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Galileo for urban mobility: moving cities ahead with space data

Sergi Paniagua[1*], Josep Laborda [2], Krzysztof Kanawka[3] , Francisco Ginot Blanco[4], Charlotte van Hek[5]

1. Pildo Labs, Spain
2. Factual, Spain
3. Bluedot, Poland
4. Reby, Spain
5. UITP, International Association of Public Transport, Belgium

Abstract

Accuracy, integrity, and continuity of the geolocation signal in complex urban environments are key features to enable new mobility services in the smart city context. Galileo is the European Global Navigation Satellite System, and along with the Satellite-Based Augmentation System EGNOS, constitutes Europe's satellite navigation programme. Galileo provides improved positioning and timing information with significant positive implications for many services and users. The system has been operational since December 2016 and can be used in combination with GPS satellites (or any other constellation) via multi-constellation receivers, already a widespread, affordable market solution. This paper reports on the applications of Galileo in the urban mobility sector, based on tested use cases in the bus, tram and shared mobility domains.

Keywords: GALILEO, URBAN MOBILITY

Satellite technology and geolocation: why they matter to urban mobility

With the urban mobility landscape evolving faster than ever, the use of positioning technologies for the geolocation of vehicles and users represents a key enabler for more efficiently planning and operating mobility services. With smartphone applications, IoT technologies and innovations such as Mobility as a Service (MaaS) and shared mobility becoming more and more ubiquitous, the accuracy, integrity, and continuity of the geolocation signal in complex urban environments are key to fully deploy the potential of this evolving urban mobility landscape.

There has never been as much choice for getting around the city and as much information about public transport and other mobility services available on real time. Whichever the case, when citizens order a

taxi from a smartphone application and are able to see their position on real time, when they locate and book the closest shared car on the street, or when commuters receive real-time passenger information, estimated time of arrival and eventual disruptions, they are benefitting from satellite technologies.

The **Global Navigation Satellite System (GNSS)** refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers, which in the case of our paper are embedded into On-Board Units in vehicles, or in the users' smartphones. The receivers then use these data to determine location. Until recently, GNSS users had depended on non-civilian USA's Global Positioning System (GPS), Russia's Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and China's BeiDou Navigation Satellite Systems.

Galileo is Europe's GNSS and along with the Satellite-Based Augmentation System EGNOS (European Geostationary Navigation Overlay Service), constitutes Europe's satellite navigation programme. Together they provide a range of positioning, navigation, and timing services to users worldwide.

Galileo-enabled mass-market receivers have become widespread and are available at very competitive costs. The vast majority (76%) of current receivers on the market are multi-constellation (i.e., compatible with at least two different constellations), and 52% are capable of working with signals from all constellations [1].

The performance of GNSS is assessed using four criteria:

- Accuracy: the difference between a receiver's measured and real position, speed or time;
- Integrity: a system's capacity to provide a threshold of confidence and, in the event of an anomaly in the positioning data, an alarm;
- Continuity: a system's ability to function without interruption;
- Availability: the percentage of time a signal fulfils the above accuracy, integrity, and continuity criteria.

The incorporation of Galileo positively impacts all existing applications of GNSS in urban mobility services and opens the way for new services in the smart city context. This is mostly accomplished as multi-constellation provides increased availability —especially in challenging environments for GNSS, such as urban canyons where satellite signals from one constellation can get completely blocked by tall buildings—, improved accuracy —because there are more satellites in view allowing for better geometry—, and improved robustness —since the position is built with data from different sources, making it less vulnerable to attacks.

One of the main benefits of Galileo compared to other GNSS, is that Galileo has higher resiliency against multipath, meaning it will determine location more accurately. Multipath errors are still one of the major error sources for conventional GNSS receivers. A multipath error is caused by the reception of signals arriving not only directly from satellites, but also reflected from the local objects in the environment. Basically, a multipath error will cause your location to be less accurately determined.

Recent tests made by the EUSPA (European Union Agency for the Space Programme) with Galileo-enabled devices achieved 1-2 metres accuracy in light urban environments and a few decimetres at full open sky (in which case it is easier to determine location).

Furthermore, the Galileo system (differently from other GNSS) authenticates its satellite signals by incorporating a digital signature to the navigation data that certifies its sources. This allows Galileo users to assess the trustworthiness of the signals, making them more robust against spoofing attacks (disguising a communication from an unknown source as being from a trusted source). Some new applications and mobility services are even hard to picture becoming a reality without authenticated signals. For instance, a seamless public transport system where ticketing relies completely on the positioning data from their passengers' smartphones. In addition, an authenticated signal not only provides more robustness, but it can even serve as legal evidence of the correctness of the GNSS position for liability issues.

Therefore, with the addition of Galileo to the global GNSS constellation, risks of satellite signal failure are reduced, minimizing the severe implications could have on public transport and shared mobility services, and positively impacting all existing applications benefitting from satellite technologies.

ARIADNA EU project and Galileo

The ARIADNA project[1] (2019-2021) is a Coordination and Support Action committed to support the adoption of Galileo for public transport and urban mobility solutions by raising awareness and market uptake of its benefits among key stakeholders of the mobility ecosystem, namely decision-makers, public transport operators and authorities, setting the framework for a fruitful cooperation with technology providers, start-ups, and academia at global level.

In the end, ARIADNA aims to promote business opportunities and strategic excellence partnerships between Galileo and urban mobility actors in Europe and beyond.

One of the key objectives of the project, conducted by the ARIADNA consortium, has been the collaboration with other projects as well as mobility providers, public transport operators and urban mobility start-ups, allowing the identification and analysis of several Galileo applications and services in the urban mobility domain.

Therefore, the focus of this paper is to illustrate three specific use cases and solutions where Galileo can bring added value to enhance existing urban mobility services.

[1]Awareness Raising and capacity building Increasing ADoption of EGNSS in urbaN mobility Applications and services. http://ariadna-project.eu/

Public transportation in urban areas

The first two use cases have been identified through the collaboration of ARIADNA with the FLAMINGO Horizon 2020 project (2017 - 2020), aimed at providing comprehensive tracking and data analysis of public transportation vehicles in urban areas. The main feature of FLAMINGO was its capability to provide positioning with an accuracy better than 50 cm.

Both use cases are a result from experiments conducted by Bluedot Solutions from Poland, a FLAMINGO consortium partner, with a series of prototype IoT devices for buses and trams, with the objective to provide advanced positioning systems for city traffic, increasing safety and knowledge about the fleet operation in the city. They have been possible thanks to the combination of high precision GNSS data with inertial measurement unit (IMU) data.

The first use case is focused on the benefits of the identification of unusual behaviour patterns in the vehicles movements before it escalates into damage that ultimately can cause vehicles to be unavailable.

European cities use hundreds of buses and trams, which operate in a constantly changing environment. Some of those typical operations were so far not properly addressed by older GPS-only devices, which provided location with significant positioning error or were too expensive or complex to be adopted. Moreover, public transportation vehicles are expensive, with prices often in range of several million euro per one unit. Once these assets are integrated into typical road operation, they can suffer from damages caused by the unsatisfactory surface conditions which can contribute to the vehicle general health, causing primary damages in a number of systems as well as secondary damages result of these primary impairments. Examples of such scenarios are badly designed turns, intersections or round-abouts on streets resulting in structural stresses on the vehicles, as well as being uncomfortable or dangerous for passengers. Monitoring the acceleration and detecting suspicious anomalies can also contribute to detect damages in the road surfaces or interconnections between roads and rails. A constantly recurring anomaly in the same location could be used as an indication of possible road damage that should be considered a priority in road maintenance.

So far, information on the quality of the road is rarely collected in real-time, which may result in a scenario where multiple vehicles are being sent on the same, defective road, increasing risks of vehicles damages. With high-precision GNSS and IMU data, this problem can be identified once the road condition starts to deteriorate and thus solved faster, even before it starts to affect the public transport system in an accumulative way. In this sense, the device created by Bluedot is a calibrated IMU unit paired with a GNSS receiver which runs with near-real-time data transfer. This allows that each asset or commuter bus can detect maximum registered discrepancies paired with GNSS-originating location. Moreover, all data can be visualised within the fleet manager, so that they can quickly compare the results reported from all vehicles, identifying anomalies across the urban area to decide what kind of action may be needed.

For example, the fleet manager may send an inspector to the site to audit the possible damage, to

change the type of vehicle (i.e., to use a shorter bus, less prone to excessive sideways accelerations) or promote route changes to bypass the problematic section. In addition, the bus driver may also receive information about imposed, dynamic limitations of certain segments of the road system and be notified where, for example, it would be required for the bus to slow down. Such a system could also become fully automated or paired with AI-based algorithms, but this was not trialled in the project.

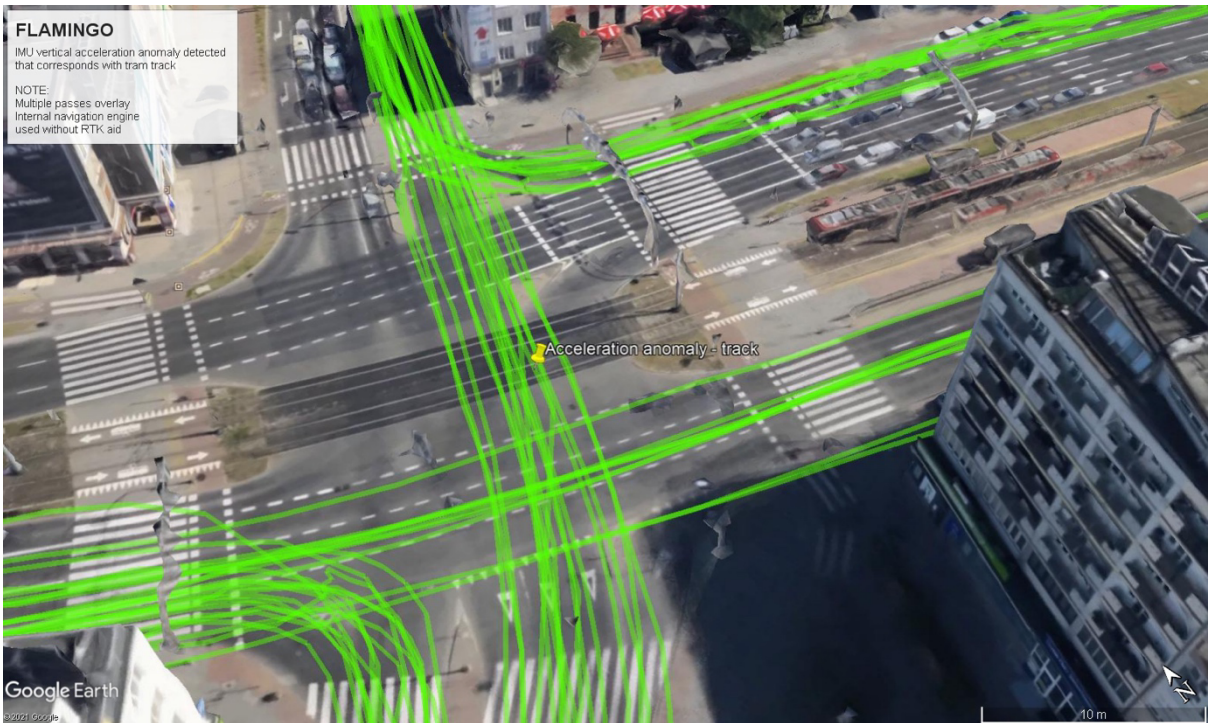

Figure 1 – IMU anomaly detected by server-side processing of the FLAMINGO data collection – data from the FLAMINGO project visualised on Google Earth (city of Gdansk, Poland)

The second use case refers to the benefits of monitoring driver's habits in order to prevent and reduce potential accidents.

The driver of any public transport vehicle, such as a bus or tram, assumes the safety and comfort of passengers as a priority. Currently, methods to continuously monitor the driver's style and habits of driving are limited, and usually such highly precise data are only available post-incident and cannot be considered as a preventive measure. In addition, almost all solutions rely on older generations of GPS receivers (typically single frequency) and thus their data is usually not reliable enough to identify key important factors that define driving habits.

The high precision of GNSS devices with embedded IMU sensors and algorithms created during the FLAMINGO project can provide valuable information, as the system is capable of near-real time data reporting offering also the possibility of further implementation of an event-driven architecture.

The verification of the acceleration and deceleration values of the IMU, paired with map data, allows the identification whether the driver is passing through crossings or roundabouts with a proper speed and acceleration and if the driver changes the lines in proper places. Furthermore, the system can directly assess if the driver drives according to the general or specific regulations. Moreover, all this

information can be stored onboard in a unit (with full sensing frequency) and on a server, which means that any changes of habits can be also detected over longer periods of time.

It could be theorized that such system paired with a dedicated AI solution could be designed to model the typical behaviour patterns of the drivers and detect deviations in driving characteristics to help prevent accidents from happening.

As a result of this monitoring activities, the manager of the public bus network could request a driver change, ask for a technical check-up of the vehicle or request a complete stop of the vehicle. In addition, if the accident had already happened, the manager could verify what was the driving style before the accident and if the system registered any abnormalities in driving patterns prior to the incident.

Figure 2 – a Gdańsk (Poland) map with overlaid 1 million points that represent individual geospatial locations collected during demonstration and testing; green circle shows the 10km range limit imposed on system by the RTK base station settings

The third use case provides evidence of the benefits of Galileo in the shared mobility business, thanks to the experience of Reby, a micro mobility company based in Barcelona which operates fleets of shared electric vehicles in twelve Spanish and Italian cities.

In the moped-sharing operation, it is paramount to always know the position of a vehicle. Therefore, every vehicle of Reby's fleet is equipped with an IoT module with geolocation capabilities. This GNSS module automatically switches between constellations to return the most accurate coordinates, using GPS, GLONASS and Galileo (the latter, providing centimetre range accuracy).

However, accuracy is not always ideal. The source of error in urban environments is mostly due to multipath fading of the received signal. Consequently, the service may be negatively impacted mainly because the probability that a user will use one of Reby's vehicles is closely related to the ease with which he/she will find it, and if he/she cannot find the vehicle, then will look for an alternative (of a competitor). In addition, Reby being a data-driven company, a great number of daily decisions are based on their own data. From an operational point of view, not locating vehicles quickly has a direct impact on the logistics and maintenance cycle. As times increases, the business incurs in additional costs. In order to reduce the location accuracy error, Reby's research and development team prepared a data pre-processing solution that improves the location accuracy in two different scenarios, during the ride and also when the vehicle is parked.

In the first scenario, when the vehicle starts the ride, the solution proposed uses DBSCAN —i.e., Density-Based Spatial Clustering of Applications with Noise, a density-based clustering non-parametric algorithm which, given a set of points in some space, groups together points that are closely packed together (points with many nearby neighbors), marking as outliers points that lie alone in low-density regions (whose nearest neighbors are too far away). This allows to find the locations where the vehicle stopped and create clusters of points and assign them to a single pair of latitude and longitude. Secondly, with this enhanced series of points, a map matching is performed, associating the position during the recording process to the road network. This approach slightly corrects most of the points and gives a clearer view of the ride route.

As we can see in Figure 3, the original points (in brown) are not line centered. In yellow we see the points corrected with map matching only, which still not don't show a unique route. Finally in blue (map matching + DBSCAN) we can see how the points are generating a route.

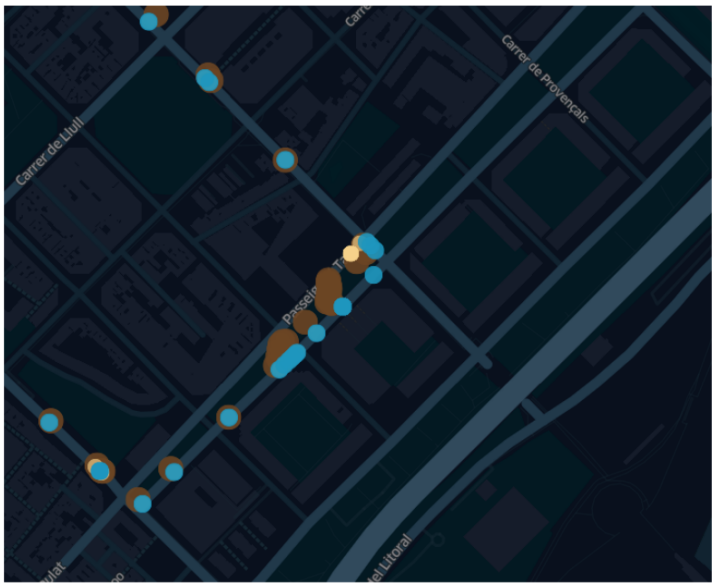

Figure 3 – Comparison: Original - Map Matching - Map Matching + DBSCAN points

For the second scenario related to parking locations, the goal of improving the accuracy of the position where a vehicle is parked is twofold. First, better accuracy means better conversion rates as users are more likely to take a trip if they can find the vehicle quickly. Second, it makes operations less costly. Therefore, reducing the time an operator takes to find a vehicle saves time, money, and emissions.

To improve the parking position, Reby associates the last available ride point to the closest parking location. Having a detailed parking location dataset is key for this method and although some city councils provide updated parking location datasets, Reby has also built their own maps from the location data of their vehicles. The distance from the rider's destination to the parking location must be under a certain threshold. Thus, only the destinations which are closer than a certain threshold of meters to the closest parking location are corrected. Reby's approach uses an adaptive method to compute this threshold. The two images below illustrate the two possible cases for the nearest parking location: the case when it can be done, and the case when it cannot.

Figure 4 – Parking association can be done

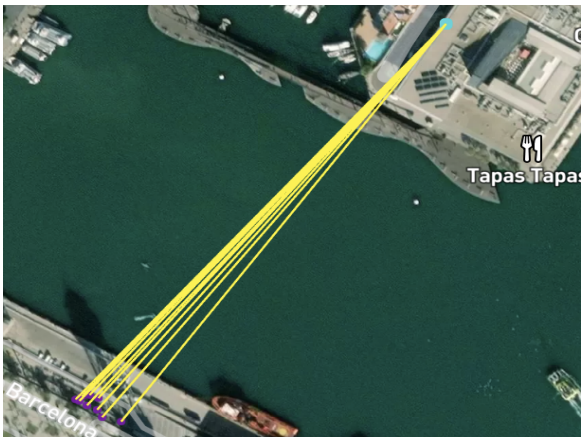

Figure 5 – Parking association can't be done

In summary, combining Galileo with other GNSS constellations overall provides greater performance of urban mobility services.

Conclusions

Overall, as illustrated by the previous use cases, multi-constellation GNSS receivers with proper data handling provide superior positioning in harsh urban conditions, playing a significant role in the mainstream adoption of urban mobility services.

Using more accurate GNSS like Galileo can increase the location accuracy, enabling users to quickly find a vehicle, the operations teams to work more efficiently, the data teams to optimise routes, determine demand clusters, and in general perform more accurate geospatial analysis. Furthermore, it enables to comply with local regulations such as designated parking areas or speed limits (e.g.,

through geofencing strategies), as well as detecting suspicious behaviours such as a vehicle being stolen or a user travelling outside the limits of the service area. Beyond the service-specific applications and use cases explained before, when Galileo-enabled mobile devices become the norm, public administrations will be able to access more insightful aggregated mobility data, thanks to the improvements in accuracy and availability enabled by Galileo. For instance, it will be easier to differentiate with which means of transport users are travelling, the moment when they transfer to a different means, and how many times they transfer during the trip.

References

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