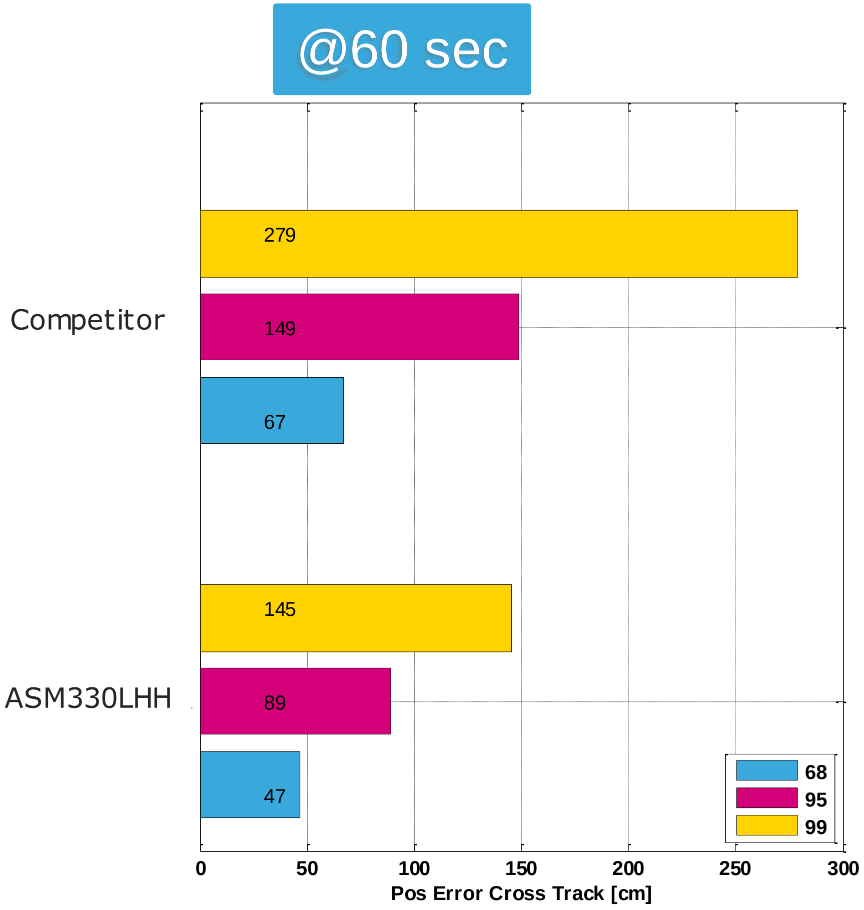


POS



Position Error Cross-Track





- Performance of DUTs after 10 s and 60 s of primary location system unavailability shows differences
- The error **cross-track**, consequence of gyroscope, shows ASM330LHH better than Competitor overall

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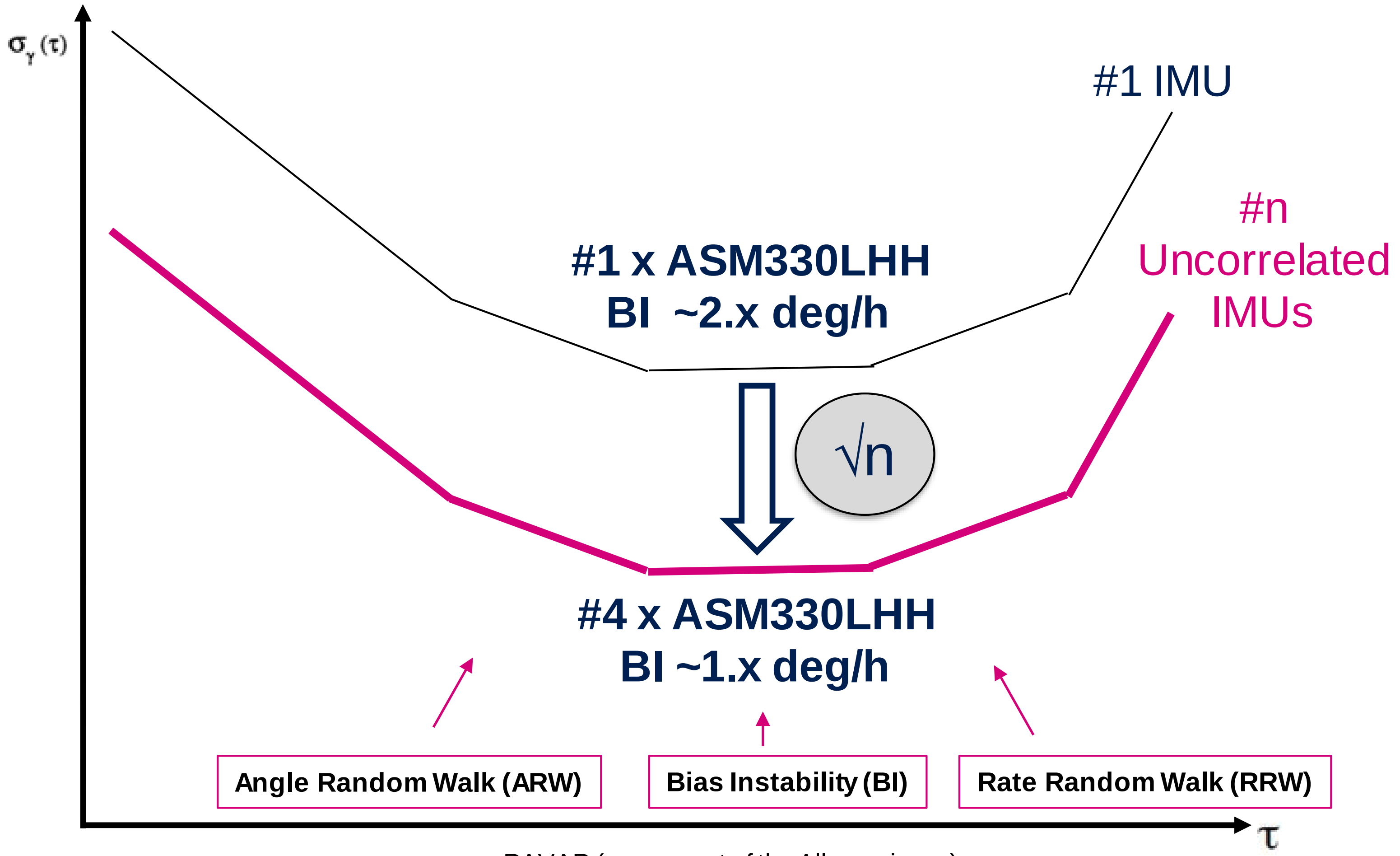
Using Multiple IMUs to Increase Accuracy



RAVAR (square root of the Allan variance)

Variance

$$\mathrm{Var}(z) = E[z^2] = \sigma^2$$

Averaged Variance

$$\mathrm{Var}\left(\frac{1}{n}\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}\mathrm{Var}\left(\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}\sum_{i=1}^{n}\mathrm{Var}\,(z_i).$$

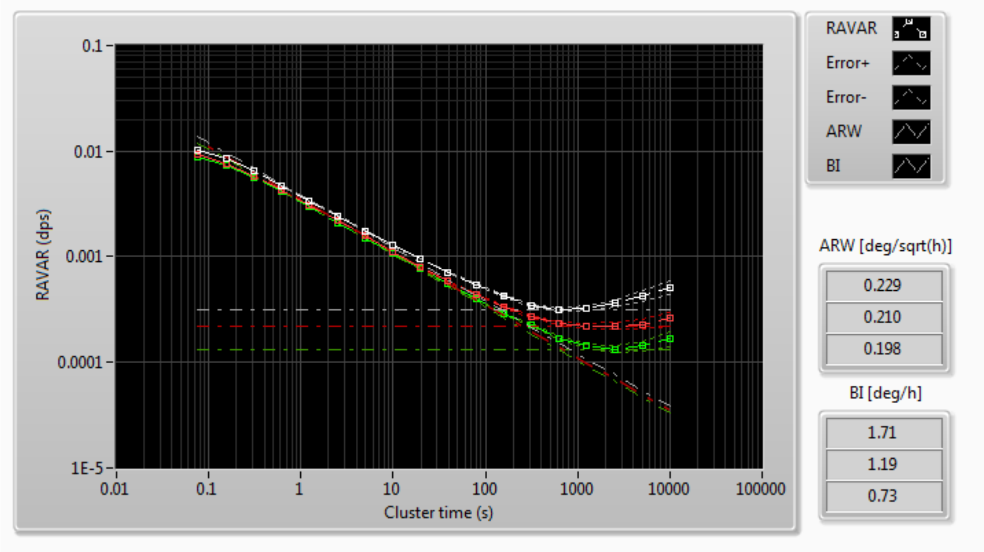
…since noise variance is constant

$$\mathrm{Var}(N_{\mathrm{avg}}) = \mathrm{Var}\left(\frac{1}{n}\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}n\sigma^2 = \frac{1}{n}\sigma^2$$

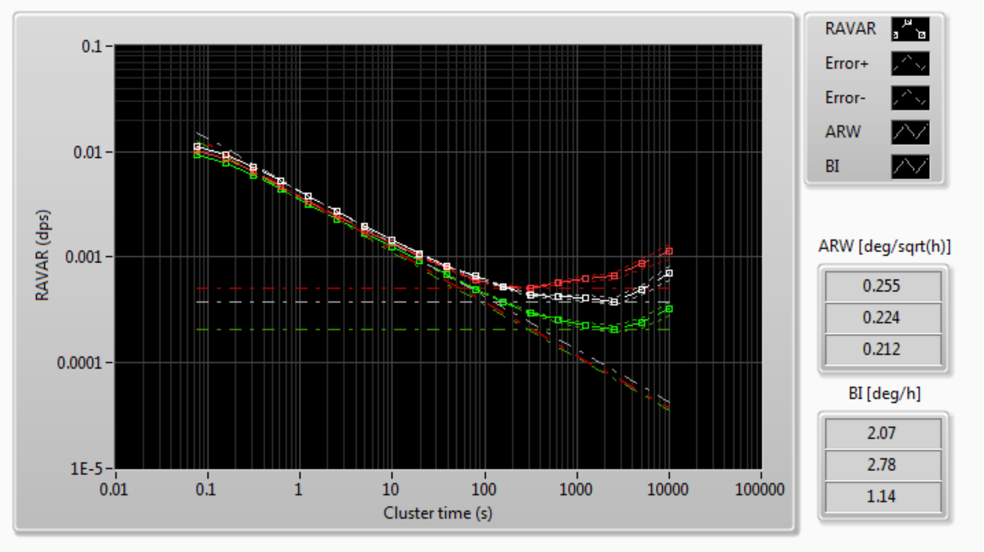
Stdev

$$\boldsymbol{Stdev(N_{avg}) = \frac{\sigma}{\sqrt{n}}}$$

ASM330LHH AVAR
Key Parameters for Navigation



Addressing the most demanding applications



ARW	Angular random walk	T = 25 °C		0.21		deg/√h
BI	Bias instability(7)	T = 25 °C		3		deg/h

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OpenIMU330BA
Automotive Grade ASIL B

ACEINNA OpenIMU330BA	
Functionality	6 DOF
Size (mm)	11 x 15 x 3
Package Type	44 Ball Grid Array
Interface	SPI / UART
Cal Temp Range	-40 to +85
Fault Tolerant Architecture	Yes
Angular Rate	
Gyro FSR (dps)	400
Gyro Bias Instability (deg/hr)	2
Gyro ARW (deg/root-hr)	0.2
Gyro Bias over T (deg/s)	0.3
Gyro Non-Linearity (%)	0.02
Acceleration	
XL FSR (g)	8 g
XL B.I. (ug)	15
XL VRW (m/s/root-hr)	0.05
XL Bias over T (mg)	3
XL Non-Linearity (%FSR)	0.03

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Disrupting Traditional IMU Module Market

ACEINNA OpenIMU400	
Functionality	6 DOF
Size (mm)	38 x 24 x 10
Package Type	AL
Interface	SPI / UART
Cal Temp Range	-40 to +85
Fault Tolerant Architecture	Yes
Angular Rate	
Gyro FSR (dps)	400
Gyro Bias Instability (deg/hr)	1
Gyro ARW (deg/root-hr)	0.1
Gyro Bias over T (deg/s)	0.2
Gyro Non-Linearity (%)	0.02
Acceleration	
XL FSR (g)	8 g
XL B.I. (ug)	3
XL VRW (m/s/root-hr)	0.02
XL Bias over T (mg)	1
XL Non-Linearity (%FSR)	0.03

Conclusions

- ST Micro leverages market leadership and core capabilities in GNSS
  - Establish requirements and benchmark sensor against real world application
  - Provide complete integrated solutions GNSS + DR + IMU
- Vertical integration and design for test supports automotive quality requirements
  - <<10dppm
- Combining capabilities to optimize cost performance trade-offs
  - Low noise design
  - Calibration capability
  - Ultralow power consumption
- Low cost/high performance sensors disrupting traditional IMU markets

Thank you

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