AUTOMOTIVE-GRADE GNSS + INERTIAL FOR ROBUST NAVIGATION

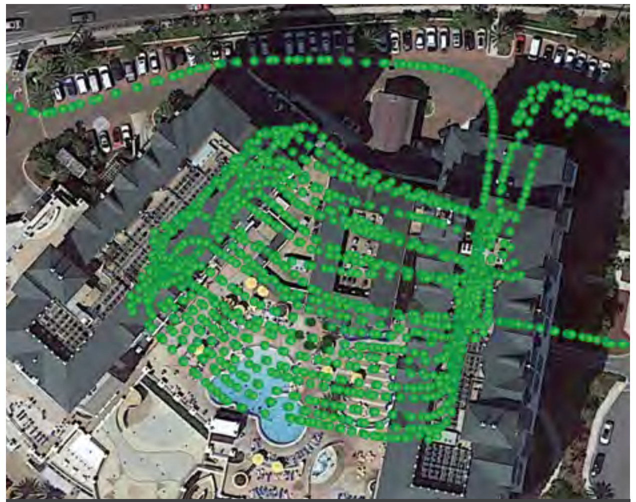


FIGURE 1 Test loops of the GIVE inside a completely enclosed parking garage; GNSS outage for 5 minutes of each loop.

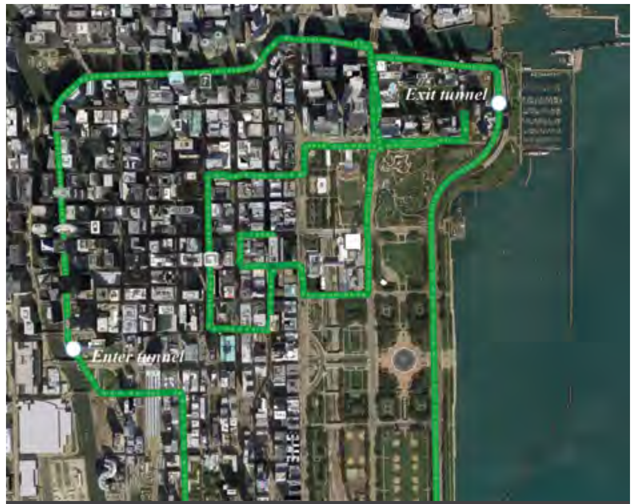


FIGURE 2 Consistent navigation performance of GIVE in long tunnel, Lower Wacker Drive, Chicago.

Three different low-cost sensor integrations, covering vehicle navigation in a range of environments, were explored and explained in the February webinar, "Automotive-Grade GNSS + Inertial for Robust Navigation." The full webinar, slides and audio, is available for download now.

Attendees learned about the options available under both GNSS-centric and inertial-centric paradigms. In both realms, low-cost sensors now accomplish so much more than they ever could before.

The webinar zoomed in close on three integrations:

- via sensor-agnostic self-contained software that performs tight coupling of carrier-phase GNSS with inertial measurements, a vehicle motion model with software-based multipath mitigation and without connecting to vehicle sensors;
- via tightly coupled GNSS, MEMS accelerometers and gyros, integrated in the GNSS module, from dual frequency with full RTK corrections and ambiguity resolution and a wheel-pulse connection (automotive dead reckoning), to single frequency, unconnected for ease of installation (untethered dead reckoning);
- via a wheel-mounted inertial measurement unit providing high-rate (2 kHz) bias-free data, road-quality measurements and instantaneous wheel dynamics estimation.

Vehicle navigation for actively engaged drivers represents today's largest, fastest growing segment for positioning technologies. Of the three possibilities covered in this webinar, two combine GNSS and MEMS inertial, with different advantages alternately for favorable or unfavorable sky/signal conditions. A third exploits completely GNSS-denied environments.

Low-cost sensors can meet requirements for map-matching, telematics and fleet-vehicle tracking, functioning in challenging environments such as urban canyons, tunnels and parking garages. A consistent and reliable positioning on the meter level, capable of withstanding 5 to 10-minute outages, answers this growing need.

Finally, for environments completely denied of GNSS signal availability, such as underground mines or construction in tunnels, new applications of inertial technology bring improved results without significant sensor costs.

The expert panel guided the audience through the intricacies of GNSS-inertial integration from three varying yet complementary vantage points:

- a sensor-agnostic software that uses inertial measurements to wring precision out of carrier-phase GNSS—not pseudoranges—without connecting to vehicle systems;
- 3D positioning in parking garage with no GNSS an automotive dead reckoning solution employing tightly coupled GNSS, MEMS accelerometers and gyros, and various vehicle sensors, that can continue to operate without GNSS;
- a constrained inertial system that provides a full solution in a completely denied GNSS environment: underground!

THE PANEL:

Andrey Soloviev, Ph.D., is a principal at QuNav. His research and development interests focus on sensor-fusion and signal-processing implementations for GNSS-degraded and GNSS-denied applications. He is a recipient of the Institute of Navigation (ION) Early Achievement Award and the RTCA William Jackson Award.

Philip Mattos, PhD., is a positioning technology expert for u-blox, with degrees in electrical engineering from Cambridge and Bristol. He designed hardware and software for GPS, Galileo, GLONASS and BeiDou systems and served on Galileo advisory groups for the European Commission. He worked as technical director and fellow applying GNSS knowledge to chipsets for satnavs, cars, asset tracking and more, for over 25 years.

Jussi Collin is CEO of Nordic Inertial (JC Inertial Oy) and adjunct professor at Tampere University. He received M.Sc. and Dr.Tech. degrees from Tampere University of Technology, Finland, specializing in inertial navigation algorithms. His research interests are in modern machine learning methods and their industrial applications in the field of inertial sensing.

Andrey Soloviev set the stage for the day's technical discussion of low-cost GNSS and inertial sensors by describing how much their performance has improved in recent years, to the extent that they can now provide meaningful navigation in a standalone format, without integration into the vehicle's system. He cited in particular vehicle tracking in GNSS-challenged environments such as urban canyons, tunnels and parking garages.

THE PANELISTS

Alan Cameron
Editor in Chief
Inside GNSS

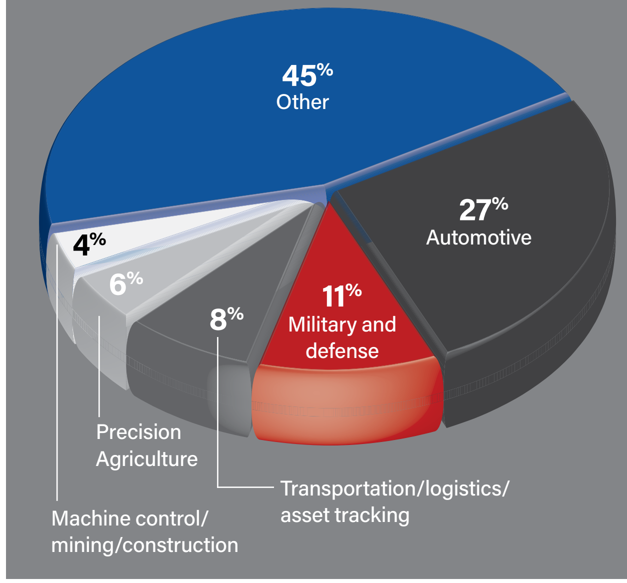
Andrey Soloviev
Principal
Qunav

Philip Mattos
GPS/GNSS
Positioning/Navigation Expert
u-blox

Jussi Collin
CEO Nordic Inertial
Adjunct Professor,
Tampere University, Finland

PARTICIPANTS BY INDUSTRY

A diverse audience of professionals attended the webinar:



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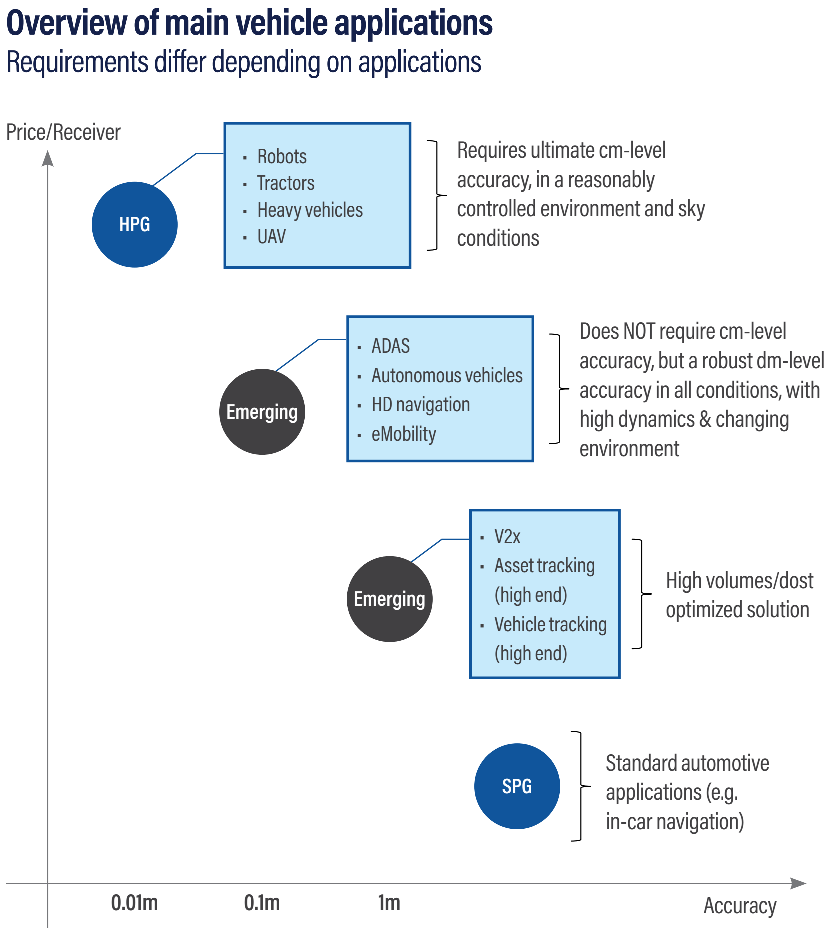


FIGURE 3 Overview of main vehicle application requirements. © u-blox AG

FIGURE 4 4 Location of inertial sensors on an articulated arm, in a machine control application.

He explored the details of a self-contained, software-based, sensor-agnostic solution using consumer-grade GNSS and MEMS inertial sensors. This GNSS/Inertial Vehicular Engine (GIVE) exploits a tight coupling of carrier-phase GNSS with inertial measurements and the vehicle motion model.

"We apply specific measures at the measurement screening level to mitigate the influence of multipath on overall navigation performance. This is pretty significant, particularly when we're talking about urban canyons."

After some discussion of the equations showing how, with carrier-phase measurements, integer ambiguities are resolved without corrections services "with a relatively simple trick," Soloviev showed some tests of real-time performance in harsh GNSS environments.

Driving two loops inside a completely enclosed parking garage, with a 5-minute GNSS outage, the GIVE system consistently kept the tracking data on the correct path **(Figure 1).** An even greater challenge came from a tunnel on Lower Wacker Drive in Chicago—2.2 miles long and a 5- to 7-minute complete GNSS outage! Again, tracking data showed consistent and accurate performance **(Figure 2).**

A MARKET IN THE MIDDLE

Philip Mattos outlined various combinations of GNSS and inertial that would support 2D and 3D assisted dead reckoning (ADR).

He displayed a diagram giving an overview of main vehicle applications **(Figure 3)**. "Traditionally, we've had very, very precise GNSS of the surveying type. At the other end we have the standard applications in the 3-meter area. What's emerging is somewhere in between. We need offer products for markets that want 10 centimeters, or that want 1 meter, to various levels of percentage, but additionally, to availability percentages. So when we go into a more difficult environment, what percentage of the time can we still achieve our 1-meter requirement, or in a different case our 10-cm requirement?"

He narrated some test results tracking a drive through a 2-kilometer tunnel, going from full GNSS to no GNSS, relying entirely on dead reckoning, then emerging to full signal availability. How much did the solution drift? He displayed single-band and multi-band GNSS results, with and without SBAS, with and without correction services.

PRECISION FOR MACHINE CONTROL

Jussi Collin introduced the technique and specific applicabilities of wheel-mounted inertial navigation, staying at GNSS-level precision without any aiding. With several slides giving the technical underpinning, he showed results of the technique in completely GNSS-denied environments, underground.

"What we see in the future is using this method, we started with the wheel but we can extend it for robot manipulators or excavator arms **(Figure 4)**. We can predict where the inertial unit is, predict its motion and give feedback to the filter. It appears by the initial tests that we will be very accurate on this and we know how the vehicle is moving we also know where it's pointing, and where it's picking up something. This looks like a very promising extension of inertial to machine control." IG

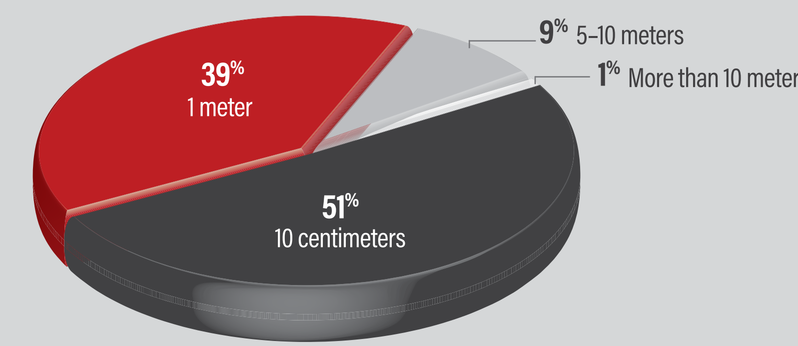
WHAT ATTENDEES WANTED TO KNOW

Participants asked live questions during the webinar. Here are a few of them:

- What are the requirements for the initial alignment–Does the unit have to be oriented in a certain way relative to the car? Is there a need for turns?
- What is the benefit of inertial if we already have the accuracy of SSR-RTK?
- What is the benefit of dual-band if we already have the accuracy of SSR-RTK?
- What is the typical stability of automotive-grade inertial sensors?
- What happens if the wheels slip?
- Could the energy for the IMU be harvested from the wheel motion?
- Were the Chicago and Atlanta tests conducted with professional-quality GNSS antennas or with consumer-grade antennas?
- How accurate does the motion model have to be, and what are the effects of inaccuracies that exceed expectations in the model?
- What about precise point positioning (PPP), how does that help improve the accuracy of the sensors in dead reckoning?
- How is the variating wheel radius managed in the filter of the navigation system?
- What position and heading accuracy did you get inside the parking garage?

BY THE NUMBERS: PARTICIPANTS' VIEWS

What are your accuracy requirements for harsh environments such as urban canyons, tunnels and parking garages?



In what platforms are low-cost inertial solutions best suited? (select two)