WHITE PAPER

Enhancing Inertial Navigation System Performance with Radar

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Introduction

As autonomous robots are deployed in increasingly challenging environments, their navigation systems need to be more robust and reliable, especially in GNSS-denied or degraded conditions. Traditional GNSS/INS systems often fall short of these performance requirements and require additional aiding sensors.

MicroStrain by HBK's latest inertial navigation system, the 3DM-CV7-INS, addresses this issue by offering a generic external measurement aiding interface to enhance GNSS outage performance. This aiding interface supports standard navigation measurements, such as GNSS position and velocity, but also more robotic-focused measurements such as body-frame velocity and wheel speed.

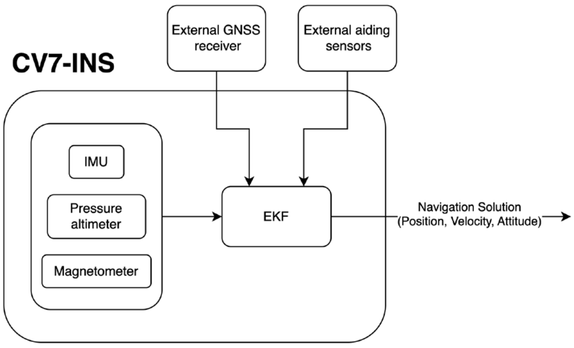
Traditionally, robots have relied on optical sensors like cameras and LiDAR for perception and navigation. However, advancements in mmWave radar technology have made radar an increasingly popular option for robotic navigation. Radar is simple, solid-state, and robust to environmental challenges (such as smoke or fog) that can affect optical sensors.

By integrating the CV7-INS with radar velocity measurements, the navigation performance during GNSS outages can be significantly improved. This integrated approach helps meet the growing demand for reliable navigation in challenging environments where traditional GNSS/INS systems may not perform adequately.

This paper shows an example system integrating radar velocity aiding with a CV7-INS. The code for this project is open source and can be found here.

CV7-INS Basics

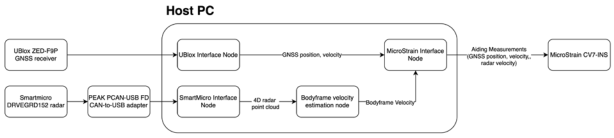
The MicroStrain CV7-INS is a tactical grade, embeddable inertial navigation system. It can integrate external aiding measurements, such as GNSS position and velocity, through its onboard Extended Kalman Filter. This filter fuses data from the system's internal sensors, including an IMU, pressure sensor, and magnetometer, with time-synchronized data from external sensors like a GNSS receiver. In addition to standard GNSS aiding measurements such as global position and velocity, the CV7 also supports a 3D body-frame velocity aiding measurement. This example demonstrates integration with a radar velocity sensor, but this aiding measurement can be generated by a variety of other navigation sensors, including lidar or visual odometry, optical flow, or wheel speed.



CV7-INS Architecture

System Architecture

A CV7-INS is integrated with a UBlox ZED-F9P GNSS receiver and a Smartmicro DRVEGRD 152 automotive radar sensor through a ROS2 interface. The GNSS receiver provides global position and velocity measurements, while the radar provides raw 4D point clouds (x, y, z, speed). Radar point clouds are first converted to 3D body-frame velocity measurements before being passed to the CV7-INS. This integrated system is mounted on an automotive test platform and operated in a suburban environment.



Test System Architecture

Radar Preprocessing

Before the radar point clouds can be processed by the CV7-INS navigation filter, they need to be converted into a more compact navigation aiding measurement. Using the Cartesian position and radial speed of each tracked radar target, a body-frame velocity can be estimated from each radar point cloud. A nonlinear least-squares solver is then used to estimate a body-frame velocity measurement and its associated measurement covariance. Robust error models are employed to reduce the influence of outliers and dynamic obstacles in the surrounding environment.

Radar Velocity Accuracy

In order to evaluate radar velocity performance, a dual antenna and RTK-enabled MicroStrain GQ7-GNSS/INS was used as a ground truth reference system. Due to the geometry of the point cloud, with most points distributed along the vehicle X axis, the observability of the Y and Z axis velocity is somewhat limited, resulting in a reduction in accuracy along those axes.

Body-frame axis	Accuracy (m/s)
x	0.09
y	0.16
z	0.35

Performance

To evaluate the benefits of radar velocity aiding in GNSS-denied scenarios, GNSS outages were simulated in post-processing. To generate a statistical estimate of outage performance, a series of 60 second GNSS outages were simulated in post-processing. Using the exact same EKF algorithm that runs in real time on the CV7-INS, the data was reprocessed 10 times, each with a different GNSS outage time window. Figures 1, 2, and 3 show the navigation performance from one of the simulated outage scenarios.

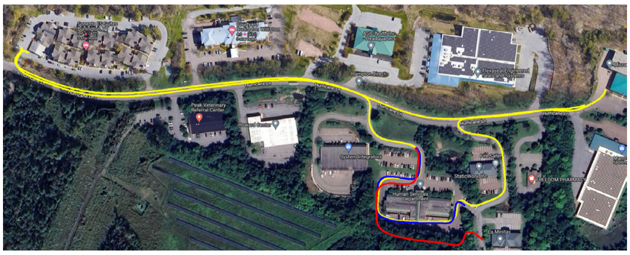


Figure 1: Example GNSS outage. Yellow: ground truth, Blue: radar-aided solution during outage, red=free inertial integrated solution during outage

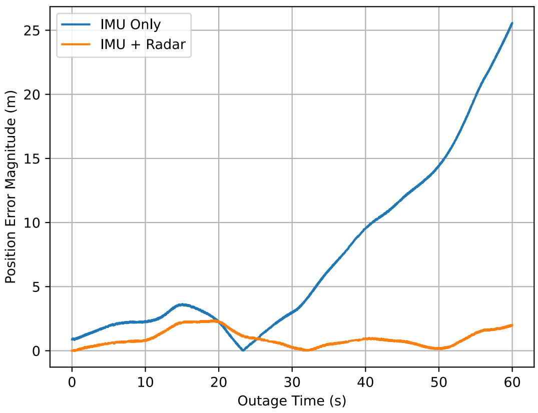


Figure 2: Absolute Error during the 60s outage

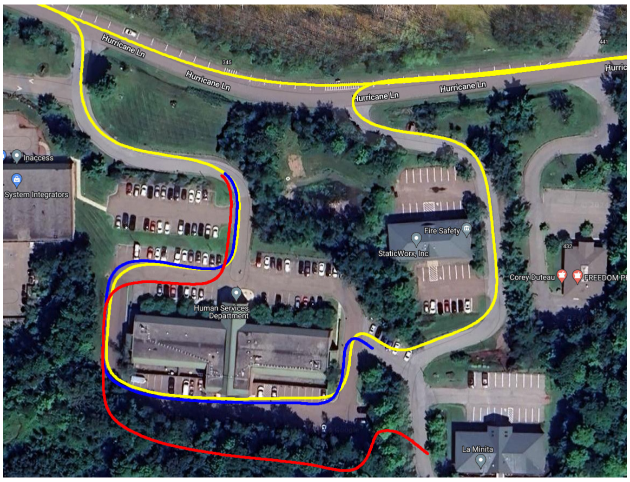


Figure 3: Area of detail for GNSS outage

Outage performance was then defined as the standard deviation of position error at each time step. Figure 4 shows the lateral navigation performance for both sensor configurations. Radar aiding resulted in a 93% increase in GNSS outage navigation performance as compared to the inertial only solution.

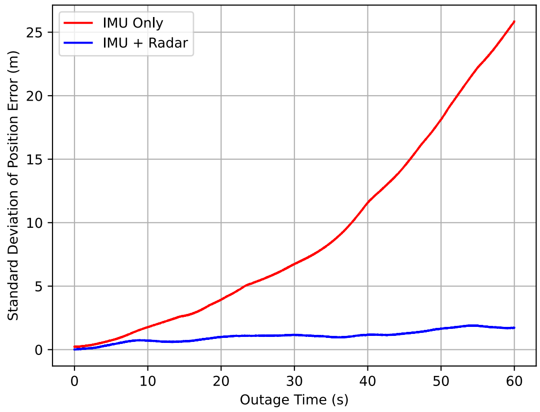
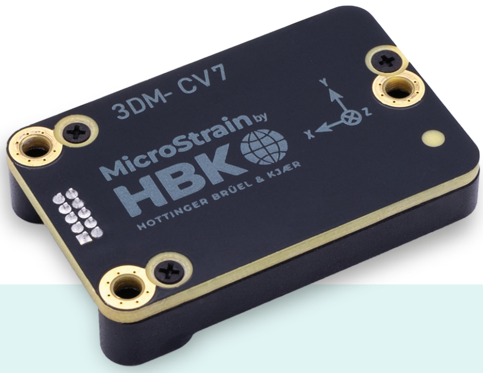


Figure 4: Standard Deviation Plot

Outage Performance (m)	10s	30s	60s
IMU only	1.77	6.74	25.84
IMU + radar	0.72	1.15	1.72

Conclusion

This example demonstrates that integrating radar velocity measurements into the CV7-INS navigation filter can improve navigation performance during GNSS outages up to 93% over free inertial integration. As the demand for reliable robotic navigation systems continues to grow, the flexible aiding interface of the CV7-INS can provide additional navigation performance in robotics applications where traditional GNSS/INS systems fall short.



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