WHITEPAPER

u-blox' 3D Dead Reckoning for Vehicle Applications

An advanced solution for modern urban navigation and positioning

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Executive Summary

Increasingly dense urban environments, park houses and multi-level interchanges pose a significant problem to navigation systems based on the reception of extremely weak satellite navigation signals. As ever more systems (e.g. car navigation, road pricing, fleet management, emergency services, etc.) depend on reliable, uninterrupted positioning and navigation, "3-Dimensional Dead Reckoning" GNSS, the ability to calculate a position in the X, Y, and Z axis when satellites signals are blocked or impeded is becoming increasingly important. This paper describes such a solution based on u-blox' sensor-fusion technology.

Multilevel highway interchanges pose a problem to satellite positioning: which road am I on? 3D Dead Reckoning solves this dilemma

3D Automotive Dead Reckoning: a new dimension in navigation

3-Dimensional Automotive Dead Reckoning ("3D ADR") aids traditional GPS/GNSS navigation via intelligent algorithms based on distance, direction and elevation changes made during satellite signal interruption. u-blox 3D ADR GNSS blends satellite navigation data with individual wheel speed, gyroscope and accelerometer information to deliver accurate positioning regardless of changes in a vehicle's speed, heading or elevation, even when satellite signals are partially or completely blocked.

Because GNSS satellites transmit their signals with the equivalent power of a 30 watt light bulb from a distance of 20,000 km, they arrive with typical signal strength, in the best case, of 120 dBm (1 x 10–15 Watts). This is millions of times weaker than a typical home WiFi signal! These signals can easily be degraded an additional 20-30 dBm in city conditions, or blocked completely, further impacting the accuracy of satellite navigation.

3D Dead Reckoning GNSS extends navigation to areas without satellite reception, while boosting accuracy along roads with changes in elevation as well as in tunnels, park houses and urban environments

Challenges to urban navigation
For vehicle navigation devices, at least 4 GNSS satellites must be identified and their information frames received and decoded before a position can be determined. Without this, satellite navigation is impossible.

Numerous barriers to already weak GNSS signals include:

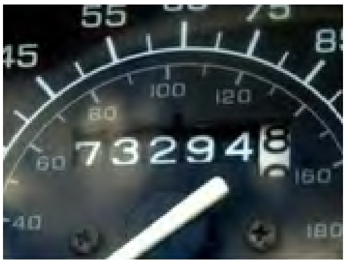
- **Tunnels and parking garages,** the worst case scenario where satellite signals are completely blocked
- **Multi-level roads,** overpasses and bridges which can confuse a satellite receiver (which road am I on?)
- **Mixed environments** such as urban canyons where partial and reflected satellite signals (multipath propagation) can trick a GNSS receiver into thinking it is somewhere else

The end result of these obstructions range from minor irritation to major problem:

Mission critical navigation: an emergency vehicle must find its way quickly to the scene of an accident

- **Emergency vehicles** such as police, fire and ambulance services are hindered from reaching the location of an incident quickly
- For **commercial transportation** services such as taxis, freight and logistics companies, the loss of positional overview and security of transported goods can have major financial ramifications
- For **drivers unfamiliar** with the area, navigation can be intermittent or fail altogether, especially when exiting tunnels and park garages, resulting in irritation, wasted time and fuel
- For **public transportation** systems such as buses and trams, the loss of expected arrival times poses an inconvenience to thousands of commuters
- **Systems used for automatic road-pricing** or pay-as-you-drive insurance have insufficient data to charge for road usage

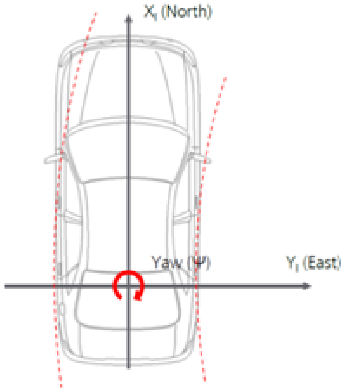
A solution: GNSS positioning enhanced with 3D Dead Reckoning



Wheel tick provides information about distance traveled

To solve these problems, u-blox has integrated 3D ADR functionality into its GNSS satellite receiver chip technology. Dead Reckoning is a centuries old concept originally used by sailors to calculate their position based on how far and in what direction they have travelled from a last known location, typically the last harbor.

Based on advanced "Sensor Fusion Dead Reckoning" technology, u-blox' 3D ADR accomplishes the same task when travelling through regions of poor or no GNSS reception. Based on the last known position, vehicle sensors (typically wheel speed sensor, gyroscope and accelerometer) feed information to the u-blox GNSS receiver indicating how far and in what direction, as well as what altitude change a vehicle has experienced based on wheel tick and vehicle pitch. In this way, a better approximation of where the vehicle actually is can be calculated, regardless of GNSS satellite visibility.



Changes in gyroscope yaw provide information about vehicle direction

Sensing distance travelled

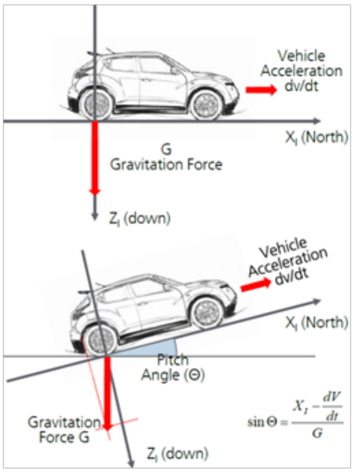
There are a variety of sensor techniques for detecting distance travelled. Typically a direct connection to the vehicle's odometer (wheel tick) is enough.

The simplest implementation of dead reckoning can be achieved through monitoring of individual left and right wheel ticks to determine both distance and heading.

Sensing direction

Dead Reckoning in a 2 dimensional plane is achieved by measurements reported by a yaw rate sensor gyroscope. The gyro measures the vehicle's rotation rate along the Z axis.

By combining rotation rate and distance travelled, Dead Reckoning is possible through curves.



Vehicle pitch is calculated through changes in gravity and acceleration vectors

Sensing changes in altitude

Gravity and vehicle accelerations information is gathered from three accelerometers placed in an orthogonal configuration. Combined with information about vehicle heading, any changes in the pitch of the vehicle can be calculated, for instance when climbing a ramp within a park house. Combined with distance measurement, change in altitude can be calculated.

This is particularly important when travelling up or down inside shielded environments, for example, when climbing, the actual distance a vehicle has travelled along the X axis will be shorter than the distance information delivered by a car's wheel tick sensor. When taking only 2 dimensions into account, this displacement error results in a navigation system thinking the vehicle has travelled further in the X direction than it actually has.

Rudolph Kalman receiving National Medal of Science by President Obama in 2008 for the development of the Kalman Filter, a mathematical technique that revolutionized control, aviation and vehicle systems.

Improved performance in multi-level highway interchanges

Map matching is often used in vehicle navigation systems. Based on an actual map, application software knows to always report a position located on an actual road, even if the extrapolation calculated by the satellite receiver is slightly off due to accumulated position and heading error. This can be a problem when driving through overlapping multi-level roads.

In this scenario, 3D Dead Reckoning delivers accurate altitude information to the map matching software to allow the navigation system to correctly discern which overlapping road a vehicle is travelling on. This is particularly important when driving under an overpass where GNSS satellite signals may be temporarily interrupted.

The u-blox 3D Automotive Dead Reckoning (3D ADR) solution
u-blox has developed a semiconductor solution based on the fusion of sensor data with GNSS satellite data. Based on the Kalman Filter, a mathematical concept first published in 1960 by Hungarian-American mathematician, Rudolf E. Kalman, the concept is widely used in control systems, avionics, and space vehicles. The filter is very powerful and able to estimate present and future states of a system, even when the precise nature of the system is unknown.

In the case of u-blox' implementation, a tightly-coupled Kalman filter algorithm is programmed in the GNSS receiver chip to determine vehicle location based on weighted averages of multiple sensor data input provided by the GNSS receiver, wheel-tick and gyroscope and accelerometers. The result is an estimated position that lies in-between the predicted and measured location that is far more accurate than if either methods were used alone. This process is repeated iteratively, with the new estimate used in the following calculation.

During times of good GNSS signal reception, the measurements from the vehicle sensors are constantly calibrated. If later a situation with bad or no GNSS signals (i.e. urban canyons, tunnels) is encountered, the solution continues to provide a highly accurate location based on the vehicle sensors' inputs.

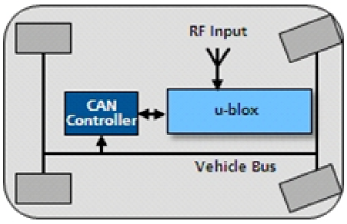
Ideal for first-mount navigation systems, u-blox' 3D ADR Solution blends data from GNSS satellites with wheel tick, gyroscope and accelerometer information available from the vehicle CAN bus. Making use of the data available from the vehicle data bus brings cost savings; no additional sensors are required to implement Dead Reckoning. The solution runs on a u-blox M8 GNSS receiver chip, the UBX-M8030-Kx-DR, and is a highly-accurate solution for car navigation and vehicle telematics systems.

u-blox' UBX-M8030-Kx-DR self-calibrating 3D ADR chip is compatible with virtually any car model

u-blox' proprietary 3D ADR solution is revolutionary in that it runs completely on the GNSS chip. Differences in individual wheel speeds (used to determine the vehicle's speed and heading rate) and accelerometers are blended with GNSS positional data and gyroscope readings. The solution requires minimum pre-configuration, and after initial set-up remains permanently calibrated.

Designed specifically for automotive dead reckoning applications, u blox' ADR chips are qualified according AEC-Q100 and manufactured on TS-16949 certified sites.

Benefits of u-blox’ 3D ADR solution for first-mount applications:



u-blox’ 3D Automotive Dead Reckoning chip connects directly do the vehicle CAN bus controller, and requires no pre-configuration

- Able to track all visible GPS, GLONASS and BeiDou GNSS satellites in operation for increased reliability (GPS+GLONASS, GPS+BeiDou, GLONASS+BeiDou)

- Supports a variety of sensor combinations depending on the desired cost and performance of the navigation system:
  - o 3D GAWT (Gyro, Accelerometer and Wheel Tick),
  - o 2D GWT (Gyro and Wheel Tick) and
  - o 2D DWT (Differential Wheel Tick)

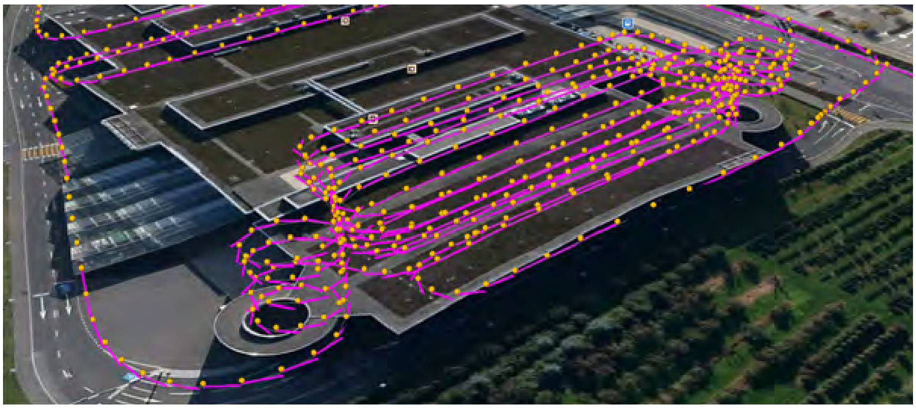
The possible dead reckoning solutions are listed here in order of decreasing accuracy:

1. z-axis or 3-axis gyro, 3-axis accelerometer and single wheel tick (3D GAWT)
2. z-axis or 3-axis gyro, x-axis accelerometer and single wheel tick (3D GAWT)
3. z-axis gyro and single wheel tick (2D GWT)
4. Differential wheel tick (2D DWT) using all four wheels
5. Differential wheel tick (2D DWT) using rear wheels
6. Differential wheel tick (2D DWT) using front wheels

Note: DWT with rear wheels is slightly more accurate than DWT using front wheels because the front wheel tick accuracy is affected by steering.

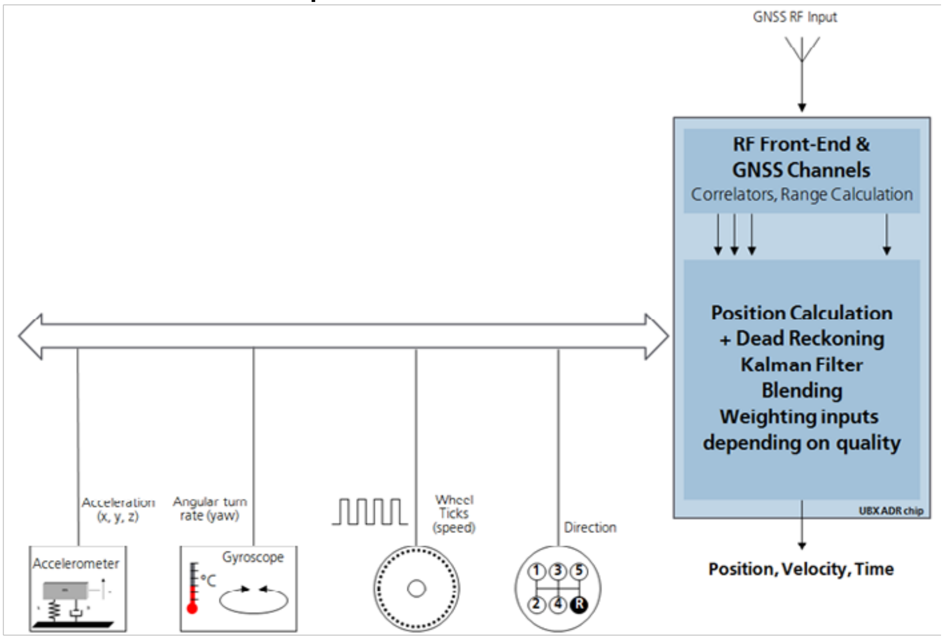
- Requires minimum host integration and customization = lower risk, lower cost, and faster time-to-market
- Self-calibrating
- Based on proven solution with Tier-1 customers
- Compatible with virtually any model car or drive train (i.e. front-, rear-, all-wheel drive)
- Suitable not only for car navigation, but for many other car telematics applications such as eCall, pay-as-you-drive insurance, road-pricing, and stolen vehicle tracking
- 3D ADR runs on u-blox’ UBX-G8030 GNSS receiver chips (standard & automotive grade)

Drive test: park house



The drive-test trace above illustrates u-blox’ 3D ADR ability to accurately track a vehicle’s position during the entire internal drive of a 5-story park garage with multiple 360 degree turns. Upon exiting the garage (upper-right), the vehicle’s position is correctly placed in the center of the left lane. GNSS satellite visibility was blocked during this drive test.

u-blox M8 3D ADR - Implementation



Features of u-blox 3D ADR

Reduced hardware costs
- Utilizes sensor data taken directly from the vehicle bus
- Supports high-end (wheel tick + gyro + accelerometer) to low-end, low-cost (wheel tick only) configurations
- Minimal host processing required to execute Dead Reckoning
- Automatically adapts to sensor head unit misalignment via software calibration
- Standard and automotive grades

Flexible implementation
- Supports various sensor configurations
- Easily supports vehicle variants
- Rich set of communication interfaces (I2C, SPI, UART, USB)
- Self-calibrating, both initially and on a continuously to compensate for sensor aging and temperature affects
- Supports low wheel tick operation
- Based on external flash allowing for future improvements and updates to adapt to new GNSS systems (e.g. Galileo)
- Embedded map-matching input to further refine navigation performance

Simple integration
- Easy testing
- Simple and modular production set-up: needs only vehicle parameters
- Minimal eBOM

Industry proven
- Successfully deployed by multiple major car manufacturers

For more information about u-blox' 3D ADR chip, contact u-blox.

About u-blox

Swiss-based u-blox is the global leader in positioning and wireless semiconductors for the consumer, industrial and automotive markets. Our solutions enable people, vehicles and machines to locate their exact position and wirelessly communicate via voice, text or video.

With a broad portfolio of chips, modules and software solutions, u-blox is uniquely positioned to enable OEMs to develop innovative personal, professional and M2M solutions quickly and cost-effectively. With headquarters in Thalwil, Switzerland, u-blox is globally present with offices in Europe, Asia and the USA. (www.u-blox.com)

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Any comments relating to the material contained in this document may be submitted to:

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