WHITEPAPER

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u-blox' Dead Reckoning for Automotive Applications

Intelligent solutions for modern urban navigation

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Executive Summary

Increasingly dense urban environments pose a significant problem to navigation systems based on the reception of extremely weak GPS satellite signals. As ever more systems (e.g. road pricing, fleet management, emergency services, etc.) depend on reliable, uninterrupted navigation, "Dead Reckoning" GPS is becoming increasingly important.

Dead Reckoning aids traditional GPS navigation via intelligent algorithms based on a vehicle's distance and directional changes during GPS signal interruption. u-blox provides two solutions for Dead Reckoning GPS based on individual wheel speed and/or gyroscopic information:

1) **For first-mount navigation and emergency call systems:**
   u-blox' Automotive Dead Reckoning (ADR) GPS receiver chips are designed for in-car navigation and telematics systems using gyro and/or wheel tick information taken directly from the vehicle data bus.

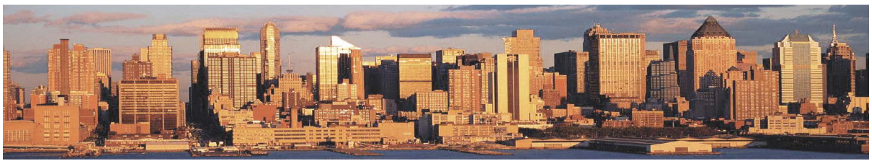
2) **For After-Market add-on devices:**
   Independent of the vehicle data bus, u-blox' LEA-6R stand-alone GPS receiver module interfaces directly to the vehicle odometer and gyro. It is therefore suitable for after-market devices such as fleet and asset management, road-pricing and insurance systems as well as Automatic Vehicle Locators (AVL).

Dead Reckoning

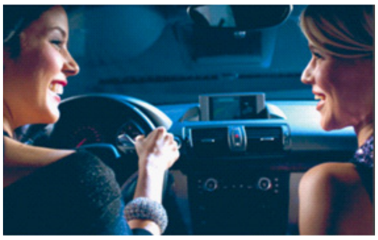
u-blox' Dead Reckoning for Automotive Applications

An intelligent solution for modern urban navigation

As millions of people migrate to cities across the globe, higher and denser building construction has become the only way to accommodate the increasing population. Add to that the requirement to accommodate more cars and increased underground traffic routes, and you have a significant challenge to GPS navigation in modern cities.



Because GPS 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 (1×10^{-15} Watts). This is millions of times weaker than a typical home WiFi signal! These signals can easily be degraded by an additional 20-30 dB in city conditions, or blocked completely, further impacting the accuracy of GPS navigation.



Dead Reckoning GPS extends coverage to areas without GPS reception, while boosting accuracy in areas with adverse signal conditions such as urban areas with heavy multipath effects.

Challenges to urban navigation

For car navigation devices, at least 4 GPS satellites must be identified and their signals received and decoded before a position can be determined. Without this, GPS navigation is impossible.

Numerous barriers to already weak GPS signals include:

- Tunnels and parking garages, the worst case scenario where GPS signals are completely blocked
- Multi-level roads, overpasses and bridges which can confuse GPS receiver (which road am I on?)
- Tall buildings which can reflect GPS signals (multipath propagation), fooling a GPS receiver into thinking it is somewhere else

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

- 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 commuters who may already know their way, traffic-jam avoidance services can be rendered useless
- For public transportation systems such as buses and trams, the loss of expected arrival times poses an inconvenience to thousands of commuters
- 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
- Emergency vehicles such as police, fire and ambulance services are prevented from reaching the location of an incident quickly
- Systems used for automatic road-pricing or pay-as-you-drive insurance have insufficient data to charge for road usage

Dead Reckoning

LEA-6R
u-blox GPS module with integrated Dead Reckoning

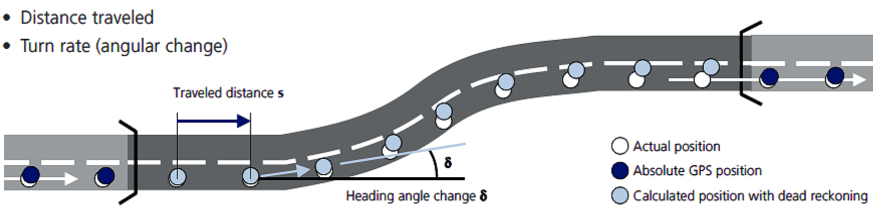
A solution: GPS enhanced with Dead Reckoning

To address this growing problem, u-blox has integrated Dead Reckoning functionality into its GPS receiver chip technology. Dead Reckoning is actually a centuries old concept originally used by sailors to extrapolate their position based on how far and in what direction they have travelled from a last known location, typically the last harbor.

Based on proprietary "Sensor Fusion Dead Reckoning" technology, u-blox ADR accomplishes the same task when travelling through regions of poor GPS reception. Based on the last known position, vehicle sensors feed information to the u-blox GPS receiver indicating how far and in what direction the vehicle has travelled. The GPS receiver processes the sensor data and blends it with GPS positional readings. In this way, a better approximation of where the vehicle actually is can be extrapolated, regardless of GPS satellite visibility.

Dead Reckoning has one drawback: the displacement and heading errors accumulate over time. The errors depend on the accuracy of the sensors, data quantization errors, and time granularity. It is the job of Dead Reckoning hardware and software to minimize the errors for as long as possible to provide accurate location information during short signal interruptions as well as long drives through tunnels.

The figure below illustrates accumulated Dead Reckoning error.



Accumulated Dead Reckoning error

The following list shows typical sensor and information sources used by Dead Reckoning technology to calculate a position:

Distance Sensing:

- Odometer pulses (absolute distance travelled, this is most typical)
- Distance information from wheel ticks
- Digital speed information (distance is reconstructed from a single integration)
- Linear accelerometers (distance reconstructed from double-integrating acceleration)
- Radar, optical, and acoustic sensors

Direction Sensing:

- Turn rate sensor (gyroscopes, most typical)
- Linear accelerometers
- Steering linkage angular sensor
- Differential wheel speed information (between left and right wheels)
- Magnetic compass

Dead Reckoning

Sensing distance travelled

There are a variety of sensor techniques for detecting distance travelled. Typically a direct connection to the vehicle's odometer is enough. If this is not available, for example for after-market installations, wheel sensors can provide the raw information for distance travelled. The variable reluctance sensor and Hall Effect position sensor are two common types of electro-magnetic sensors for this purpose.

Sensing direction

Besides distance, direction or turn-rate information (measured, for example, in degrees per second) is also needed to extrapolate the travelled route. The easiest approach is to use a small turn-rate sensor, also called a gyroscope. Several types of gyroscopes exist: mechanical (a rotating mass suspended in gimbals), optical, and micro-electromechanical system (MEMS) vibrating structures.

The first two types provide excellent accuracy but are large and expensive. MEMS gyroscopes excel in their small size, good performance, and user-friendliness and are relatively inexpensive. They are also available as surface-mount devices easily installed on a printed circuit board.

Map matching

In addition, a technique known as map matching can be used. 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 GPS receiver is slightly off due to accumulated position and heading error.

Ultimately, an approach of using the Dead Reckoning solution based on both GPS and sensor measurements simultaneously together with map matching delivers the best result in city environments where a wide range of signal conditions can be expected: partial, reflected, and blocked GPS signals.

Dead Reckoning

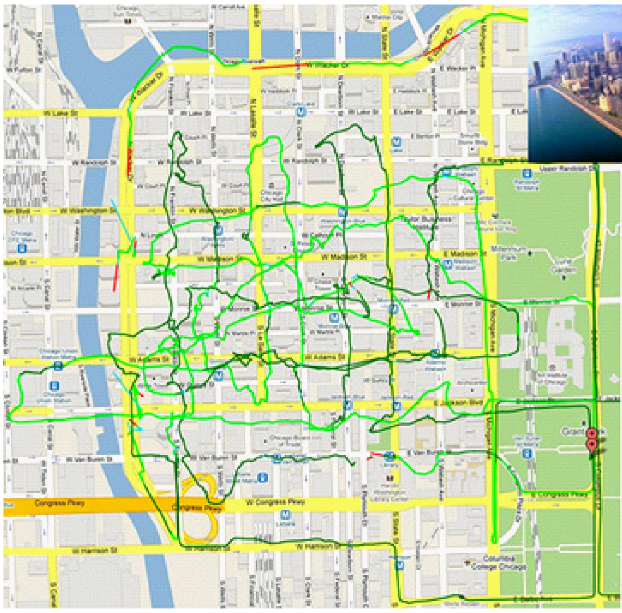
The u-blox ADR solution

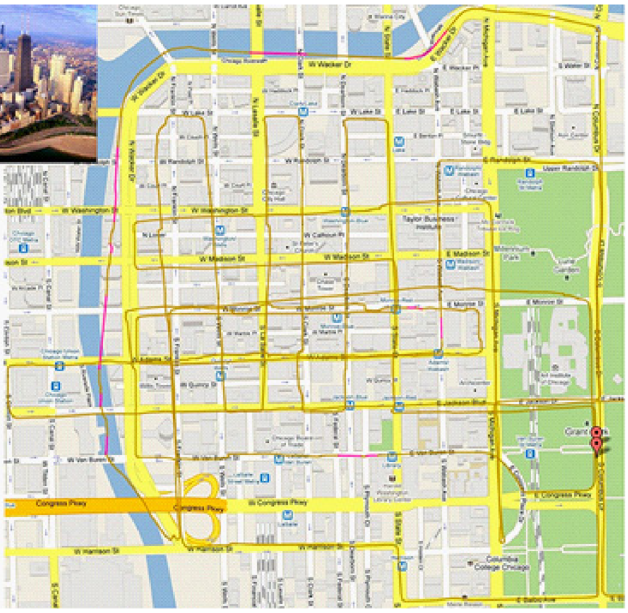
u-blox' ADR solution is based on the Kalman Filter, a mathematical concept first published in 1960 by Hungarian-American mathematician, Rudolf E. Kalman. The concept is widely used in control systems, avionics, and space vehicles. The filter is very powerful and able to estimate present and future states of a system, even when the precise nature of the system is unknown.

In the case of u-blox ADR, a tightly-coupled Kalman filter algorithm is programmed in the GPS chip to determine vehicle location based on weighted averages of multiple sensor data input provided by the GPS receiver, wheel-tick and (optional) gyroscope sensors. 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 GPS signal reception, the measurements from the vehicle sensors are constantly calibrated. If later a situation with bad or no GPS signals (i.e. urban canyons, tunnels) is encountered, the u blox ADR solution continues to provide a highly accurate location based on the vehicle sensors' inputs.

The u-blox ADR solution has been extensively tested in real-world environments, including city drive tests in Detroit, Chicago, San Francisco, New York City, and Zurich with excellent results. The figure below shows the performance of u-blox' ADR solution during a drive test in Chicago versus GPS alone.





GPS only

u-blox Automotive DR solution

u-blox Automotive DR solution: drive test in Chicago

This drive test was done through dense urban canyons, including some of the world's tallest skyscrapers, as well as through underground tunnels. As can be seen by the positional traces, the u-blox ADR solution (right) delivered a much higher degree of accuracy than a system relying on GPS satellite signals alone (left).

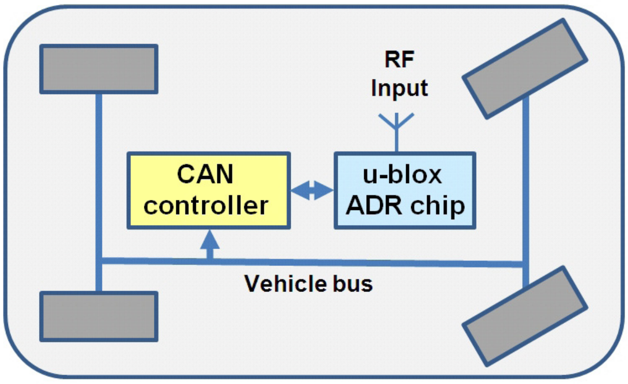
Dead Reckoning

Solution for Automotive Tier-1 suppliers

Ideal for first-mount navigation systems, u-blox’ Automotive Dead Reckoning Solution (ADR) blends data from GPS satellites with wheel tick and (optional) gyroscope information taken directly from the vehicle data (i.e. 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 u blox’ GPS receiver chip and is a highly-accurate solution for in-car navigation and vehicle telematics systems.

u-blox’ Automotive DR solution is compatible with virtually any car model

u-blox’ proprietary ADR solution is revolutionary in that it runs completely on the GPS chip. Differences in individual wheel speeds (used to determine the vehicle’s speed and heading rate) are blended with GPS positional data and optional 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 AEC-Q100 qualified and manufactured according to TS-16949 standards.

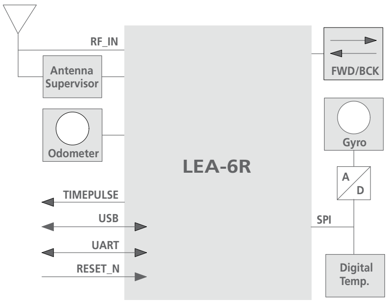


u-blox’ Automotive DR chip connects directly do the vehicle data bus, and requires no pre-configuration

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

- Requires minimum host integration and customization = lower risk, lower cost, and faster time-to-market
- Self-calibrating
- Proven solution with Tier-1 reference customers
- Compatible with virtually any model car or drive train type (i.e. front-wheel, rear-wheel, 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
- Supports multiple sensor configurations, but does not require a gyro to work
- ADR runs on u-blox’ automotive-grade, industry-certified GPS receiver chips

Dead Reckoning



LEA-6R u-blox GPS receiver module with Dead Reckoning interfaces directly to the vehicle odometer and gyroscope

LEA-6R: u-blox' solution for after-market devices

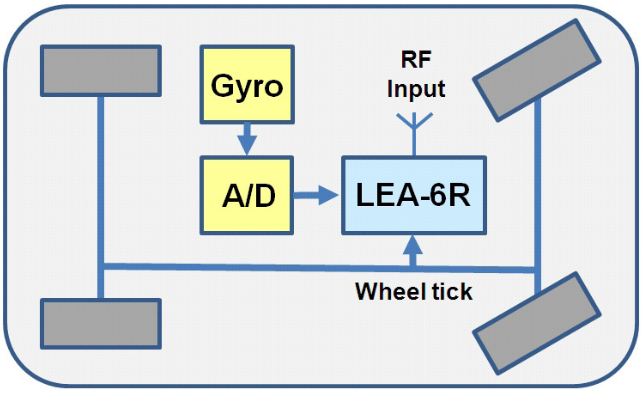
Using gyroscope and odometer pulses from a tachometer, the u-blox LEA-6R GPS receiver module solution is independent of the vehicle data bus and thus ideal for after-market add-on systems requiring uninterrupted navigation such as fleet and asset management, road-pricing and insurance systems as well as Automatic Vehicle Locators (AVL).

The LEA-6R supplements satellite GPS information via direct connection to a vehicle-mounted gyroscope (turn rate sensor) and the vehicle's odometer to execute dead reckoning navigation through periods of poor GPS reception.

Depending on the quality of the available GPS signals, the LEA-6R uses a proprietary algorithm specially developed by u-blox to extrapolate future positions accurately by using a combination GPS receiver and sensor inputs. The LEA-6R is a stand-alone solution requiring no host integration.

u-blox' Dead Reckoning technology can be evaluated with u-blox Dead Reckoning evaluation kit EVK-6R which can be ordered via u-blox' Online Shop at:

http://www.u-blox.com/en/online-shop.html



Using gyroscope and odometer data, the u-blox LEA-6R GPS receiver module is independent of the vehicle data bus and thus ideal for after-market applications

u-blox Dead Reckoning evaluation kit

Additional reading:

- Technical paper: "Performance of low-cost real-time navigation system using single frequency GNSS measurements combined with wheel-tick data"
- LEA-6R Application Note
- u-blox DR article published in GPS World: "Continuous Navigation: Combining GPS with Sensor-Based Dead Reckoning."

About the Authors

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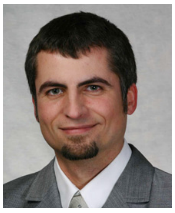
Etienne Favey is Vice-President Navigation Software Development at u-blox AG, Thalwil, Switzerland. He obtained his Ph.D-degree in Geodesy and Geomatics in 2001 from the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland. His research interests include innovative positioning techniques, and combination of GPS with other methods and sensors.



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Carl has 25 years of international experience working in the semiconductor, software, telecoms, and GPS industries based in the USA and Switzerland. Carl is a published author of numerous technical articles and conference papers in the areas of embedded computing, telecom services billing, and broadband multimedia distribution. Carl holds a Bachelors of Science in Electrical and Computer Engineering from the University of California. Carl is a classical pianist and avid chess player.

About u-blox

u-blox is a leading fabless semiconductor provider of embedded positioning and wireless communication solutions for the consumer, industrial and automotive markets. Our solutions enable people, devices, vehicles and machines to locate their exact position and wirelessly communicate via voice, text or video.

With a broad portfolio of GPS modules, cards, chips, and software solutions together with wireless modules and solutions, u-blox is uniquely positioned to enable OEMs to develop innovative solutions quickly and cost-effectively. Headquartered in Switzerland and with global presence in Europe, Asia and the Americas, u-blox employs 200 people. Founded in 1997, u-blox is listed on the SIX Swiss Exchange.

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

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