RNI: DELENG/2005/15153
Publication: 23rd of every month
Posting: 27th/28th of every month at DPSO

No: DL(E)-01/5079/2023-25
Licensed to post without pre-payment U(E) 28/2023-25
Rs.150

www.mycoordinates.org

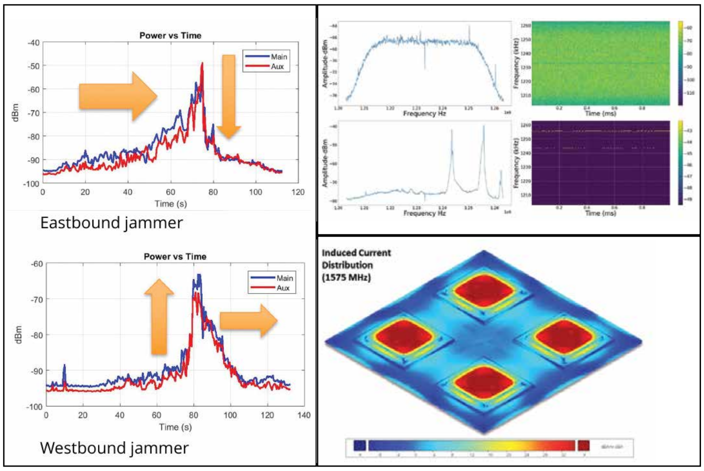
Coordinates

ISSN 0973-2136
Volume XIX, Issue 4, April 2023

THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Protecting GNSS against intentional interference

National Geospatial Policy, 2022: An urban perspective



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This issue has been made possible by the support and good wishes of the following individuals and companies
Ahmed Al-Tahmeesschi, Alessio Martinelli, Anne Marie Tobie, Arul Elango, Chiara Manno, Daniel Lopour, Filippo Rodriguez, Francesco Inzirillo, Gaetano Pastore, Giovanni Galgani, Hanaa Al Bitar, Laura Ruotsalainen, Livio Marradi, Mahavir, Marco Puccitelli, Mikko Saukkoriipi, Prabh Bedi, Rodolfo Guidi, Titti Malmivirta and Yuval B. Yossef; GPS Satsys, Riegl, SBG System, and many others.

Mailing Address
A 002, Mansara Apartments
C 9, Vasundhara Enclave
Delhi 110 096, India.
Phones +91 11 42153861, 98102 33422, 98107 24567

Email
[information] talktous@mycoordinates.org
[editorial] bal@mycoordinates.org
[advertising] sam@mycoordinates.org
[subscriptions] iwant@mycoordinates.org
Web www.mycoordinates.org

Annual subscription (12 issues)
[India] Rs.1,800* [Overseas] US$100*
*Excluding postage and handling charges

Printed and published by Sanjay Malaviya on behalf of Coordinates Media Pvt Ltd
Published at A 002 Mansara Apartments, Vasundhara Enclave, Delhi 110096, India.
Printed at Thomson Press (India) Ltd, Mathura Road, Faridabad, India

Editor Bal Krishna
Owner Coordinates Media Pvt Ltd (CMPL)

This issue of Coordinates is of 36 pages, including cover.

Genie is out

Several tech doyens have called for a six-month pause on AI chatbot research.

The UNESCO has urged the governments around the world
to implement an ethical framework for AI systems.

Italy temporarily bans ChatGPT over privacy concerns.

Few other countries are regulating, legislating or may even follow Italy's path.

An Australian mayor threatens to file defamation case against
OpenAI unless it corrects ChatGPT's false claims about him.

The potential of the AI chatbots are yet to be fully explored,

And the ramifications are yet to unfold.

While this emerging phenomena baffles the users across the world,

It seems that the genie is out of the bottle.

Bal Krishna, Editor
bal@mycoordinates.org

National Geospatial Policy, 2022: An urban perspective

A clear, methodical and scientific distinction needs to be drawn between land use and land cover, especially in the context of urban planning and development

Dr Mahavir
Former Professor and Dean (Academic), School of Planning and Architecture, New Delhi, India

Dr Prabh Bedi
CEO, Resonance Integrated Solutions Canada Inc., Canada

The geospatial industry got another impetus from Government of India on 28th December 2022 in the form of National Geospatial Policy, 2022. The policy has been received well by the industry, especially the private sector. It has been lauded for enabling the promotion of digital economy, involving private enterprises, blue economy, and taking India forward to become a world leader in global geospatial space with the best ecosystem for innovation (Government of India, 2022).

The geospatial sector has grown from a largely government owned and enabled segment to increasingly privatized industry. It is pertinent to note that, the spatial data has been created at the base level by various government bodies like Survey of India (SoI), since before Independence.

As geospatial industry matured in the country and the role of information technology became more and more embedded in various segments of the economy, the importance of geospatial information came to be realized across the government hierarchies and sectors. The realization of data as infrastructure (Mahavir and Bedi, 2012) led to the opening up of the sector from times when data could only be bought from government authorities to the most recent de-regulation of geospatial sector in 2021 (Ministry of Science and Technology, 2021). It had been stated (Majumdar and Tavawalla, 2021) that some bottlenecks still needed to be addressed to ensure a more decentralized and democratic adoption.

> It is pertinent that the Survey of India be revitalized. The dilution of its role that is stated in the policy by involvement of private sector in data creation needs to be seriously addressed, which at least in the geospatial industry is now being dominated by the international brands.

The geospatial industry as it exists today can be broadly categorized into data creators, data builders, data providers, and data users. Organizations like Indian Space Research Organisation (ISRO) and National Remote Sensing Center (NRSC) can be categorized as data creators, which use remote sensing technology to gather data. The output of these organizations, in form of satellite images and aerial photographs, is used across industries. To this, in recent years, the drone images have been added. Dominated by private sector, the use of drones and drones generated data has been facilitated by the recent Guidelines for acquiring and producing geospatial data and geospatial data services including maps, 2021 (Jayadevan, 2021). This has brought to the forefront a new method of high-resolution spatial data creation specifically for smaller areas, anticipated to serve as an input for faster decision-making in urban infrastructure and development projects.

The data builders are organizations that build maps using surveying techniques, and more recently satellite images. Survey of India (SoI) has been the key organization in this arena providing toposheets at various scales. There are other organizations like National Atlas and Thematic Mapping

Organisation (NATMO), National Bureau of Soil Survey and Land Use Planning (NBSSLUP), and schemes like National Urban Information System (NUIS) that provide sector-based value-addition to the base data, using either toposheets as the base or the images produced by data creators.

The data providers are all those organizations listed above that have been creating and building the spatial data. Traditionally, this has been done by SoI and other segment specific government bodies. In recent decades there have been attempts to aggregate this role into Spatial Data Infrastructure organizations at national and state levels like National Spatial Data Infrastructure (NSDI), Delhi State Spatial Data Infrastructure (DSSDI) and National Urban Information System (NUIS).

The last category is that of data users, consisting of government bodies, academia and research organizations, NGOs, and private organizations across industries. The data creators, builders, and providers till recent years have been solely government bodies. The role of private organizations and consultants until the recent years has been limited to sub-contracted projects and spatial and/or non-spatial surveys or those organizations that have provided technology in form of hardware and software to various data creators, builders, providers as well as users.

As stated, the role of private enterprise in mapping sector commenced in the allied field of surveying which largely became inputs to updating base maps. With advancements in information technology, private sector led another ancillary segment of the mapping industry, namely, the software and hardware, an industry that emerged and gradually branched into training and application development on the respective proprietary software platforms. In time, these private companies ventured into providing consulting services (using proprietary software) to government organizations. This came to fore with the realization that toposheets required updates using surveying techniques and/ or derived inputs from then aerial photographs and later satellite images. This became an important step in keeping data updated specially as most updated data was a vital input in plan making and led to speedier map/ plan production. At each of these stages, the capacity of government authorities was not substantially upskilled, increasing the dependencies on the private enterprises.

Building of spatial data by the private organizations using Survey of India toposheets for numerous urban planning and development projects came into foray at a much later stage wherein the images for updates were required to be procured from government agencies, namely data creators. This saw numerous consultants and private organizations foray into the business of digitization and updating the base data of Survey of India using satellite images.

In the geospatial industry, since early stages, international, proprietary and privately developed software has dominated the geospatial data and software development segment (Sardana, 2022 and FICCI, undated). The software have developed from standalone versions to client/ server architecture to on-the-cloud versions, where both the data and software may reside in some remote server, maybe outside the country, which brings the question of security to the fore. The recent de-regulations in the geospatial industry to involve the private sector to the stated extent actuates to willingly giving away the data, keeping nearly nothing secure, concern that has been voice by others in the industry as well (Katoch, 2023 and Ajaykumar, 2022).

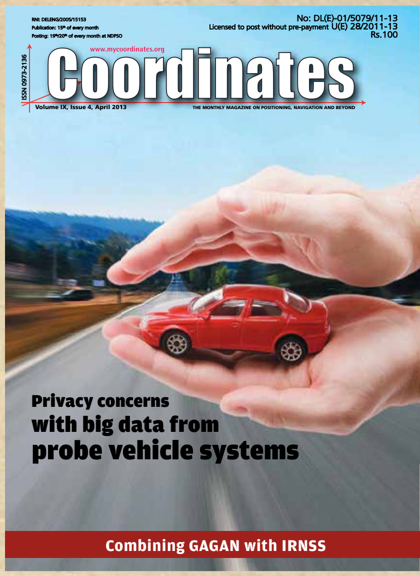
In the past few months since the release of the National Geospatial Policy, much has been written in terms of its benefits and has been welcomed especially by the private sector (Siddiqui, 2022 and Geospatial World, 2023). The elimination of the requirement of seeking permissions and even scrutiny has been much welcomed. The Policy states that companies can self-attest, confirming to government guidelines without actually having to be monitored by a government agency (Government of India, 2022).

The Policy limits the role of Survey of India being “generation and maintenance of minimal foundational data and core functions”, “maintaining geodetic reference frame, orthoimagery, elevation, functional areas and geographical names… collaboration with…private sector”. The Policy encourages the “ministries to engage with private sector…for creation and development of geospatial data”. The Policy further states that Survey of India would be transformed into a fully civilian organization. The role of the private sector is emphasised in the Policy in playing a “key role in creation and maintenance of geospatial and mapping infrastructures, innovation and process improvements and monetization of geospatial data”. Diminishing the role of Survey of India and increasing the role of private enterprises will have a far-reaching impact on the security of the country.

Many parallels can be drawn between the trajectory that the emerging geospatial industry is taking and that of the urban planning and development sector of the country. It has been stated in numerous instances that the delay in completion of the development plans had always been due to no data or long time taken in creating and updating the data. This process initially consisted of conducting surveys followed by updating base map keeping SoI toposheets as the bases, which though have been accurate but, in many instances, outdated. Later, after the availability of satellite images for public use, lengthy processes in securing permissions from Ministry of Defence to obtain these images was cited at the cause for delays in updating maps. Data constitutes a major and vital aspect of any development plan. In the recent years, under various missions, these plans, especially for small and medium towns, have been prepared in under 4 to 6 months. The speed up has surely been due to easier availability of satellite data either from government or private agencies to update the base data. NUIS has been an endeavour to bridge this data

In Coordinates

10 years before...



mycoordinates.org/vol-9-issue-4-April-2013

Privacy concerns with big data from probe vehicle systems

Masaaki SATO, PhD
Visiting Research Fellow, KEIO-NUS CUTE Center, National University of Singapore, Singapore

Probe vehicle systems have become the new focus on 'BIG DATA from Vehicle' sharing infrastructure. Basically, a probe vehicle system processes the data statistically to generate useful information, so that probe vehicle systems don't require data subject identification. On the other hand, many probe vehicle systems need consecutive data group for high quality service. Moreover, the perfect anonymity requires a high cost that is unrealistic in terms of cost-effectiveness.

Using satellite altimetry to monitor and determine sea level

Dr Dexter Davis and Dr Michael Sutherland
Department of Geomatics Engineering and Land Management Faculty of Engineering University of the West Indies St. Augustine, Trinidad and Tobago

The paper outlines how satellite altimetry can be used as a method to fill the gaps in available mean sea level data in the Caribbean region. The technique is examined in its utility to effectively monitor and compute MSL, and subsequently derive sea level rise (SLR) rates for the Caribbean

Combining GAGAN with IRNSS

Vyasaraj Guru Rao
University of Calgary, Canada & Accord Software & Systems Pvt Ltd, Bangalore, India

Gérard Lachapelle
Professor of Geomatics Engineering, University of Calgary, Canada

Till date the navigation and the augmentation system (satellites) have been different in every GNSS. This research explored the possibility of combining the GAGAN (SBAS) with IRNSS. In addition, with new messages included, the proposed SBAS can also transmit the corrections for IRNSS. From a regional perspective, this proposal provides the optimal coverage, more advantages (for example, availability, reduced satellite count, SBAS of IRNSS) is achieved with less (without additional) satellites.

Mitigating the systematic errors of e-GPS leveling

Lao-Sheng Lin
Associate Professor, Department of Land Economics National Chengchi University, Taiwan

In this paper, it is found that the systematic errors of e-GPS leveling can be mitigated effectively if BP&CFM is applied, using the data sets from Tainan City. However, if the test area is increased, such as the southern region of Taiwan, and even extended to the entire island of Taiwan, the BP & CFM algorithm, is still valid? Remains to be further validated in the future.

Investigating effects in GPS time series

Ismail SANLIOGLU and Tahsin KARA
Geomatics Department, Selcuk University, Architecture and Engineering Faculty, Aladdin Keykubad Campus, Konya, Turkey

In this study, when height (Up) components of permanent GPS stations' coordinates are studied, seasonal effects are observed and it is researched if these Up constitutes have a relationship with temperature and pressure gap, by creating a national level urban information system, which is a unique concept worldwide (Bedi and Mahavir, 2013). In recent times, projects have been based on private data sources that may not have been as accurate as the SoI toposheets.

Under the situation, the quality of data and analysis needs a thorough review. The plans in many instances have emerged to being replicas amongst a bunch of cities. The role of the state and local authorities being limited to accepting and approving the plans prepared by the private organisations rather than being involved in the preparation of the plan. Last 20-25 years have seen this trend of sub-contracting the task of preparation of development, infrastructure, and related plans to private agencies to complete the task in tight deadlines. The privatized and hasty plan preparations may have indirectly landed us in situations of waterlogging and flooding of the urban areas every monsoon, unwanted sprawl, extreme densities, poor sanitation, and other vagaries of privately planned and developed urban India.

On the other hand, the urban planning field has grown from a stage where plans were made only for large metropolitan cities to have the plans for small and medium towns. This has been achieved due to Government of India schemes as AMRUT and the trainings and hand holding sessions held for building the capacity of planners in various government authorities at local levels with the involvement of Town and Country Planning Organisation (TCPO), Survey of India and NSRC (Mahavir, Surendra and Khan, 2020).

The Policy states the use of very high-resolution satellite images (5-10 cm resolution) for urban areas. Is this really a requirement for preparing a development plan or a neighborhood plan or an infrastructure plan? Would emphasis on excessive data lead to making of good plans and good implementation? A clear, methodical and scientific distinction needs to be drawn between land use and land cover, especially in the context of urban planning and development. It needs to be understood that data and maps are one part of plan making, in which the resolution and granularity of data is important. Excessive detail in data would lead to unnecessary distractions and deviations. Plan making is integration of multifaceted concepts of space, environment, socio-cultural and economic conditions that lead to a plan for the future of an area. The Policy talks about National Digital Twins of major cities and towns, with no reference to City Digital Twins in the context of Smart Cities Mission or 4IR.

Urban India is projected to house 40 percent of country's population by 2030 (United Nations, 2019). The key bodies of urban planning and development at the national level, Ministry of Housing and Urban Affairs (MoHUA) and its advisory, Town and Country Planning Organisation (TCPO), have no representation in the National Geospatial Policy, 2022. The role of MoHUA seems limited to providing of certain layers including addresses, some of which may not be in their direct domain. On the contrary, one of the leading planning schools should be a Centre of Excellence in the field of application of geospatial technologies in planning.

Till the time spatial data was created using non-digital techniques or manual methods, this sector was completely owned and run by the government. With gradual digitalization of the methods of creating data, the role of private sector has substantially increased. When the methods of creating maps was manual, the tools, like surveying instruments, printers, and ancillary hardware to create the maps was provided by private sector, but the key task of creating the map remained in the government domain. In these modern times, the tools for creating the maps (software and hardware) are still being provided by the private sector, then why is the task of creating maps being contracted out to the private organizations? Is there a learning here, to keep the core data building activity in the domain of the government totally?

Instances can be drawn from World over, where data creation and building at national level is the sole responsibility of the government, as illustrated in the table below:

A lacuna had got created due to the slower pace of capacity enhancement and training of planners with the various government agencies at state and local levels. With the help of the national level missions, the gap has been reduced. However, much still needs to be done at a continuous and ongoing mode in building and enhancing the capacity of the planners across the hierarchy to keep their technology skills relevant in the rapidly evolving technological environment. This is essential to enable the planners to handle the new and emerging technologies and concepts in plan-making. This will in time negate the need for hiring international experts in project management for urban planning and infrastructure development projects.

It needs to be mentioned that the geospatial industry has largely grown from the needs of data and allied services in primarily the defence, urban and infrastructure segment and sub-contracting of government tasks is a similitude between the urban planning/ development and geospatial industries.

At this juncture of geospatial industry's growth in the country, it is pertinent that the Survey of India be revitalized. The dilution of its role that is stated in the policy by involvement of private sector in data creation needs to be seriously addressed, which at least in the geospatial industry is now being dominated by the international brands. The emerging trajectory appears to be similar to what has happened in the field of urban planning and development. To take an analogy, the urban sector has been by and by privatized through various schemes and missions, the execution of which was thought to be in excess of the capabilities of the urban planning and management authorities of government. The tasks that are the core of an urban planning professional as preparation of the development plans have been gradually sub-contracted to the private agencies – international and national. Similarly, the project management consultancy of most missions and schemes have been contracted to intranational big brands.

Table 1: Base national level spatial data creation agencies in different countries, 2016

Sl. No.	Country	Key organisation responsible
1	Australia	Geoscience Australia
2	Brazil	Brazilian Institute of Geography and Statistics
3	Canada	Natural Resources Canada
4	China	National Administration of Surveying, Mapping and Geoinformation
5	Colombia	Geographic Institute Agustín Codazzi
6	Denmark	Danish Geodata Agency
7	France	Institut Géographique National
8	Germany	Federal Agency for Cartography and Geodesy
9	Great Britain	Ordinance Survey
10	Guatemala	National Geographic Institute of Guatemala
11	Japan	The Geospatial Information Authority of Japan
12	Kenya	Survey of Kenya
13	Mexico	Instituto Nacional de Estadística y Geographía,
14	New Zealand	Land Information New Zealand
15	Russia	Federal Service for State Registration, Cadastre and Cartography
16	Saudi Arabia	General Commission for Survey
17	Singapore	Singapore Land Authority
18	South Africa	Chief Directorate: National Geo-spatial Information
19	The Netherlands	Kadaster
20	USA	United States Geological Survey

Source: https://en.wikipedia.org/wiki/National_mapping_agency#:~:text=A%20national%20mapping%20agency%20is,also%20deal%20with%20cadastral%20matters (2016)

The question that needs to be addressed is why at each stage, government agencies have not been amply strengthened and enhanced in their capacities to address the inadequacies that have arisen out of the rapidly evolving technological domain.

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Protecting GNSS against intentional interference

This paper offers a state-of-the-art review of several proposed methods for interference detection and mitigation with solutions ranging from traditional to machine learning-based approaches.

Arul Elango
Department of Computer Science, University of Helsinki, Finland

Ahmed Al-Tahmeesschi
Department of Computer Science, University of Helsinki, Finland

Mikko Saukkoriipi
Department of Computer Science, University of Helsinki, Finland

Titti Malmivirta
Department of Computer Science, University of Helsinki, Finland

Laura Ruotsalainen
Department of Computer Science, University of Helsinki, Finland

Abstract

The vulnerabilities associated with modern systems relying on Global Navigation Satellite Systems (GNSS) due to intentional and unintentional interference is an increasing threat. Since radio frequency interference (RFI) significantly degrades the performance of a GNSS receiver. Several traditional critical applications such as aviation, maritime and rail transport systems to more recent applications such as autonomous vehicles, can be severely affected by such undetected nor mitigated RFIs. More- over, critical infrastructures such as power supply and money transfer, are becoming more and more dependent on the accurate timing information provided by GNSS. Thus, interference detection and management techniques are crucial to be utilised in order to reduce interference effects. This paper offers a state-of-the-art review of several proposed methods for interference detection and mitigation with solutions ranging from traditional to machine learning-based approaches. In addition, to be able to characterise the RFI threats and develop mitigation techniques, it is essential to monitor RFI systematically and share recorded data with interested entities. Therefore, three GNSS threat monitoring systems are briefly described. This White paper is a compilation of the seminar presentations given at a seminar on ”Protecting GNSS against intentional interference” in March 2022 in Finland.

Introduction

Modern society, especially its critical infrastructure, is becoming more and more reliant on accurate and reliable Position, Velocity and Timing (PVT) information obtained using Global Navigation Satellite Systems (GNSS). GNSS signals travel more than 20000 km from the satellite signal transmitter in space to the user receiver on Earth. Radio waves disperse energy as they propagate; therefore the signals are very weak and vulnerable to interference when they reach the receiver. Interference caused by the atmosphere and signal reflections on the ground have been active research areas already for decades. Intentional interference, namely operations deliberately performed by humans for interfering with GNSS signals, is a continuously increasing problem. Its incidence is anticipated to increase with the increase of number and relevance of the applications relying on GNSS.

Basics of GNSS positioning

GNSS encompass the United States Global Positioning System (GPS), the Russian GLONASS, Chinese COMPASS/BeiDou and the European Galileo systems. In GNSS based positioning the traverse time of a signal from the satellite to the user receiver antenna is estimated. When this time is multiplied by the speed of light a geometric range between the satellite and the user is obtained. In an ideal case, measurements from three satellites would provide an accurate three dimensional position of the user. In reality, the measurements are erroneous, the main error source being the timing errors between the receiver clock and the satellite clock from the system time. Therefore the measured range is called the pseudorange. The satellite clocks are precise and synchronized by the ground control segment of the system. However, the clocks in the user receivers are low-cost with typically a large timing error which has to be estimated as a parameter in the navigation solution. Observations from at least four satellites are needed for three dimensional positioning, namely the fourth observation is used for resolving the receiver clock error. Any electromagnetic source interacting with the signals is interfering with the previously mentioned process of estimating the traverse time. In the atmosphere, mainly in the ionospheric layer, electron concentration causes delays in signal propagation. Signal reflections on the ground, when added to the line-of-sight signals from the satellites, cause self-interference to the signal called multipath. Intentional interference is the most harmful type of interference because it is specifically designed to interfere with GNSS operations and will be discussed a bit in more detail in the following section and throughout this document.

Intentional Interference

Intentional interference, called either jamming or spoofing depending on the method of implementation and effect on the GNSS signal, deteriorates the obtained PVT solution significantly or completely denies its computation. Jam ming means transmission of radio frequency energy at some of the GNSS frequency bands which masks GNSS signals at the related band with noise and thereby prevent the PVT computation [Dovis, 2015]. Although the use of jammers, i.e., equipment used for transmitting a jamming signal, are illegal in most of the countries, many people still use them for the protection of personal privacy. Personal privacy protection in this context means preventing the operation of GNSS receiver that could track its own location and transmit the information to for example the employer monitoring the working time or place [Pullen and Gao, 2012]. Jammers transmit signals with power and characteristics disturbing acquisition and tracking of GNSS signals [Mitch et al., 2011]. The use of easy-access low-cost jammers results in degraded positioning accuracy or total loss of GNSS signals and, therefore, may cause serious damage if the jamming signals are not properly detected and their effects mitigated. In addition to privacy protection purposes, intentional interference is caused by political activists with political agenda, cybercriminals for financial purposes and foreign states to damage others' systems ([Richter, 2022], presentation). These latter groups doing for criminal purposes have usually higher capabilities and therefore create more significant threat for the GNSS dependent systems. Spoofing, in turn, means the malicious transmission of counterfeit GNSS-like signals and fools the receiver to output an erroneous PVT solution. The greatest danger of spoofing is that its occurrence can be difficult to detect. Fortunately, it is so difficult to be implemented unobtrusively that it cannot be done with off-the-shelf devices without special expertise. In order to be able to create a credible spoofing attack one must be able to generate true GNSS signals including data, modulation and timing, maintain time synchronization close to true GNSS time and adapt the signal power levels to match those of the true signals ([S¨oderholm, 2022], presentation).

> Intentional interference, namely operations deliberately performed by humans for interfering with GNSS signals, is a continuously increasing problem. Its incidence is anticipated to increase with the increase of number and relevance of the applications relying on GNSS

It should be noted, that some radio devices, such as amateur radio and mili tary systems, cause natural ”jamming” for the GNSS signals ([S¨oderholm, 2022], presentation). In addition to interference, GNSS systems can fail such as Galileo ground system atomic clock failure in December 2020, have created interference to GNSS ([Richter, 2022], presentation).

Contents and Organization of this White Paper

In order to secure the critical infrastructure and assure continuous availability of GNSS, all forms of interference have to be detected and their impact on GNSS-based systems mitigated. This White Paper has

Table 1: List of presentations

Title	Presenter	A liation
Using the Swedish CORS Network to detect GNSS interference, results from tests and measurements	Mikael Alexandersson	FOI
R&D Activities on Resilient PNT at Finnish Geospatial Research Institute	Zahidul Bhuiyan	FGI
PNT& GNSS Testing Techniques to Mitigate Risk	Robert Burke	Orolia
GNSS anomaly monitoring	Arul Elango	University of Helsinki
European Union's Galileo and its PRS	Jari Hänninen	Traficom
GNSS interference by space weather storms	Kirsti Kauristie	FMI
SWEPOS data quality monitoring – GNSS signal interference and disturbance monitoring system	Kibrom Ebuy Abraha	Lantmäteriet
Interference detection, localization, and mitigation in GNSS	Elena Simona Lohan	Tampere University
Jammer ngerprinting	Titti Malmivirta	Univeristy of Helsinki
The ARFIDAAS system design and operation	Aiden Morrison	SINTEF
GNSS – Threats and Countermeasures	Philipp Richter	u-blox
Advanced RFI Detection, Analysis and Alerting System II (ARFIDAAS II)	Laura Ruotsalainen	University of Helsinki
GNSS jamming & spoofing attacks, techniques, countermeasures	Stefan Söderholm	Septentrio
Analysis of a full year of multi-band RFI data from multiple sites in Europe	Nadia Sokolova	SINTEF

been compiled based on presentations given at the ”Protecting GNSS against intentional interference” seminar, held on 24.3.2022 at the University of Helsinki. The presentations discussed the state-of-the-art activities related to GNSS vulnerabilities in Nordic countries.

The impact and detection of interference has been discussed widely in the literature, e.g. [Guo et al., 2021] for ionospheric effects, [Borio et al., 2013] for jamming and [Psiaki et al., 2014] for spoofing. However, current detection methods are not sufficient for the ever-evolving interference attacks and society’s growing dependence on GNSS. Therefore, Section 2 of this document will look into most recent methods for detecting the interference, unintentional (Section 2.1) and intentional (Section 2.2). Section 2.2 will also go through methods for identifying the specific jamming device in order to encounter its use. Counter- measures to protect the critical infrastructure will be discussed in Section 3 and the deployment of large scale interference monitoring infrastructure in Section 4. The document will summarize the main findings in Section 5.

Interference detection

A GNSS radio receiver usually consists of two main parts: the analog and the digital part. The analog part includes the antenna and the radio front-end (RFE). The RFE is responsible for amplifying the weak signal received by the antenna, filtering it by a band-pass filter to minimize out-of-band contributions and down-converting it to Intermediate Frequency (IF). Finally, the Analog-to- Digital Converter (ADC) converts the analog signal to a digital version, with an Automatic Gain Control (AGC) lower quantization losses apparent in the digitization process by automatically adjusting the signal dynamics.

The digital part of the GNSS receiver is processing the digitized signal to obtain a PVT solution. Figure 1 shows the GNSS receiver’s digital processing blocks. Acquisition block detects the signal presence and gives a rough estimate of the two parameters required in the process, code delay and Doppler shift. When these are obtained, processing transfers to the tracking stage, where the code delay and Doppler shift estimates are fined down. Tracking outputs are monitored by the signal monitoring block, which also computes the signal quality measures, Carrier-to-Noise (C/N_0) values. Tracking provides signal observations called carrier phases and pseudoranges, which together with the navigation data information (satellite parameters and time of the signal transmission) packed into the signal, are used for computing the PVT solution at the navigation block.

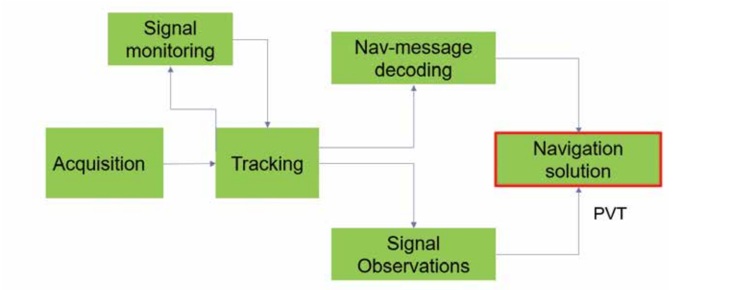

Figure 1: GNSS receiver’s processing blocks

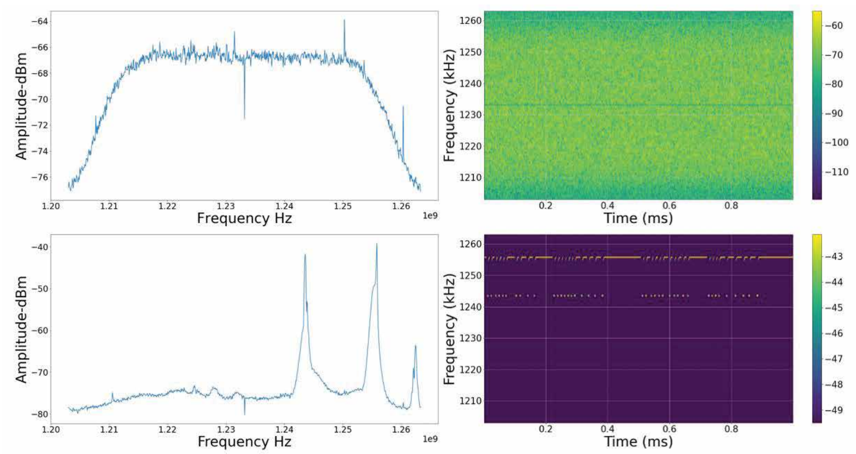

Figure 2: Original GNSS signal (top) and jammed signal (bottom) spectrum (left) and time-frequency (right) plots ([Elango, 2022], presentation).

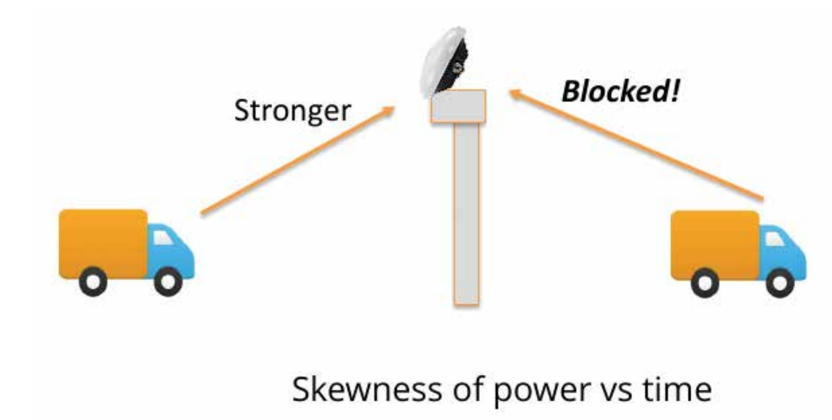

Figure 3: Interference source inside truck approaching antenna from left ([S¨oderholm, 2022], presentation). The jamming signal gets stronger when the source approaches the antenna and decreases fast when a tilted choke-ring antenna blocking the signals from below is used.

Detecting unintentional interference

As discussed before, concentration of free electrons in the atmosphere, specifically ionosphere, degrade the GNSS signal and therefore their effect has to be compensated for. When the positioning solution may be computed using signals at more than one GNSS frequency band, the ionospheric effect can be cancelled out, and in the case of only single frequency it can be modelled and its impact can be reduced. However, sometimes existing electron density irregularities disrupt the signal propagation and introduce scintillation, which means fluctuating signal's amplitude and phase [Dovis, 2015]. The extent and effect of scintillation is dependent on solar and geomagnetic activity, geographical location, time and signal frequency. For example day and night variation on the electron density may be 100 fold, and 10 fold according to solar cycle ([Kauristie, 2022], presentation). The most feasible method for detecting GNSS scintillation is the use of a dense GNSS receiver network, where the network GNSS stations are static and provide scintillation indices and other observables indicating the signal quality. Some networks provide also near-real-time data, for both research and operational use.

Detecting intentional interference

Jamming deteriorates the GNSS signal. Figure 2 shows the spectrum (left) of the original GNSS signal (top) and jammed signal (bottom) and time-frequency plots for the signals (right), respectively. Detection of the presence of a jam ming signal is crucial for being able to protect the GNSS signal reception and provision of the PVT solution. Interference detection methods can be classified into domain-specific techniques and generic techniques. Domain-specific refers to implementation of methods in specific receiver stage (front-end, acquisition, tracking or navigation techniques) ([Lohan, 2022], presentation). The front-end specific methods include for example monitoring the AGC level changes, acquisition looking at time-based and frequency-based transforms, tracking monitoring the C/N_0 levels and navigation correlation of propagation-dependent observables and consistency checks With additional sensors. Generic techniques include techniques like using machine learning for anomaly detection or radio frequency fingerprinting.

Jammer fingerprinting

Radio frequency fingerprinting refers to identifying radio transmitters based on unique signal distortions. The distortions are caused by irregularities in hardware components in signal processing chains. The distortions are unique to each device, which makes it possible to use radio frequency fingerprinting to detect spoofing ([Lohan, 2022], presentation) as well as identify individual jamming devices. While commonly used cheap jammers tend to not have very complex signal processing chains, the signals from similar jammer devices can and do still vary. Machine learning has provided good performance in classifying individual jammers ([Malmivirta, 2022].

In addition to identifying the sources of interference, it is also important to be able to localize them or find the signal direction in order to stop such harmful activities. Multi-antenna arrays can be used for localization or direction finding ([Lohan, 2022], presentation). An example of jammer direction sensing was presented by Stefan Söderholm ([Söderholm, 2022], presentation). Dual-antenna receiver was placed on a highway with several lanes. Direction detection method used was based on power changes in signals as a function of time. This was done by directing one antenna to face left figure 3 so that it received stronger signals when interference source was approaching from left. After the signal source has passed the antenna the signal power level decreases rapidly. This is due to the use of a tilted professional grade choke-ring antenna, which is implemented in a way that it blocks the signals arriving from the below the antenna. However, as the antenna is tilted, the "below" is actually pointing to right of the figure.

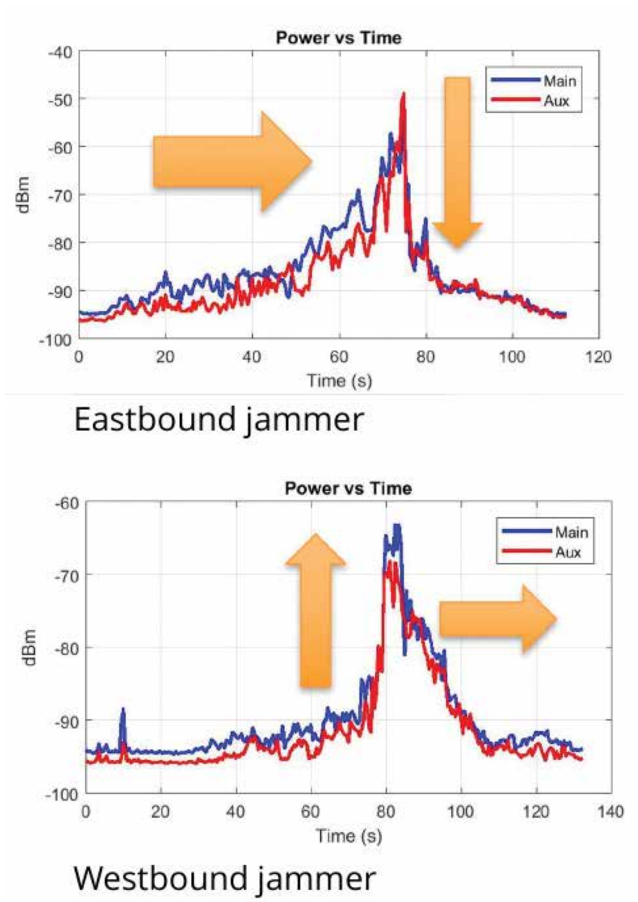

Figure 4: Jammer direction detection: signal power level changes as function of time as interference source passes antennas ([Söderholm, 2022], presentation). Up: jamming source is arriving from left, assigned here as the east direction and the power level increasing while approaching the antenna at the time 75 s and decreasing rapidly. Down: similar phenomena may be observed while the jamming source is approaching the same antenna setup from west.

Direction of the source can be seen from power changes in signals as seen in figure 4. Upper graph in figure 4 shows the signal power as a function of time when interference source is carried by a truck arriving from the left, where we consider the left side of the figure being east direction. The figure shows that when the interference source approaches the antenna, the signal power level rises slowly. Same can be seen in lower graph of figure 4 plotting the change of the jamming signal power level when the source is westbound.

GNSS anomaly detection

Anomaly means different or abnormal, in GNSS domain we can consider anomalies all features in the signal that are caused by a signal degradation source. Thereby, GNSS anomaly detection means the detection of both unintentional and intentional interference. The goal is to both observe that something is wrong with the signal and in the best case to classify its source. At present, anomaly detection provides promising results when machine learning and especially deep learning based methods are used.

The conventional deep learning methods, usually based on neural networks, ignore the temporal domain, which is not very feasible in the case of navigation data. Long Short Term Memory (LSTM) methods are so called recurrent models, which process the data as time sequences. An autoencoder is an unsupervised neural network able to learn efficient codings of unlabelled data. It learns a representation for the input data by training the neural network to ignore noise. Autoencoder is comprised of an encoder function, which converts the input data into a different representation, and a decoder function, which converts the new representation back into the original format. Autoencoders may be realized with various neural network architectures. To accommodate for temporal correlations in the data, the encoder and decoder are implemented using the LSTM architecture. In anomaly detection, encoder section first modifies the data into a time-dependent sequence, preserving only the most important features of the data. The decoder then modifies the data back to the original format. This back-and-forth editing will result in an error that will be minimized. The training data is clean, meaning it has no anomalies. If a beforehand set threshold is exceeded when the algorithm uses real data, anomalies are declared.

In general, part of the GNSS signal is considered to be anomalous in comparison to the whole GNSS signal [S. Wang, 2021]. In addition, for the time domain representation of the GNSS signal, signal behaviour changes and cannot be easily visualized. Therefore, frequency domain representation is utilized for anomaly detection ([Elango, 2022], presentation). The method which is specific to deal with time series is the LSTM which falls in the category of supervised deep learning method [Farshchi et al., 2018].

An autoencoder network comprises of two parts: an input layer (endcoder) and an output layer (decoder). The encoder block compresses the N-dimensional GNSS data into an X-dimensional code (where X < N), which contains most of the features carried in the input. The decoder, reconstructs the input from the lower-dimensional code (also refereed to in the literature as latent space representation). The way one can use trained autoencoders for anomaly detection is that in normal conditions, when normal signal is fed into the network, it can only reconstruct the signal that does not include abnormalities. If the error between the original signal and the reconstructed signal is small then the data containing anomalies can be used to recognize the changes in the original signal. In figure 5 initially the signal of interest (GPS signal) is fed to the network so that the output layer could be able to reproduce the same GPS signal but when jamming signal is included (continuous wave interference (CWI) in our case) the root mean square error (RMSE) between the input and the output is calculated if that error exceeds the predefined threshold then it is spotted as anomaly region as indicated in red coloured region at the top right hand side of figure 5.

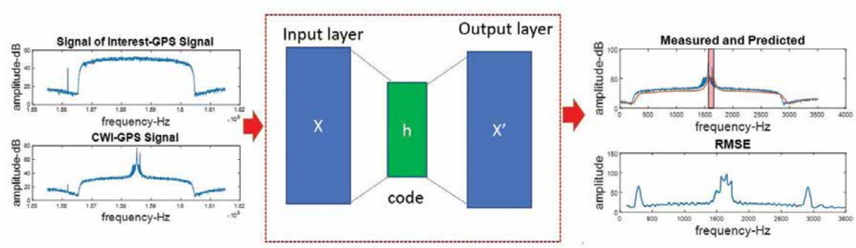

Figure 5: LSTM Autoencoder based GNSS Anomaly detection ([Elango, 2022], presentation).

GNSS interference research and development requires the use of simulated data. Many of the interference events are rare and difficult to be captured from the real signal data, and as the research is still actively ongoing their identification and correct classification might not be doable. Orolia Skydel GNSS signal simulator ([Burke, 2022], presentation) provides not only simulating the different kinds of jamming, spoofing and multipath signals but also support for multiple technologies such as GNSS Augmentations, RTK, Low Earth Orbiting (LEO) Satellite simulations. Orolia Skydel uses Graphical Processing Unit (GPU) accelerated computing to create GNSS/RF signals digitally and software defined radios (SDR) to output the RF. Another salient feature of this simulator is that it provides an intuitive application program interface (API) to configure the simulator.

Counter measures for interference

GNSS interference mitigation techniques can be roughly divided into five categories; signal processing means [Ferrara et al., 2018] antenna configuration- based methods, encryption of signals, sensor integration, and system deployment related approaches. This section

discusses the four first categories, system deployment related approaches, namely interference monitoring infrastructures, are discussed in the following section.

Signal processing based interference mitigation

Signal processing based interference mitigation may be grouped into frequency-domain and time-domain techniques [Dovis, 2015]. Interference mitigation using signal processing means, namely filtering, is best to be performed in the frequency-domain. Two of the most feasible filtering methods are called Notch and Frequency Domain Adapt Filtering (FDAF) [Falletti et al., 2020]. They are both able to adjust at some extent to the situation, where the interfering signal changes its spectral characteristics in time. Although the processing of the signal in the time-domain is feasible for the interference detection purposes, it often is not for mitigation as the interfering signal is usually mixed with the original signal.

Antenna configuration-based mitigation

Antenna polarization defines the geometrical orientation of the oscillations of the wave. To maximize the received signal strength, the polarization of the receiving GNSS antenna must match the transmitted signal. GPS satellites transmit signals in the form of Right-Hand Circularly Polarized (RHCP) wave and the polarization may change from right to left when the signal is reflected from obstacles. As a result, multipath effects will be diminished in the pre-processing stage. The observation of GPS signal using right hand and left-hand circular polarization antennas will help us better understand the characteristics of multipath GNSS signals and thus mitigate their effects [Manandhar et al., 2004]. This is achieved by introducing left hand polarization to handle NLOS signals to nullify the effects of multipath. Nevertheless, the mitigation effectiveness on satellite visibility and may not be enough for treating all the kind of threats. In the case of jamming, adaptive antenna systems and null steering (the use of spatial signal processing for nulling the interference) antennas provide mitigation ([Richter, 2022], presentation). Spoofing mitigation may be done by using antenna arrays for angle of arrival (AoA) detection and thereby evaluating if the signals are really coming from the space or falsely from the ground.

Table 2: Galileo signal lexicon and signals used by different Galileo services.

Frequency Band	Carrier Frequency (MHz)	OS	HAS	PRS
E1	1575.420	✓	×	✓
E5	1191.795	✓	×	×
E6	1278.750	×	✓	✓

> One emerging technology for error calibration is the use of visual perception. Visual sensors, i.e., cameras, are feasible instruments for constricting the growth of the errors and are also resistant to GNSS interference. Deeply-coupled GNSS, inertial navigation system (INS) and vision fusion has proven to be a feasible method for interference mitigation Integration

European Union's Galileo

New GNSS systems provide system based means for interference mitigation. The best example of such is Europe's own Galileo system's Public Regulated Service (PRS) which will provide the European authorities protection against GNSS spoofing.

Galileo is an entirely civilian global navigation system managed by the European Union (EU) and the European Space Agency (ESA). In the management of Galileo, the EU is responsible for the legal and political issues, and ESA manages the technological development. Galileo has been designed to be open, global, and highly reliable while being completely independent of the other satellite systems. The Galileo project contracts were signed in 1999, and the declaration of Galileo's initial service happened in December 2016. While Galileo is an independent satellite navigation system, it was not designed to replace or compete with other global navigation systems. Instead, it is designed to be interoperable with them while offering complete sovereignty.

Once Galileo is fully operational, it will offer four services [Gal, 2021]. These are Open Service (OS), High Accuracy Service (HAS), Public Regulated Service (PRS), and the Search and Rescue Service (SAR). OS is the conventional navigation service provided by Galileo globally and free of charge and directed at mass markets requiring meter level accuracy. HAS, on the other hand, is aimed at professional or commercial applications requiring centimeter level performance, which is higher than offered by the OS. It will be offered globally and free of charge.

SAR/Galileo is EU's contribution to Cospas-Sarsat, an international satellite-based search and rescue distress alert detection system. SAR/Galileo is two-way, meaning it forwards the distress signals to the relevant rescue authorities and returns an automated acknowledgement message back to the user in distress [Sar, 2021]. The carrier frequencies of OS, HAS and PRS are introduced in table 2. High precision and reliable timing are critical in satellite navigation. To meet these requirement, each Galileo satellite has four high-precision atomic clocks. Two of these are Rubidium Atomic Frequency Standard (RAFS) clocks with a precision of 10 ns per day. The other two are Passive Hydrogen Maser (PHM) clocks with a precision of 1 ns per day. The RAFS clocks are used to secure short-term stability, while the PHM clocks guarantee short and long-term stability [Hofmann-Wellenhof et al., 2007].

Even though Galileo is relatively new, and the first Galileo-enabled mobile phone came to market in 2016, it is already widely used in civilian applications. Currently there are over 3 billion Galileo-enabled mobile phones and over 15 million Galileo-equipped cars ([H¨anninen, 2022], updated post presentation).

Galileo Public Regulated Service (PRS)

PRS is an encrypted navigation service for government-authorised users in the EU and in duly authorised third countries and international organisations. In Finland, the Finnish Transport and Communications Agency (Traficom) is the competent PRS authority (CPA), and preparations for building a national PRS management infrastructure are underway ([H¨anninen, 2022], presentation).

When the PRS reaches full operational capability, it is expected to serve a wide range of authorised users. These users include police, defence forces, border guard, emergency services, and selected security-of-supply companies that are part of the critical national infrastructure and logistics ([H¨anninen, 2022], presentation). When comparing Galileo PRS to open and commercial GNSS services, PRS offers several benefits. Most importantly, it gives protection against interference, jamming, and spoofing, making it significantly more reliable under adversarial conditions. PRS uses two spectrally separated and encrypted carrier frequency bands (E1 & E6) to maximize the inference resistance and make it more difficult to attack the signal. EU [Law, 2011] also emphasises that PRS must have service continuity even in the most serious crisis situations ([H¨anninen, 2022], presentation).

Deeply-coupling Methods

Deeply-coupled GNSS receiver and self-contained sensor integration for jamming and spoofing mitigation has not been discussed in the extent it deserves, because it seems to be one of the most promising countermeasures. Sensors are not affected by radio interference and the attitude and acceleration information they provide are good complements to GNSS from other aspects too. An advanced integration method called deep-coupling uses information obtained from self- contained sensors to aid the signal processing algorithms and therefore enhances the robustness of GNSS to interference [Ruotsalainen et al., 2014]. However, self-contained sensors suffer from biases and drift errors that may decrease the position accuracy substantially. Especially when using consumer grade Micro- Electro-Mechanical System (MEMS) sensors, suited when weight and cost have to be considered.

Typically, deep-coupling with GNSS signals corrects the above-mentioned bias and drift errors in self-contained sensors, but if the interference continues for a longer time forestalling the use of proper GNSS signals, degradation of the combined position solution will incur after some period. Therefore, other sensors or methods have to be used to calibrate the errors in self-contained sensors frequently for a robust result. One emerging technology for error calibration is the use of visual perception. Visual sensors, i.e., cameras, are feasible instruments for constricting the growth of the errors and are also resistant to GNSS interference. Deeply-coupled GNSS, inertial navigation system (INS) and vision fusion has proven to be a feasible method for interference mitigation Integration [Cristodaro et al., 2019].

Interference monitoring infrastructure

The vulnerability in GNSS-based systems to intentional and unintentional interference requires having disparate monitoring systems continuously monitoring the GNSS signals for anomalies. In general, monitoring

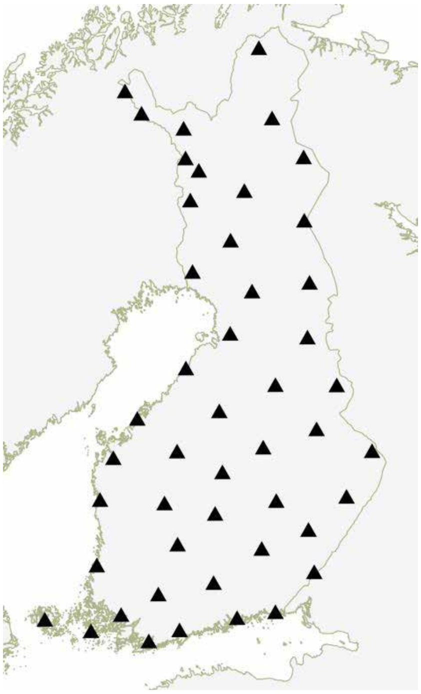

Figure 6: FinnRefs stations' locations ([Bhuiyan, 2022], presentation).

Table 3: Overview of the considered GNSS threat monitoring systems.

Monitoring System	Constellations monitored	Interference type classification	Spoofing detection	Interference localisation	Interference localisation	Low-price	Redeployment
FinnRef	GPS, GLONASS, Galileo, BeiDou	✗	✗	✗	✓	✗	✗
SWEPOS	GPS, GLONASS, Galileo, BeiDou	✓	✓	✓	✓	✗	✗
ARFIDAAS	GPS, GLONASS, Galileo, BeiDou	✓	✓	✓	✓	✓	✓

Figure 7: Typical FinnRef station ([Bhuiyan, 2022], presentation).

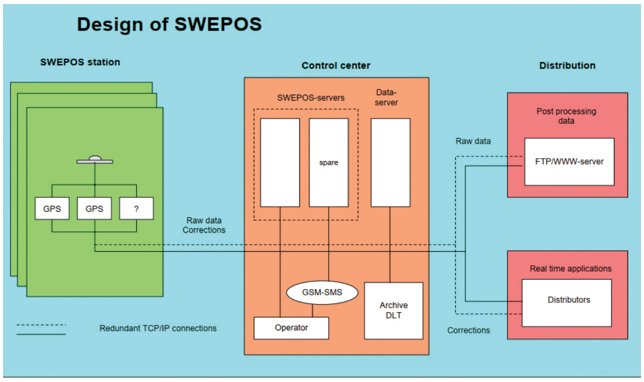

Figure 8: Design of SWEPOS [Hedling et al., 2001].

Figure 9: SWEPOS network (green dots) and message alerting system ([Kibrom Ebuy, 2022], presentation).

systems can be classified into two main categories; fixed and portable [Thombre et al., 2018]. The fixed monitoring systems are installed at a site to operate over long periods. In addition, the fixed monitoring systems can be expanded to multiple monitoring nodes connected to a central control unit. The raw observed data are sent via the communication channels to the control unit. The control centre stores the observed GNSS received signals and makes them available for post-processing to the end users. The portable monitoring systems are typically small handheld or mounted on vehicles which are intended to be operated over shorter periods. In this section, three fixed European monitoring infrastructures to monitor interference will be explained. Table 3 shows a comparison summary which is based on the capabilities of the threat monitoring systems; based on their capabilities to classify the interference type, detection of signal spoofing, if they are capable of geo-localisation of the interference source, price per station and redeployment capability (i.e., more feasible to change monitoring station position).

Finnish National Reference Network (FinnRef)

Finnish National Reference Network (FinnRef) includes 47 fixed stations to monitor GNSS signal quality with locations as can be seen in figure 6 and a typical station is seen in figure 7. FinnRef forms the basis for the national reference frame, EUREF-FIN and is maintained by the National Land Survey of Finland. Moreover, some of the stations also serve as International GNSS Service (IGS) stations to provide open access, high-quality GNSS data for scientific, educational, and commercial applications. In addition, one station is co-located with European Geostationary Navigation Overlay Service (EGNOS) Ranging and Integrity Monitoring Station (RIMS) which are used to improve the performance of GNSS. The Real-time positioning service ‘FINPOS’ uses FinnRef data to provide Differential-GNSS (DGNSS) and Network RTK measurement data to improve localisation accuracy for end users. The information from multiple global constellations i.e., GPS, Galileo, GLONASS and BeiDou are monitored. The monitored information is available in RINEX format and in real-time streams for the monitored constellations, where RINEX is a standard format that allows the management and disposal of the measured data ([Bhuiyan, 2022], presentation). In addition, the FinnRef monitors the GNSS signals for interference and jamming. It sends alert messages to Traficom when signal anomalies are detected [Gns, 2022].

GNSS-Finland Service

The data obtained from FinnRef forms the backbone for GNSS-Finland Service where the obtained data from the network are continuously analysed in real- time. The service creates a signal quality indicator for the monitored GNSS signal strengths. The indicators are ”good”, ”satisfactory” or ”poor”. The specific observed GNSS signal at a specific station is estimated as the average C/N0 demonstrating the quality of the signal for all observed satellites excluding satellites with an elevation angle less than 15 degrees. As for the signal quality indicator of the above-mentioned grades based on average C/N_0, two thresholds are empirically estimated for all signals. More details on thresholds values can be found at [Gns, 2022]. The Finnish Meteorological Institute uses the FinnRef receiver data in its space weather services to monitor ionospheric activity.

SWEPOS

The Swedish network of permanent reference stations for GNSS includes 500+ fixed nodes scattered all around Sweden. The receiver nodes are connected to a control centre that provides access to the whole accumulated GNSS data in real-time [Norin et al., 2008]. Each node is equipped with antennas and receivers which enable the network to track GPS, GLONASS, Galileo and Beidou signals. In addition to spectrum monitoring, SWEPOS also provides a range of applications such as: network real-time kinematic (NRTK) correction for real-time applications, Data for geoscientific and meteorological research and serves as the backbone of the Swedish national geodetic reference frame ([Kibrom Ebuy, 2022], presentation).

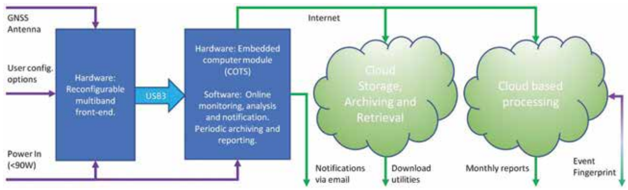

Figure 10: ARFIDAAS system design ([Morrison, 2022], presentation).

(a) ARFIDAAS antenna.

(b) Insidean ARFIDAAS station.

Figure 11: ARFIDAAS monitoring station ([Morrison, 2022], presentation).

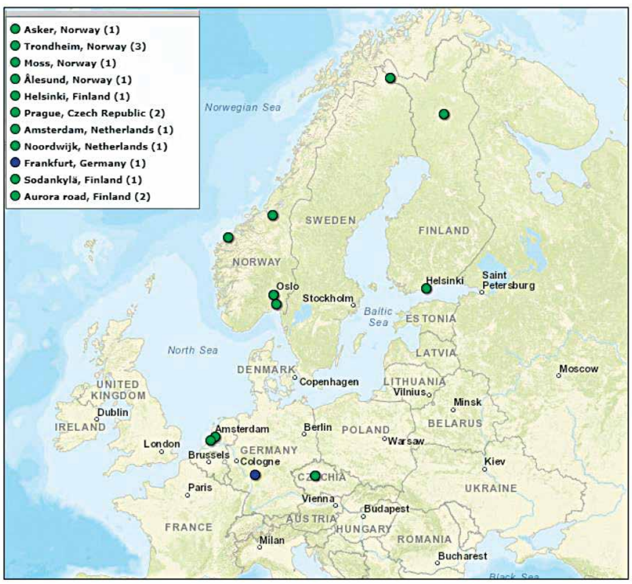

Figure 12: Locations of presently deployed ARFIDAAS systems in green, with expected 2022 deployment sites in blue, and the number of systems indicated in brackets ([Sokolova, 2022], presentation).

Figure 8 shows the design of the the SWEPOS-network. The SWEPOS stations are connected to the control centre at the National Land Survey through TCP/IP connection. The quality of raw data and the Differential GPS (DGPS) corrections checked at the control centre, and then, the control centre provides the data in a RINEX format for post-processing through a WWW/FTP-server. In general, most of the SWEPOS stations are built in areas with an undisturbed line of sight to the monitored satellite constellation.

The SWEPOS network infrastructure is utilised to monitor multi-GNSS constellations at multi-frequency bands. In addition, testing has been done in order to characterise and detect radio frequency interference in Sweden for both jamming and spoofing events in near-real-time from C/N0 history and characteristics [Alexandersson, 2022]. Moreover, it sends alarms when radio frequency interfernece (RFI) is detected (Figure 9. Also, it characterises the GNSS RFI events and geolocates the RFI sources for the use of the Swedish Post and Telecom Authority (PTS) based on the power and duration of the interference ([Kibrom Ebuy, 2022], presentation).

Advanced RFI Detection, Analysis and Alerting System (ARFIDAAS II)

The Advanced RFI Detection, Analysis and Alerting System (ARFIDAAS II) project is a collaboration between SINTEF (Norway) and the University of Helsinki (Finland) with stakeholders NKOM (Norway) and Traficom (Finland). ARFIDAAS II is a European Space Agency NAVISP element 3 project running from 2021 through 2022 and continuation of SINTEF's ARFIDAAS project operational from 2018 through 2019. The project is focused on the capture, collection and classification of RFI events impacting GNSS L-band signals and fingerprinting the jamming devices causing the RFI. One of the key features of the ARFIDAAS project is that it utilises custom monitoring hardware front- ends to simultaneously observe 240 MHz of aggregate spectrum divided into four tuneable sub-bands. The typical configuration is of one covering the L1 band including BeiDou B1 through GLONASS G1 signals, and the other three partially overlapping bands spread between the Galileo E5a+E5b, GPS L2 and Galileo E6 signals. The custom developed software for triggering, analysis and reporting runs on an off the shelf low cost computer. One of the main drivers in the front-end development was low deployment cost. At present, the cost of the whole system (Figure 10); front-end, computer, cabling and an antenna (Figure 11), is below 2000 euros ([Morrison, 2022], presentation). Low costs would enable increasing monitoring network density and thereby the detection of situations of potential failure in PVT computation.

Between 2019 and 2021, eleven ARFIDAAS quad-band RFI monitoring stations had been deployed between Norway (6), Finland (1), the Czech Republic (2), and the Netherlands(2), and have together observed nearly five thousand RFI events impacting one or more GNSS signal bands ([Sokolova, 2022], presentation). At the beginning of 2022, three more stations were deployed to the Arctic environment in Northern Finland ([Ruotsalainen, 2022], presentation). During the five operational months, over ten RFI events have been observed. One more station is being deployed into Germany during 2022. The full geographical coverage of the stations is seen in Figure 12, where the operating sites are shown with green and the planned 2022 deployment in blue, number of systems per site shown in brackets after each site name.

Summary

The disruptions to GNSS based navigation systems due to intentional and unintentional interference is a global phenomenon. Therefore, interference management techniques are crucial to mitigate interference effects. This white paper provides an overview of GNSS interference sources and methods to detect it. Specifically, traditional and machine learning methods are used to detect abnormal behaviour in the GNSS signal. Basic type of autoencoder is used for anomaly detection in the CWI interference type. In addition, jammer finger- printing methods are described. RF fingerprinting is based on detecting unique signal distortions caused by hardware irregularities, and this can be used to detect the signal transmitter. Moreover, methodologies to mitigate interference such as, Deeply coupling methods and Galileo Public Regulated Service (PRS) were discussed. Lastly, three GNSS signal monitoring infrastructures were briefly introduced.

> The vulnerability in GNSS-based systems to intentional and unintentional interference requires having disparate monitoring systems continuously monitoring the GNSS signals for anomalies

Seminar presentation

[SeminarAlexandersson, 2022] Alexandersson, M. (2022). Using the swedish CORS network to detect GNSS interference, results from tests and measurements. Seminar Presentation.

[SeminarBhuiyan, 2022] Bhuiyan, Z. (2022). R&D activities on resilient PNT at finnish geospatial research institute. Seminar Presentation.

[SeminarBurke, 2022] Burke, R. (2022). Resilient positioning, navigation and timing. Seminar Presentation.

[SeminarElango, 2022] Elango, A. (2022). GNSS anomaly monitoring. Seminar Presentation.

[SeminarH ̈anninen, 2022] Ha ̈nninen, J. (2022). European union's Galileo and its PRS. Seminar Presentation.

[SeminarKauristie, 2022] Kauristie, K. (2022). GNSS interference by space weather storms. Seminar Presentation.

[SeminarKibrom Ebuy, 2022] Kibrom Ebuy, A. (2022). SWEPOS data quality monitoring, GNSS signal interference and disturbance monitoring system. Seminar Presentation.

[SeminarLohan, 2022] Lohan, S. (2022). Interference detection, localization, and mitigation in GNSS. Seminar Presentation.

[SeminarMalmivirta, 2022] Malmivirta, T. (2022). Jammer fingerprinting. Seminar Presentation.

[SeminarMorrison, 2022] Morrison, A. (2022). The ARFIDAAS system design and operation. Seminar Presentation.

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Table 4: List of Abbreviations (alphabetical order)

Abbreviations	
AoA	Angle of Arrival
API	Application Program Interface
C/N0	Carrier-to-Noise density ratio
CPA	Competent PRS Authority
CWI	Continuous Wave Interference
DGNSS	Differential-GNSS
DGPS	Differential GPS
ESA	European Space Agency
EU	European Union
FDAF	Frequency Domain Adaptive Filter
FFT	Fast Fourier Transform
FGI	Finnish Geospatial Research Institute
FinnRef	Finnish National Reference Network
GNSS	Global Navigation Satellite Systems
HAS	High Accuracy Service
IGS	International GNSS Service
INS	Inertial Navigation System
LEO	Low Earth Orbit
LSTM	Long Short Term Memory
MEMS	Micro-Electro-Mechanical System
NEMA	National Marine Electronics Association
NLOS	Non Line Of Sight
NRTK	Network Real-Time Kinematic
OAPP	Orolia Academic Partnership Programs
OS	Open Service
PHM	Passive Hydrogen Maser
PRS	Public Regulated Service
PVT	Position, Velocity, and Time
RINEX	Receiver Independent Exchange
RHCP	Right-Hand Circular Polarization
RAFS	Rubidium Atomic Frequency Standard
RFI	Radio Frequency Interference
RIMS	Ranging and Integrity Monitoring Station
RTK	Real Time Kinematic
SAR	Search and Rescue Service
SDR	Software Defined Radio
SOI	Signal of Interest

Dual-Frequency EGNOS and Galileo-based GNSS Receiver and Antenna for Railway: TRENI Project

This paper presents the TRENI railway GNSS receiver and antenna development, to be used directly or integrated in a train multi-sensor safe positioning platform, suitable for railway safety-related applications

Marco Puccitelli
Thales Alenia Space Italia., Via E. Mattei 1, 20064 Gorgonzola (Milan), Italy

Chiara Manno
Thales Alenia Space Italia., Via E. Mattei 1, 20064 Gorgonzola (Milan), Italy

Livio Marradi
Thales Alenia Space Italia., Via E. Mattei 1, 20064 Gorgonzola (Milan), Italy

Gaetano Pastore
Thales Alenia Space Italia, Via Saccomuro 24, 00131 Rome, Italy

Hanaa Al Bitar
Thales Alenia Space France, Av. Champollion 26,31100 Toulouse, France

Anne Marie Tobie
Thales Alenia Space France, Av. Champollion 26,31100 Toulouse, France

Rodolfo Guidi
EikonTech, Via Livornese 1019, 56122, San Piero a Grado (Pisa), Italy

Giovanni Galgani
EikonTech, Via Livornese 1019, 56122, San Piero a Grado (Pisa), Italy

Francesco Inzirillo
Mermec, Via G. Oberdan 70, 70043 Monopoli (Bari), Italy

Filippo Rodriguez
Telespazio Italia, Via Tiburtina 965, 00156 Rome, Italy

Alessio Martinelli
Telespazio Italia, Via Tiburtina 965, 00156 Rome, Italy

Yuval B. Yossef
Saphyrion, Strada Regina 16, 6934 Bioggio, Switzerland

Daniel Lopour
EUSPA, Janovského 438/2, 170 00 Prague 7, Holesovice Czech Republic

Abstract

The railway signalling system in Europe is currently undergoing a major change, converging towards interoperability and safety to be ensured by the ongoing deployment of the European Rail Traffic Management System - ERTMS. However, at present, ERTMS does not envisage the use of GNSS positioning technology for safety relevant train localization. Introduction of GNSS is an opportunity to contribute towards increasing of both safety and security or simplifying and reducing trackside equipment. It can also contribute to reducing overall signaling system costs which is instrumental especially for keeping the rural capillary lines competitive with other modes of transport. To enable such benefits and to contribute toward Green and sustainable transport services the European Commission and European Union Agency for the Space Program (EUSPA) are collaborating with the main rail and space stakeholders on the inclusion of GNSS into the future evolution of ERTMS.

This paper presents the TRENI railway GNSS receiver and antenna development, to be used directly or integrated in a train multi-sensor safe positioning platform, suitable for railway safety-related applications.

This project is part of "Fundamental Element" framework and is being conducted under a grant related to the development of a Galileo Receiver for localization in train signalling (GSA/GRANT/05/2019), supported by the European Union Agency for the Space Program (EUSPA) and coordinated by Thales Alenia Space Italia S.p.A (TAS-I), in collaboration with Thales Alenia Space France S.A.S. (TAS-F), MERMEC S.p.A. (Italy), Telespazio Italia S.p.A. (TPZ-I) and Saphyrion Sagl. (Switzerland).

Introduction

According to the latest EUSPA GNSS Market Report [1], GNSS plays an important role in many non-safety related applications and the introduction of GNSS in future safety-related applications is expected to increase railway network capacity whilst decreasing operational costs. However, the rail scenario introduces several challenges: it is a dynamic scenario, moving in different environments from rural to urban, with different visibility conditions of the GNSS signals and with varying RF environment conditions. In addition, the criticality of the application requires a GNSS system robust to threats that may occur during operations.

In this context, the TRENI project aims at implementing a double step forward with respect to current state-of-the-art GNSS railway solutions. On the one side, the GNSS receiver will provide a dual-frequency (L1/L5) Galileo/GPS multi-constellation platform, with enhanced robustness and integrity features granted by the capability to autonomously identify and counteract to failures resulting from GNSS constellations faults, RF environment threats or from the receiver itself. Key features in terms of robustness to harsh RF environments will be based on receiver digitally Controlled Radiation Pattern Antenna (CRPA) techniques, pre/post-correlation algorithms for Jamming or Spoofing detection & mitigation and lastly PVT hybridization with complementary PNT sensors (IMU and odometers) (Figure 1). On top of this, the integrity information broadcasted by SBAS (EGNOS) will be used for the evaluation of the Along-Track Protection Level (ATPL) and solution confidence intervals, with alerts provision in case predefined thresholds for the service are exceeded. The second innovative element brought by the TRENI solution consists in the antenna element design. Indeed, currently only single-band (L1) GNSS antennas certified for rail applications (i.e. designed and tested against EN applicable standards) are available on the market, raising the need to develop a dual-band (L1/L5) multi- element CRPA antenna capable to support the interference mitigation functionality and to comply with the EN standards, thus being certifiable for the use in railway environment.

Use cases, CONOPS and rail environment threat scenario

GNSS may be used to increase the capacity of the railway network by allowing the development of future train operations such as moving block or virtual coupling. These systems are evaluated with the aim of ensuring fail-safe train location and location integrity. Moreover, GNSS is part of the digitalization that is reflected in the development of new applications, such as enhanced passengers information services, but also bringing benefits to railway operators and infrastructure managers because of the improved asset management and maintenance, thereby reducing the operational costs.

Different applications can be hence addressed by the TRENI platform, starting from primary safety systems, where GNSS is involved in direct safety chain of rail operations. As non-exhaustive examples, these primary safety systems encompass:

- Train integrity (i.e. train length monitoring);
- Train control (virtual balises, absolute positioning, guidance and navigation);
- Trains spacing over the line for traffic control systems.

In addition, overlaid safety systems can be considered as a potential use case, in which the GNSS could be to provide information to safety back-up systems, for instance:

- Simplified signalling (back-up) systems, capable of providing safety in operational conditions (e.g. cold movement detectors or level-crossing protection).
- Driving intelligent assistance (e.g. alarms to train driver);

Dealing with non-safety applications examples could be:

- Fixed asset management (e.g. infrastructure surveying and monitoring);
- Rolling stock management (e.g. fleet management, cargo monitoring, energy charging);
- Passenger Information (e.g. journey assistant, customer information, on-train reservations).

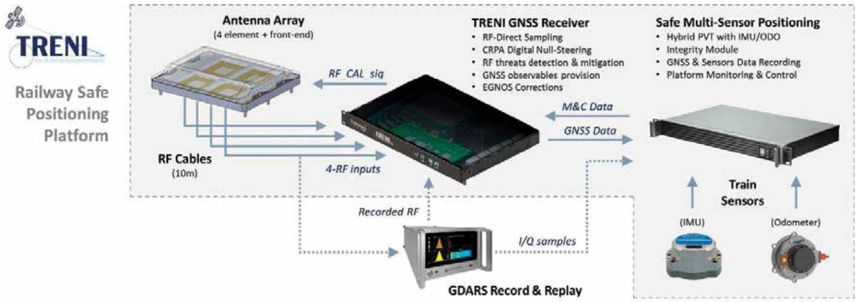

Figure 1: TRENI Platform functional diagram

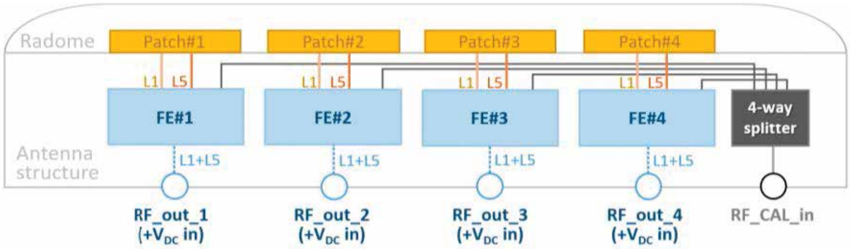

Figure 2: CRPA antenna high-level architecture

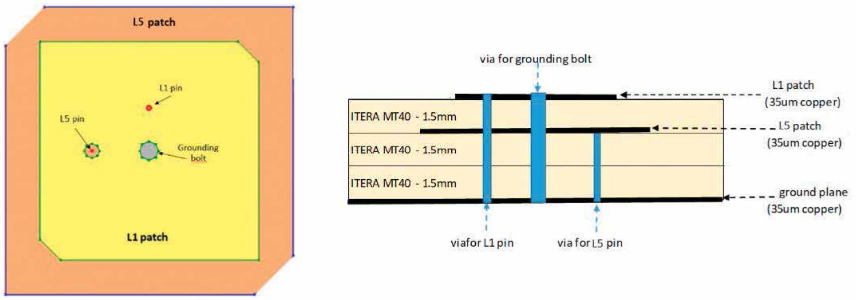

Figure 3: CRPA single antenna radiating element design & stack up

Table 1: GNSS threat sources, relative models and anomalies implemented in the emulation environment.

Threat Source	Models	Anomalies
Clocks	Atomic clock model for satellite clock, Quartz clock model for Rx clock.	Excessive acceleration, clock steps/ ramps.
Ephemeris	Ephemeris model defined by NAVmsg.	Missing Update, Unflagged Maneuvers, Erroneous Broadcasting.
Ionosphere	NeQuick model for ionospheric error.	Spatial and temporal gradient.
Troposphere	RTCA DO-229F MOPS model for tropospheric error component.	Excessive troposphere components w.r.t. identified model.
Interference	Interference by analogue TV or DVTB, jamming by device on train or in station.	-
Spoofing	Spoofing attack performed by a device located either on board or in station.	-
Multipath & Rx noise	Multipath/RX noise pseudorange error mapped vs elevation (scenario dependent parameters and DSM model considered).	-
Signal Loss	Loss of signal based on visibility mask.	-

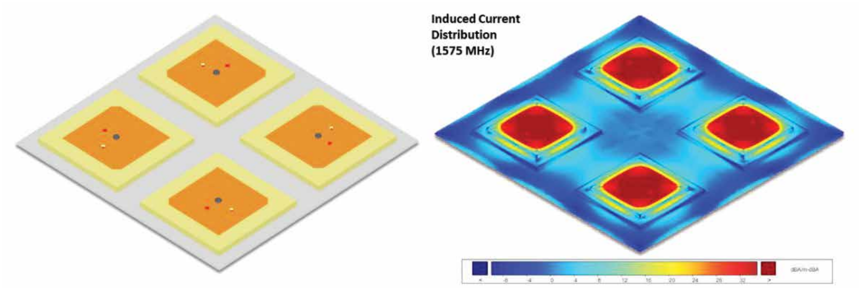

Figure 4: CRPA array sequential rotation layout (left) and induced current distribution (right)

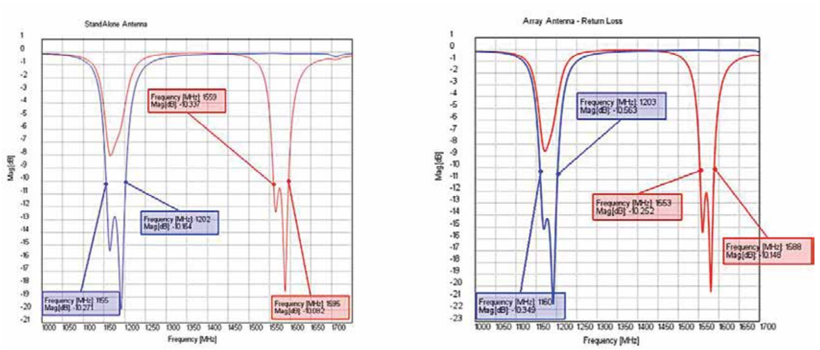

Figure 5: Single radiating element (left) and antenna array return loss (right) [dB]

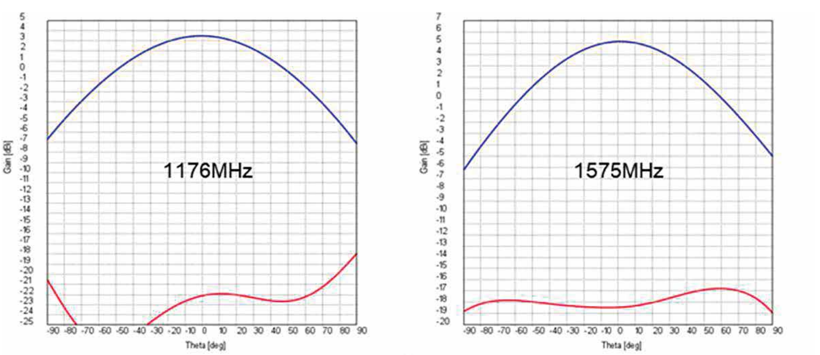

Figure 6: Single Element Antenna RHCP and LHCP Gain [dBi] in L5 and L1 bands

The main GNSS threats affecting accuracy and integrity of the position solution in the railway environment are listed in Table 1, which defines also associated models and anomalies that will be considered for the in laboratory validation campaign of the GNSS receiver.

Four critical scenarios have been selected to stress the performance of the GNSS receiver: the first two refer to the train in a stationary state respectively located at the station and in a rural area; the second two respectively refer to the train moving at low speed and located in urban environment and the train moving at high speed and located in rural area.

Dual-band CRPA antenna

The GNSS antenna for the TRENI project is asked to have features not available in commercial GNSS antennas currently on the market. Indeed the antenna is required to be dual band (i.e. L1/E1+L5/E5a) and to give the possibility to perform null forming by the receiver, in order to maintain integrity in presence of interference and spoofing. This leads to an antenna architecture of a 4-element array, necessary to apply beam forming strategies that give the additional requirement of an inter-element spacing within lambda/2 at maximum operating frequency. Another constraint, not related to performance, is the need to design an antenna system keeping the cost within limits compatible with the railway market. An RF Front-End, capable to amplify the GNSS signal of about 25 dB and to reject quite demanding near and out-of-band interferences, is part of the antenna system. A calibration circuit allows the equalization of the four FEs. The whole antenna architecture is shown in Figure 2.

Radiating elements & array design

The main characteristics of the radiating elements are listed below and shown in Figure 3 - Figure 4:

- Patch antenna technology for an easy and cheap manufacturing;
- Grounding pin not interfering with radiative performance, implemented as overvoltage protection from overhead catenary;
- Dual-band self-diplexed with two separated outputs (i.e. one for L1/E1, one for L5/E5), thus optimizing the front-end architecture;
- Sequential rotation applied to array layout, in order to assure axial symmetry during installation.

The Single Element Return Loss (left plot in Figure 5), shows that the -10dB target in E5/L5 (i.e. in the band 1166 – 1186 MHz) and E1/L1 (i.e. between 1565 – 1585 MHz) is satisfied with a safe margin, allowing the matching of the requirement also at array level (right plot in Figure 5).

Lastly Figure 6 show the expected antenna average gain for RHCP (blue lines) and LHCP (red lines) components, respectively at 1176 MHz (left) and 1575 MHz (right), for each stand-alone antenna patch.

Regarding the antenna front-end (FE) architecture, it consists in a single amplification stage based on COTS amplifier components and custom design band-pass filters, with low insertion loss and steep transition regions, specifically tailored to cope with RF interference masks specified by [2],[3]. At the antenna FE level also coupling microstrip sections are foreseen to inject the RF calibration signal, provided by the GNSS Receiver for the end-to-end RF chain calibration (amplitude and phase).

TRENI GNSS receiver

The TRENI GNSS Receiver is a customization of Thales Alenia Space Italia latest Test User Receiver (TUR) 19”-1U platform, already foreseen to be used for rail applications, as well as for avionic or maritime users. The baseline architecture is adapted to handle and process signals from up to 4 parallel RF inputs, with a future-proof design granted by the RF Direct Sampling and Digital Down- Conversion approach, intrinsically allowing the receiver to accommodate any GNSS signal scenario evolution in terms of frequency plan and signal modulations by simply updating FPGA FW and Receiver Application SW.

The high-level architecture of the receiver is presented in Figure 7, mainly consisting in a power supply module (i.e. a COTS AC/DC converter in the TRL7 prototype), an Analogue RF Front-End section (for RF signal filtering and antenna elements power feeding), a Digital Section (in charge of RF sampling, signal acquisition/tracking and navigation processing, calibration signal generation and external communication handling) and an I/O interface expansion module (for 1PPS and ERR/RESET TTL signals provision).

Starting from the TUR building block, the TRENI Receiver implements specific functionalities, among which the following ones can be considered the most relevant ones w.r.t. future rail solution:

- GPS/Galileo multi-constellation satellite tracking and combined solution capability;
- PVT solution configurability (single to dual-constellation dual-frequency, L1/E1+ L5/E5a);
- Application of EGNOS corrections at receiver level based on SBAS MOPS [2] and DFMC [3] standards, provided either by live EGNOS SiS or available through EURORADIO link (e.g. according to EUG-CR1368 guidelines, [4],[5]);
- Techniques for improved receiver resilience with active anti-jamming (i.e. digital pulse blanking in the time domain, excision in the frequency domain), anti-spoofing (including Galileo OSNMA capability) and multipath mitigation (based on multi-correlators DLL discriminators);
- Capability to implement at digital pre-correlation level up to 2 run-time nulls in the direction of detected interference/jammer sources;
- RAIM algorithm for the mitigation of local threats, with fault detection and exclusion (FDE);
- Provision of accurate 1PPS signal for the synchronization of on-board equipment and sensors;
- Real-time provision of raw observables, navigation data as well as Measurements/Signal Quality Monitoring (MQM/SQM) outputs for service level evaluation;
- Compliance to main railway safety standards (EN50126, EN50128, EN50129, EN50159).

Besides the TRENI GNSS Receiver HW, the “Safe Multi-Sensor Positioning” equipment (i.e. a companion Host PC) will be interfaced to allow the receiver monitoring & control, GNSS raw observables real-time visualization and storage (e.g. for post-processing and test replay under different configurations and data-fusion with external sensors data for GNSS-IMU Hybrid PVT solution evaluation).

Digital Null-steering with CRPA

Among pre-correlation techniques considered within the TRENI Receiver for mitigation of unintentional RF interference and/or malicious jammer, a focus is here below proposed w.r.t. the well- known MUltiple SIgnal Classification (MUSIC) [6] and Power Inversion (PI) [7] methods, applied to antenna pattern digital null-steering. Both the mentioned algorithms can be implemented at receiver FPGA level by conveniently combining the I/Q digital signal samples generated by the digital Down- Conversion Chains (DDCs), associated to the different radiating elements. In particular the Digital Board FPGA engine performs the following main tasks associated to the CRPA functionality:

- reception of 8 high-speed lanes (carrying I/Q samples from the 4 RF Channels) and feeding of the “covariance matrix” calculation block;
- covariance matrices computation engine & communication with DSP processor for provision of covariance indexes and reception of associated complex weights (computed by DSP for the following I/Q samples digital combination);

- management of the calibration signal synthesis through an external dedicated DAC.

The Eigen value decomposition of the covariance matrix, computed by the DSP processor as described above, gives a perfect interference detector: indeed without interference (i.e. without correlated signal at the antenna array), the correlation of the array matrix will be close to diagonal (signals of each antenna would consist in uncorrelated white noise) and the Eigen values will then correspond to the noise power. Otherwise, in presence for instance of one jammer, one Eigen value will increase to represent the power of the interference source.

Hence starting from the covariance matrix decomposition in eigenvalues and eigenvectors, the null- steered antenna element complex weights (ω^*) are computed with MUSIC or PI method and used to multiply the I/Q signal samples to generate a unique stream as follows:

$$y_{out} = \sum_{n=1}^{N_{ant}} y_n \cdot \omega^* , \quad (1)$$

The effects of a jammer on weighted signals combination, if properly managed, will result mitigated after the null-forming process. In general, despite the superior performance expected for MUSIC algorithm in terms of Direction of Arrival (DoA) estimation and maximum “peak-to-null” gain ratio (i.e. interference rejection), PI method is typically preferred in GNSS applications due to its simpler implementation based on a “blind” approach (i.e. it does not require a-priori knowledge about antenna array such as antenna element orientation, gain/phase patterns, calibration values, etc.).

Before qualitatively assessing the null-steering capability, by assuming an AWGN only environment (i.e. no interference) as the nominal antenna operating condition, default CRPA weights can be defined, for instance, in order to optimize RHCP gain pattern at zenith. The results for the combination of antenna elements embedded RHCP gain patterns in a single equivalent one are reported in the following Figure 8.

In case environmental conditions are characterized by the presence of EMI source(s), null-steering algorithm can be executed to mitigate interference effects at the receiver level. The maximum number of EMI sources that can be simultaneously

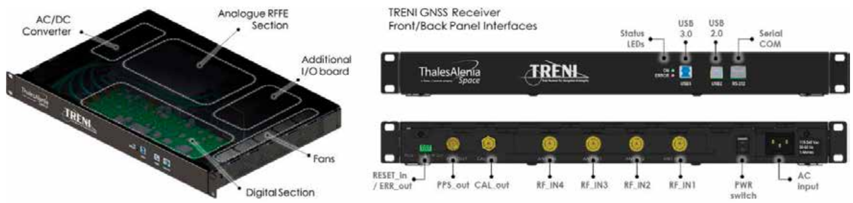

Figure 7: TRENI DFMC GNSS Receiver architecture layout (left) and interfaces (right)

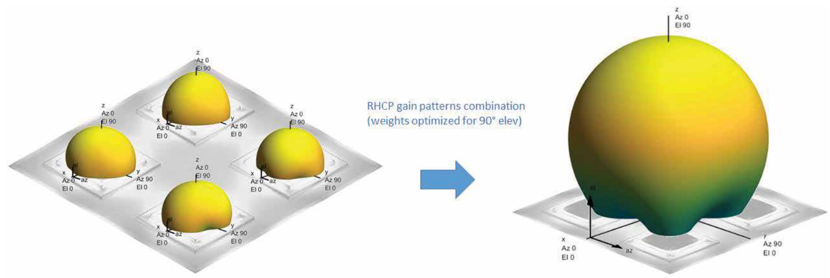

Figure 8: CRPA digitally combined pattern in AWGN only condition (weights optimized for zenith)

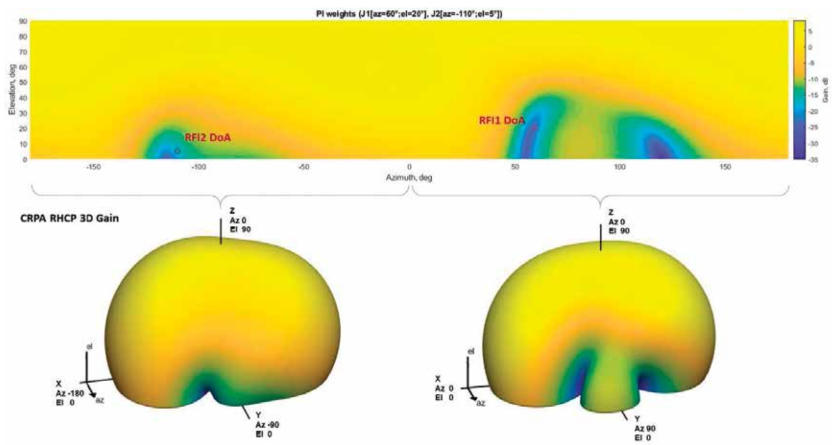

Figure 9: Digital Null-Steering capability example in presence of 2 RFI sources

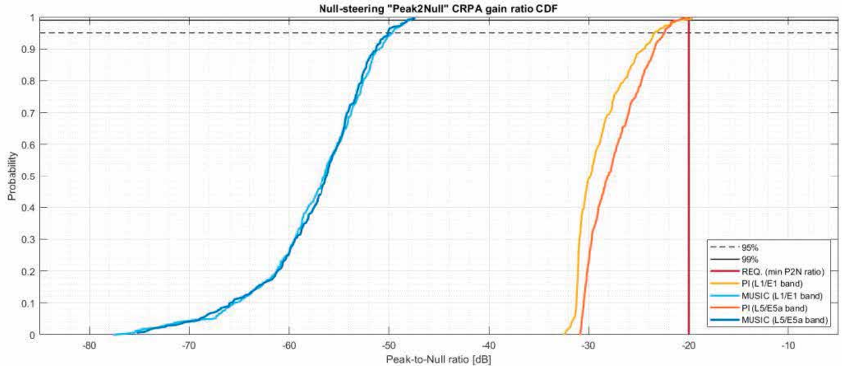

Figure 10: CRPA Peak2Null (P2N) gain ratio cumulative distributions for MUSIC and PI methods

(and effectively) mitigated by the current CRPA antenna design is approximately equal to $N_{RFI} \leq N_{ANT}/2 = 2$ (where $N_{ANT}=$ 4 is the number of radiating elements).

In order to characterize the null-steering capability, a fixed JNR resulting in -3dB degradation of C/N_0 is considered in the figure below, in presence of two terrestrial interference sources simulated at 1176 MHz and with DoA1[azm=60°,elv=20°], DoA2[azm=-110°,elv=5°] (highlighted by red markers).

Similarly to the previous example (i.e. given a fixed JNR resulting in -3dB C/N_0 degradation), the expected null-steering capability for the antenna patterns over L1 and L5 bands have been statistically characterized by simulating different jammers directions of arrival over entire antenna coverage area, with a spatial resolution of 10 deg (i.e. DoA bins defined by azm=[0:10:360] deg, elv=[5:10:85] deg).

Simulations results are provided in Figure 10, showing as expected a higher interference rejection for MUSIC (minimum P2N ratio in the order of 50dB), compared to the PI algorithm one (approx. 20dB).

Safe Multi-Sensor Positioning: Hybrid PVT & Integrity

Hybridized PVT solutions will be implemented and evaluated in order to demonstrate the enhancements brought by GNSS data hybridization with additional sensors installed on the test rolling stock. This integration will allow for:

- FDE capability to remove faulty ranges;
- Accurate train positioning even under GNSS signal limited-visibility conditions;
- Along track position, speed and the associated integrity protection level (ATPL).

Each of these steps are briefly described in this section. An IMU is a complete 3D dead-reckoning navigation system. Therefore, it does not allow to obtain an absolute positioning solution by itself, but can significantly improve the accuracy and the integrity of the positioning solution when combined with other sensors. In the TRENI project, the IMU will be hybridized with GNSS, odometer and possibly 2D maps.

In order to prevent unavailability of maps or unavailability of associated integrity information, it is proposed to limit the impact of the map on the navigation filter design while keeping its potential information useful. If available and associated with integrity, it has been proposed to use the map to correct the navigation solution after the hybridization filter. Since the cartography in the Railways domain is expected to be highly accurate (yet with no integrity data associated), it is proposed to assume it fault free for the integrity concept. The method consists in projecting the navigation solution on to the nearest point of the rail in the map.

If the map is available, FDE methods will have to be derived to ensure that, in case where 2 rails are side by side but heading in opposite directions, the navigation solution is projected to the correct rail.

Therefore, in this article, the focus is on the coupling scheme between GNSS, IMU and odometer. According to [8]; several hybridization schemes may be considered: loose (LC), tight (TC) and ultra- tight coupling (UTC).

The choice of the coupling strategy is not straightforward. A critical analysis has been performed and the TC is preferred for the TRENI hybridization module. The arguments considered are the following: the TC provides a more accurate solution than a LC and, a PVT can be computed even with less than 4 GNSS satellites but at the expense of a slightly more complex implementation. In addition, a TC solution requires the knowledge of the ephemeris as well as an accurate synchronization between the integrated navigation systems.

Following the previously defined TC solution, an integrity concept is also proposed. Solutions are designed at several levels (pre-processing

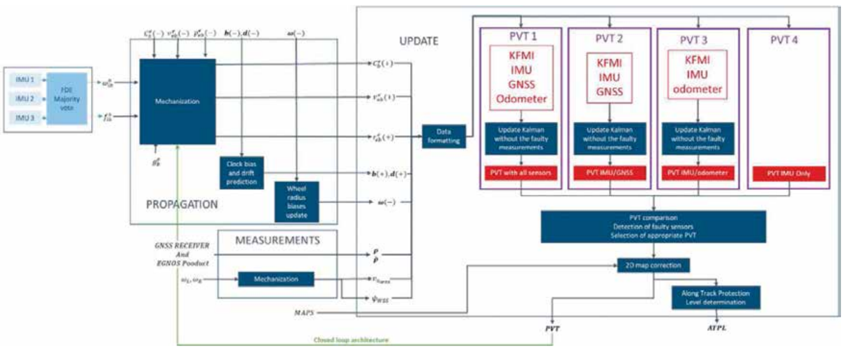

Figure 11: TRENI Integrity concept – architecture overview

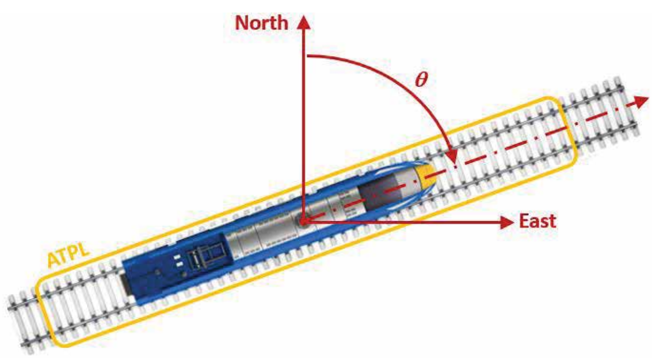

Figure 12: TRENI Integrity concept – along track protection level (ATPL)

techniques, error characterization and measurement rejection approaches) in order to meet the integrity requirements and Key Performance Indicators (KPIs).

The proposed integrity concept is illustrated in Figure 11. On one side, the IMU is used to propagate the solution, and, on the other side, the odometer and GNSS are the measurements considered to update the solution.

The integrity solution leverages on a mixed use of Kalman Filter Measurement Innovation (KFMI) principle, and majority vote redundancy scheme. The FDE methods are applied both in the pre-processing step and in the update step. Majority vote method is applied in the pre-processing step to ensure the validity of the IMU measurements. Then, the combination of the KFMI based solution with majority vote solution is used to identify and reject potential faulty sensors.

In Figure 11, four PVT solutions are represented: a hybrid IMU/GNSS/odometer tight coupling filter (PVT 1), a hybrid IMU/GNSS tight coupling filter (PVT 2), a hybrid IMU/odometer tight coupling filter (PVT 3) and an IMU only filter (PVT 4).

In order to limit the computational burden, a first step will consist in computing PVT 2, 3 and 4. If all 3 solutions are identical (assuming a tolerable variance), then PVT 1 will be computed and will be the final solution.

For PVT solutions 1, 2 and 3, the KFMI is applied, therefore, it is expected that faulty GNSS measurements will already be detected and excluded. PVT 4, IMU only, is expected to be fault free since the pre-processing step is expected to have detected and excluded faulty IMUs (based on majority voting among 3 IMUs). The comparison of PVT 2, 3 and 4 will allow the detection of remaining errors and the exclusion of sensors if they are identified as faulty. Majority vote methods will be applied to identify these remaining faults. For example:

- If PVT 2, 3 and 4 provide the same solution (assuming a pre-defined tolerable difference) then the final solution will be PVT 1.
- If PVT 2 and 4 are equal but different from PVT 3, the odometer is detected as faulty, the final solution will be PVT 2.
- If PVT 3 and 4 are equal but different from PVT 2, the GNSS is detected as faulty, the final solution will be PVT 3.

Based on the final PVT choice, the 2D map can be applied to correct the position, to ensure that the train is on the correct rail. As explained above, the map is expected to be use in a post PVT step to correct the PVT, therefore, it is assumed that the map is correct and fulfils integrity requirements to be defined.

Finally, the last step of hybridization section is the definition of the PL, as illustrated in Figure 12. In fact, for the train case, the definition of PL can be simply projected on the train track in order to provide the ATPL (since there are no other degrees of freedom in the train motion, and thus the problem is essentially 1D).

In this way the horizontal PL "collapses" into a 1D PL in the horizontal plane. Hence the ATPL, computed using all non-excluded measurements, is defined as:

$ATPL = K_{PMI} \cdot \sigma_{along}$, (2) where K_{PMI} is a protection coefficient defined as a function of the integrity risk probability P_{MI}, and σ_{along} is the along track standard deviation defined as:

$$\sigma_{along} = \sigma_E \cdot sin(\theta) + \sigma_N \cdot cos(\theta), \quad (3)$$

where θ is the azimuth of the track line segment on which the train has been determined to be situated, σ_E and σ_N are the East and North standard deviation components.

Way forward & conclusion

The TRENI platform will go through an extensive verification and validation activity. Different phases are envisaged starting from laboratory subsystems integration and functional verification, validation at Telespazio laboratories in Rome against worst case expected threats models generated by a realistic emulation test bed, and lastly relying on the field test campaign, supported by additional equipment that will record I/Q data streams from the GNSS antenna during the train runs on the Italian national railway line (RFI). The gathered data will be very useful to replay the experienced scenario in laboratory and will allow for the characterization of the RF environment during the field test runs, as well as allow for the testing and comparison of the different receiver algorithms and techniques on the replayed data. Moreover GNSS receiver measurements gathered along with the IMU & Odometer sensors data (but also with other external sensors data such as physical balises and geo-located reference points along the track), will finally allow for the definition of an a-posteriori reference "truth" trajectory, that will be exploited for the verification of GNSS performance achieved during the field tests campaign and verification of the hybridized PVT solution and integrity concept performance.

Acknowledgements

This project is part of "Fundamental Element" framework and is being conducted under a grant related to the development of a Galileo Receiver for localization in train signalling (GSA/GRANT/05/2019), supported by the European Union Agency for the Space Program (EUSPA) and coordinated by Thales Alenia Space Italia S.p.A (TAS-I), in collaboration with Thales Alenia Space France S.A.S. (TAS-F), MERMEC S.p.A. (Italy), Telespazio Italia S.p.A. (TPZ-I) and Saphyrion Sagl. (Switzerland).

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ICL-GNSS 2022 WiP, June 07–09, 2022, Tampere, Finland.

Ireland's new National Land Cover Map

The new National Land Cover Map was produced by the National Mapping Division of Tailte Éireann (formerly Ordnance Survey of Ireland) in partnership with the Environmental Protection Agency (EPA). It was released on 21 March 2023. The aim of a land cover map is to map what is physically present on the Earth's surface, for example forests, grasslands, and artificial areas. This Map was produced based on 2018 data and is known as NLC 2018. It includes detailed information on land cover types in Ireland and marks a significant improvement in land evidence. It will have many uses in environmental assessments on water, climate, air, noise, and biodiversity and will be an important resource into the future. *www.epa.ie*

Descartes Labs partners with Comtech

Descartes Labs will become Comtech's third publicly revealed EVOKE technology partner. It will work with Comtech to infuse the power of artificial intelligence (AI), Machine Learning (ML), predictive intelligence, and monitoring insights across Comtech's business verticals. *www.comtech.com*

NOAA, communities to map heat inequities

This summer, NOAA and citizen scientists will map the hottest parts of 18 communities in 14 states across the USA and in one international city. Identifying these hotspots, called urban heat islands, helps local decision-makers take actions to reduce the health impacts of extreme heat, which often target the most vulnerable.

Now in its seventh year, the NOAA Urban Heat Island (UHI) mapping campaign addresses extreme heat, the number one weather-related cause of death in the U.S. for the last three decades. Urban heat islands— areas with few trees and more pavement that absorbs heat — can be up to 20 degrees fahrenheit hotter than nearby neighborhoods with more trees, grass and less black asphalt.

The cities and counties selected this year have a range of experiences with extreme heat, but each is looking for equitable ways to implement cooling solutions in their communities. For example, Chicago experienced one of the nation's most deadly heat waves in 1995. *www.noaa.go*

Cupix adds CupixWorks to Bentley's iTwin program

Cupix has announced the addition of its leading product, CupixWorks, to Bentley Systems' powered by iTwin program. CupixWorks is a state-of-the-art 3D digital twin platform that enables decision-making and collaboration through all stages of a building's life cycle. Project Managers, General Contractors, Architects, and Owners can remotely view, track, and manage on-site progress via 3D spatial contexts and life-like 3D navigation. *www.cupix.com*

AI: UNESCO calls on all Governments to implement Global Ethical Framework without delay

Following calls by over 1000 tech workers for a pause in the training of the most powerful AI systems, including Chat GPT, UNESCO calls on countries to fully implement its Recommendation on the Ethics of Artificial Intelligence immediately. This global normative framework, adopted unanimously by the 193 Member States of the Organization, provides all the necessary safeguards.

UNESCO's Recommendation on the Ethics of Artificial Intelligence is the first global framework for the ethical use of artificial intelligence. It guides countries on how to maximize the benefits of AI and reduce the risks it entails. To this end, it contains values and principles, but also detailed policy recommendations in all relevant areas.

UNESCO is concerned by many of the ethical issues raised by these innovations, in particular discrimination and stereotyping, including the issue of gender inequality, but also the fight against disinformation, the right to privacy, the protection of personal data, and human and environmental rights.

Industry self-regulation is clearly not sufficient to avoid these ethical harms, which is why the Recommendation provides the tools to ensure that AI developments abide by the rule of law, avoiding harm, and ensuring that when harm is done, accountability and redressal mechanisms are at hand for those affected.

UNESCO's Recommendation places a Readiness Assessment tool at the core of its guidance to Member States. This tool enables countries to ascertain the competencies and skills required in the workforce to ensure robust regulation of the artificial intelligence sector. It also provides that the States report regularly on their progress and their practices in the field of artificial intelligence, in particular by submitting a periodic report every four years.

To this date, more than 40 countries in all regions of the world are already working with UNESCO to develop AI checks and balances at the national level, building on the Recommendation. UNESCO calls on all countries to join the movement it is leading to build an ethical AI. A progress report will be presented at the UNESCO Global Forum on the Ethics of Artificial Intelligence in Slovenia in December 2023. *unesco.org*

FNT Software releases GeoMaps 4.1

FNT Software released a new version of FNT GeoMaps, a Geo-Intelligent component within its Cable and Outside Plant Management solution.

Powered by Esri ArcGIS, FNT GeoMaps provides advanced geographic features that enhance the planning, operation, and management of passive inside and outside plant infrastructure with spatial intelligence. *www.fntsoftware.com*

Synchronizing Galileo's satellites with an ensemble of high-performance atomic clocks

Europe's Galileo is a precise satellite navigation system, providing meter-level accuracy and precise timing. An essential ingredient to ensure this stays the case are the atomic clocks aboard each satellite, delivering pinpoint timekeeping that is maintained to a few billionths of a second. These clocks are called atomic because their "ticks" come from ultra-rapid, ultra-stable oscillation of atoms between different energy states. Sustaining this performance demands, in turn, even more accurate clocks down on the ground to keep the satellites synchronized and ensure stability of time and positioning for users.

ESA's ESTEC technical center in the Netherlands is continously monitoring the "Galileo System Time" at the heart of Europe's satellite navigation system—on an independent basis from the operational Galileo system itself.

For this, the establishment hosts in its UTC Laboratory an "ensemble" of high-performance atomic clocks that are kept in thermally stabilized cleanroom conditions. This collection of fridge-sized atomic clocks, together with means to measure and compare them, provides stable, accurate timing typically accurate to a billionth of a second, almost ten times better than Galileo System Time. *https://phys.org*

ICAO Council adopts new dual-frequency multi-constellation standards

The International Civil Aviation Organization (ICAO) council achieved a major milestone this week in the global standardization and roll-out of new dual-frequency multi-constellation (DFMC) capabilities for international aviation's Global Navigation Satellite System (GNSS).

DFMC GNSS permits the combined leveraging of dual frequency signals from up to four GNSS constellations simultaneously, including the GPS system, Galileo, GLONASS and BeiDou.

The capability has been enabled through latest advances in aircraft-, satellite-, and ground-based augmentation systems, and will become more prevalent as aircraft become increasingly equipped with DMFC-capable avionics. Currently, global aviation GNSS capabilities rely mainly on just one constellation and one frequency via GPS L1, meaning that the new multi-constellation capability will assure greater system accuracy and redundancy, delivering important air network capacity and safety benefits. *www.icao.int*

Eos Positioning Systems announces support for Galileo HAS

Eos Positioning Systems, Inc. announced its Arrow Gold+™ GNSS receiver that supports the free, new Galileo High-Accuracy (HAS) Initial Service correction service. With this, Arrow Gold+ users can achieve better than 20 centimeter real-time accuracy with 95% confidence anywhere in the world.

Galileo HAS is a widely anticipated differential correction service from the European Space Agency and European Union Agency for the Space Programme (EUSPA). Its Initial Service constitutes Phase 1 of its go-live, which occurred on January 24, 2023. On that date, Galileo HAS become the first global differential correction service to provide subfoot accuracy to compatible GNSS receivers anywhere in the world, completely free of charge.

The Arrow Gold+ is currently the only high-accuracy GNSS receiver designed specifically for the GIS market to support the Galileo HAS. *https://eos-gnss.com*

Saildrone scales production of new mid-size USV

Saildrone announced recently the 33-foot (10 m) Voyager, which is specifically designed for near-shore ocean and lakebed mapping, and to meet the challenges of IUU (illegal, unreported, and unregulated fishing), ISR (intelligence, surveillance, reconnaissance), law enforcement and maritime safety, drug interdiction, and border and harbor security. *www.saildrone.com*

TOPODRONE – RASA Surveying partnership

TOPODRONE and RASA Surveying have entered into a technological partnership to advance airborne surveying approaches and accommodate coastal management and monitoring demands in the Philippines. RASA Surveying will adapt Swiss hardware & software for data collection and processing to overcome local operational limitations for coastal mapping. *topodrone.com*

Drones help reverse deforestation and empower local communities

The Gran Chaco region in Paraguay not only contains the second-largest forest in South America, but it also has one of the world's highest deforestation rates. Therefore GainForest, with the help of drone data from Globhe, now uses smart AI tools that reverse deforestation and empower the local communities.

GainForest has introduced NFTrees in the region, a digital asset representing conservation specific to this area. This gives conservationist donors a proof-of-impact certificate that is constantly updated with metadata that, in near real-time, shows the status of the forest.

GainForest also works together with the country's Ministry of Environment and Sustainable Development to empower, fund, and reward the local communities and promote the protection of the local forest. The drone data from Globhe plays a key role in monitoring tree cover and carbon capture and mapping large areas of land in the Gran Chaco region. *globhe.com*

Airbus achieves in-flight autonomous guidance

Airbus Defence and Space and the company's subsidiary, Airbus UpNext, have achieved in-flight autonomous guidance and control of a drone using an A310 MRTT.

In a first step towards Autonomous Formation Flight and Autonomous Air-to-Air refuelling (A4R), the technologies demonstrate for future aerial operations involving manned and unmanned assets.

Known as Auto'Mate, the technologies were integrated on an A310 MRTT flying testbed, which took off from Getafe, Spain, on 21 March, and on several DT-25 target drones, acting as receiver aircraft and flying from Arenosillo Test Centre (CEDEA) at Huelva, Spain.

Over the waters of the Gulf of Cadiz, the control of the drone transitioned from a ground station to the A310 MRTT, autonomously guiding the DT-25 to the in-flight refuelling position. *www.airbus.com*

First tranche of drone PLI allocation soon

The Government of India will be announcing first set of production linked incentives for drones soon, Union aviation secretary Mr Rajiv Bansal said recently. He said the government has been focusing on drones and so far 15 drone categories have been certified. This number, he said, would go up to 50 this year. Mr Bansal said eVTOLs (electric vertical take-off and landing) offer a whole new solution to mobility. On the specific technology of eVTOL, he said it was not as far as it seems and is much closer. *www.cii.in*

Event 38 and PLACE Partner to Map Turks and Caicos

Mapping drone manufacturer Event 38 Unmanned Systems has announced deployment of its E400 fixed-wing mapping drone for the collection of aerial imagery and mapping data in Turks and Caicos, which had not been mapped in at least ten years. The drone gathered sufficient data to produce orthomosaics of the entirety of both islands, totaling 238 square kilometers. The project was conducted by PLACE, a global non-profit organization granting access to mapping data by providing hyperlocal and precise optical imagery. *https://dronelife.com*

Coal India to digitize 7 major coal mines with Aereo

Aereo (formerly Aarav Unmanned Systems wins the largest drone solutions contract from Coal India Limited (CIL).

It will provide advanced analytics through its proprietary web platform and indigenous survey-grade PPK drones to 7 mines in Northern Coalfields Limited (NCL) and South Eastern Coalfields (SECL) under CIL for a tenure of 3 years. This will help improve mining safety, environmental compliance, and overall efficiency of the open cast mines.

Chennai police to launch AI powered hi-tech drone unit

Drones equipped with hi-tech cameras and powered by Artificial Intelligence would form part of an exclusive 'police drone unit' set to be launched soon in Chennai India.

The unit shall comprise six swift action surveillance drones, a heavy-lift multirotor drone and two long range surveillance droneswith a range of 5-10 kms. *www.business-standard.com*

Space Flight Laboratory announces launch of nine satellites

Space Flight Laboratory (SFL), has announced the launch and successful deployment of nine satellites. The SpaceX Transporter-7 ride-sharing mission carried SFL-designed microspace platforms into orbit for four different repeat customers.

The Transporter-7 launch included:

- HawkEye 360 Cluster 7, based on SFL's 30-kg DEFIANT platform, is comprised of three formation-flying, radio frequency geolocating microsatellites integrated at HawkEye 360 Inc.'s U.S. facility under SFL's Flex Production program.
- Three next-generation greenhouse gas monitoring microsatellites, known as GHGSat-C6, C7 and C8, built by SFL on its 15-kg NEMO platform for GHGSat Inc. of Montreal, Canada.
- NorSat-TD microsatellite built by SFL for the Norwegian Space Agency on SFL's DEFIANT platform to carry multiple advanced or experimental payloads.
- Commercial communications CubeSats developed using the SFL 6U-XL SPARTAN design for a Toronto-based company. *www.utias-sfl.net*

China launches new Yaogan-34 remote sensing satellite

China successfully sent a new remote sensing satellite of the Yaogan-34 series into space on March 31, 2023. This remote sensing satellite will be used in areas such as land resources survey, urban planning, crop yield estimation etc. It was the 470th flight mission of the Long March carrier rocket series. *https://english.news.cn*

Egypt launches "Horus-2" satellite for remote sensing

Egypt has successfully launched the "Horus- 2" satellite from the launch base in northwest China. It carried high-resolution imaging cameras on board. "Horus-2" is among a group of remote sensing satellites, and it is being developed through the full participation of a team of Egyptian and Chinese experts. *www.sis.gov.eg*

MasterMover partners with BlueBotics

MasterMover has announced a new partnership with vehicle automation leader BlueBotics to provide best-in-class ANT navigation technologies for MasterMover's range of Automated Guided Vehicles. It also offers a range of advanced solutions, spanning remote control operation, line follow navigation and fully autonomous solutions. *www.bluebotics.com*

Comtech awarded contract for blended comms tech + location service

Under this contract, Comtech will design, develop, install, integrate, and test communications and location-based technologies for Yahsat's Location Tracking Services Platform and User Terminals. It's offerings will help enable blended communications and enhanced location-based services for end users of Yahsat's network. Comtech's communications capabilities and location-based services are designed to support the convergence of global communications infrastructures. With the merging of space, satellite, terrestrial, and wireless technologies, Comtech is uniquely positioned to enable hybrid network infrastructures.

Abu Dhabi Autonomous Racing League

Abu Dhabi, ASPIRE, has announced the launch of the autonomous racing league, in keeping with the goal of creating a top-tier R&D base in Abu Dhabi, UAE. The race will begin in Q2 of 2024 with the autonomous vehicle race.

The Racing League will feature a number of autonomous vehicle competitions, including autonomous off-road racing, autonomous drone racing, and others. Fans can anticipate real-time information from Augmented Reality (AR) and Virtual Reality (VR) infographics and on-screen displays. Race fans will get to explore a brand-new realm of entertainment while witnessing the adrenaline of head-to-head automated driving racing.

Voyis releases the discovery vision system

Voyis launches its new product line, Discovery Vision Systems, to address the trade-off that is currently made between Piloting Cameras and 3D Inspection Cameras. Piloting cameras prioritize low latency video at the expense of the image data required for 3D model generation. Conversely, 3D cameras prioritize image data at the expense of piloting effectiveness, limited by a higher latency and smaller field of view. The Discovery is a vision platform without compromise, delivering 4K piloting video together with 3D data. Voyis offers two versions of the Discovery: The Discovery Camera and the Discovery Stereo. *www.voyis.com*

Safran partnership with Xona Space System

Orolia, a Safran Electronics & Defense company, has announced a partnership with Xona Space Systems to develop support for Xona's Low-Earth-Orbit (LEO) constellation and navigation signals in its Skydel™-powered simulation and testing products. Xona is developing PULSAR – a high-performance positioning, navigation, and timing (PNT) service enabled by a commercial constellation of dedicated LEO satellites.

Xona's PULSAR service will advance capabilities in global PNT security, resilience, and accuracy by augmenting existing GNSS while also operating as an independent PNT constellation. *www.xonaspace.com*

Veripos launches Apex PRO Correction Services

Veripos has announced the launch of Apex PRO Correction Services with breakthrough RTK From the Sky technology. Hexagon's Autonomy & Positioning division's RTK From the Sky enables global, centimetre-level precise point positioning (PPP) accuracy in as fast as 3 minutes — without compromising on high reliability. Now, this technology comes to the offshore marine market through Apex PRO corrections to support safer operations and increased efficiency, resulting in higher productivity and minimised downtime. *veripos.com*

Leica Geosystems and Xwatch Safety Solutions

Leica Geosystems and Xwatch Safety Solutions have announced a significant milestone in their partnership, enhancing construction site safety and infrastructure protection.

Leica Geosystems and Xwatch announced their collaboration in 2021 and previously introduced the Leica iCON PA80 avoidance solution integration with the Xwatch XW 4 and 5 series safety systems. This new solution not only improves safety for construction workers and pedestrians around busy work sites, but also protects existing infrastructure, as the solution safeguards construction assets from interruption which can cause significant costs and delays.*https://leica-geosystems.com*

CNH Industrial to acquire Hemisphere GNSS

CNH Industrial has entered into an agreement to purchase Hemisphere GNSS, currently owned by Unistrong, China. This acquisition is a critical step that advances the automated and autonomous solutions for Agriculture and Construction. Combined with Raven Brand's capabilities, this development gives us full control of its precision and navigation technologies. *www.cnhindustrial.com*

CHC Navigation releases 3D Grade Control System

CHCNAV TG63 Grade Control for Motor Graders is now available worldwide. With a tightly coupled dual-GNSS positioning system and inertial sensor, it provides reliable 3D positioning and heading to control the motor grader blade with the highest accuracy. It is designed to withstand the harsh environment of construction sites and supports multiple applications, including real-time kinematic networked transport of RTCM via internet protocol and ultra-high frequency base stations. *https://chcnav.com*

SYNTACS Navigation System for Indonesian MCM vessels

The first of the two new vessels, which are among the most modern ships of their kind, is currently successfully completing its sea trials.

The integrated solution is equipped with Synapsis NX navigation and bridge systems, an integrated SYNTACS command and control system, as well as a state-of-the-art mine-hunting sonar. This enables leading-edge MCM operations that are highly precise, safe and efficient from mission initiation to mission success. Efficient mine countermeasures are of crucial importance for safe maritime traffic and the protection of maritime infrastructure. A newly developed software module for SYNTACS provides the capabilities required to plan, execute, coordinate and monitor MCM missions. *www.anschuetz.com*

Septentrio launches Agnostic Corrections Partner Program

Septentrio has started the Agnostic Corrections Partner Program. This program facilitates the use of Septentrio receivers with various high-accuracy services, which offer varying levels of accuracy, coverage and delivery methods. This also allows integrators and users to select the service which is most suitable for their specific application and business model. *septentrio.com*

GPSdome 2 – Anti-Jamming Device

The GPSdome 2 is tailored to defend small- to medium-sized tactical UAVs as well as manned and unmanned ground vehicles. With a small form factor (500 g, 87 mm x 91 mm x 61.55 mm) and minimal power consumption, it is suitable for loitering munitions as well as UAVs. Fully retrofit and completely standalone, the system is compatible with almost any off-the-shelf GNSS receiver as well as standard active GNSS antennas, meaning that it can be integrated into existing GPS systems or into new product lines, manned or unmanned. *infinidome.com*

Topcon expands MC-X platform

Topcon Positioning Systems has announced the availability of a new GNSS option for its MC-Mobile compact machine control solution. Rounding out the company's compact solutions portfolio, this GNSS option allows contractors to easily integrate their compact machines into fleets already powered by GNSS technology. This expansion gives owners of skid steers, compact track loaders (CTL) and mini excavators the broadest offering of machine control options to date. *www.topconpositioning.com*

ComNav modules now compatible with Galileo HAS

ComNav Technology's K8 series GNSS modules can use the Galileo High Accuracy Service (HAS) precise-point positioning (PPP). The PVT algorithm upgrade to the K8 series module supports Galileo HAS with an accuracy of 20 cm horizontally and 40 cm vertically. Galileo HAS provides free access to information necessary to estimate accurate positioning using a PPP algorithm in real-time through the Galileo signal E6-B and an internet connection. It was declared on January 24, enabling users within the service area to achieve improved positioning performance. *www.comnavtech.com*

All-In-One System for On-Machine Excavator Guidance by Trimble

Trimble has introduced the Trimble® Siteworks Machine Guidance Module, extending the capabilities of Trimble Siteworks Software from surveying and layout to support on-machine excavator guidance and operator assistance. With the addition of the new software module,

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Geo Business 2023
17-18 May
London, UK
www.geobusinessshow.com

9th International Conference on Geomatics and Geospatial Technology
22-25 May 2023
Kuala Lumpur, Malaysia.
http://ggt2023.uitm.edu.my

EUREF 2023 Symposium
23 - 26 May
Gothenburg Sweden
www.chalmers.se

FIG Working Week 2023
28 May - 01 June
Orlando, Florida, USA
www.fig.net/fig2023

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TransNav 2023
21-23 June
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https://transnav2023.umg.edu.pl

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Esri User Conference
10–14 July, 2023
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www.esri.com

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www.iugg2023berlin.org

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16 - 21 July
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https://2023.ieeeigarss.org

September 2023

Commercial UAV Expo
5-7, September 2023
Las Vegas, USA
www.expouav.com

ION GNSS+ 2023
11-15 September
Denver, Colorado, USA
www.ion.org

October 2023

Intergeo 2023
10-12 October
Berlin, Germany
www.intergeo.de

November 2023

Trimble Dimensions 2023
6-8 November
Las Vegas, USA
www.trimble.com

contractors can use the same rugged Site Positioning Systems hardware and software to perform a variety of tasks on the job site, including surveying, machine guidance, in-field design and reporting. *www.trimble.com*

CompassCom releases CompassLDE Connectors

CompassCom Software has announced availability of CompassLDE Connectors for the Cityworks work order management solution that feed real-time automated vehicle location (AVL) details for viewing on the Cityworks Office and Respond maps. The Connectors also deliver valuable asset and job data to automate back-end workflows for more efficient and cost-effective operations. Built on the Esri ArcGIS JavaScript API, Cityworks provides a dynamic map interface where supervisors can assign, review, and modify work orders related to the lifecycle management of assets owned by local governments and utilities. *www.compasscom.com*

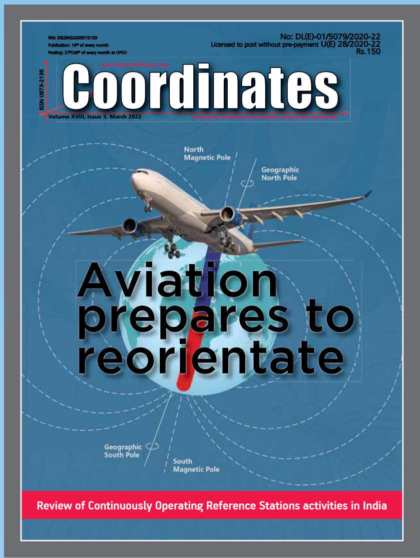
HERE Technologies and Iteris partnership

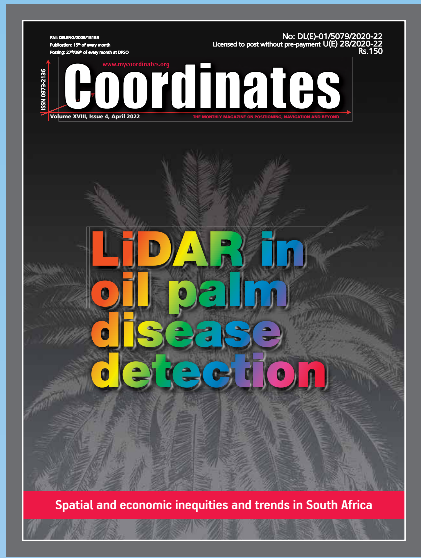
HERE Technologies and Iteris recently announced a multi-year agreement to integrate a broader suite of location-based services and user capabilities from HERE Technologies into Iteris' ClearMobility Platform, including HERE Traffic Products, HERE Maps and HERE platform services.

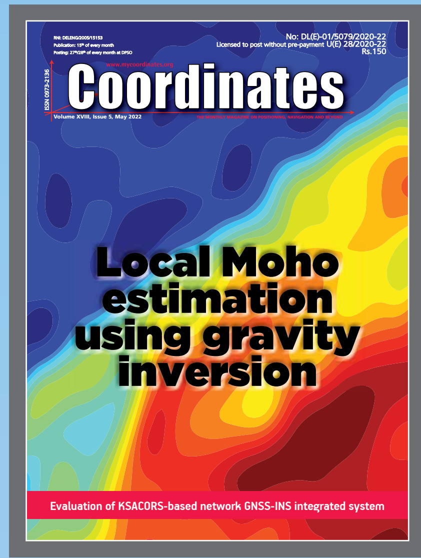
The integration will enhance the dynamic contextual services of the ClearMobility Platform and enrich the insights of Iteris' mobility intelligence application, ClearGuide *here.com*

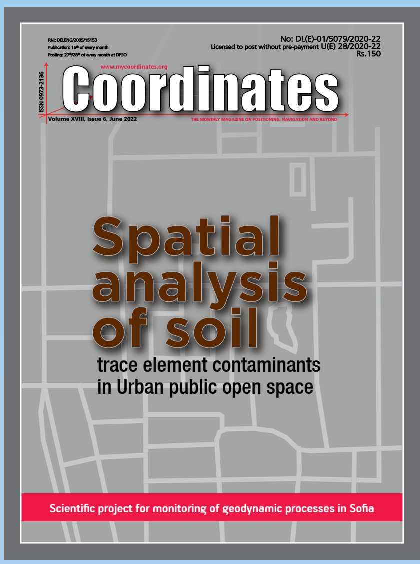
May Mobility launches 3rd gen autonomous driving system

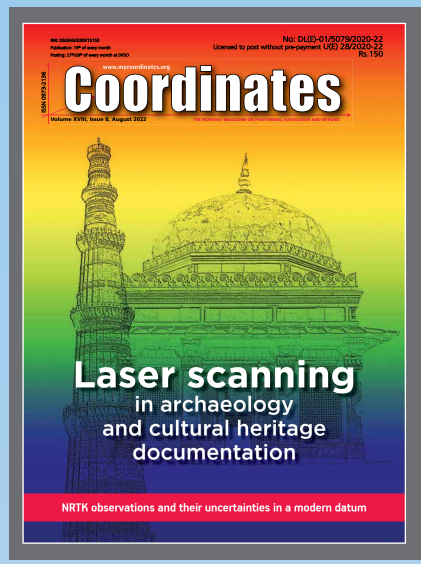
May Mobility announced the launch of its third-generation autonomous driving system. Improvements include increased speed, tele-assist capabilities and improved detection accuracy. *www.maymobility.com*

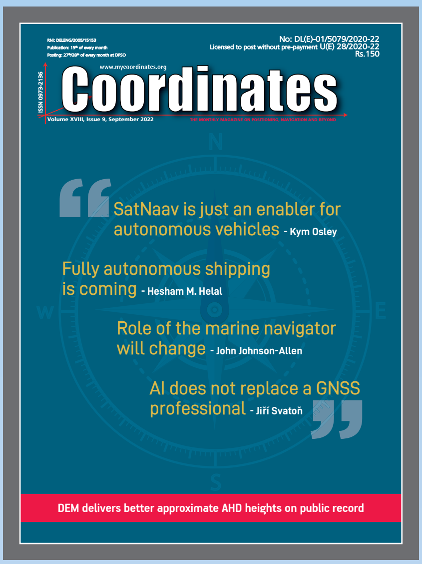


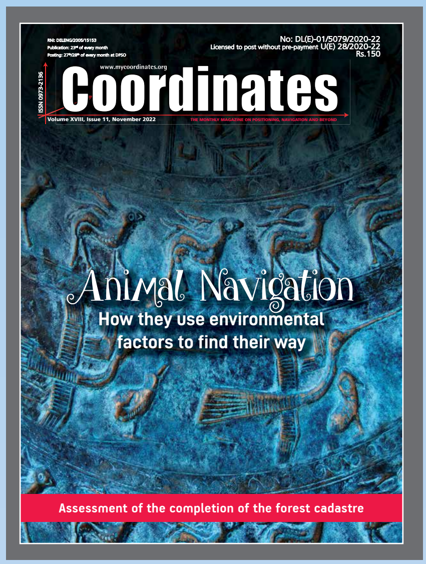












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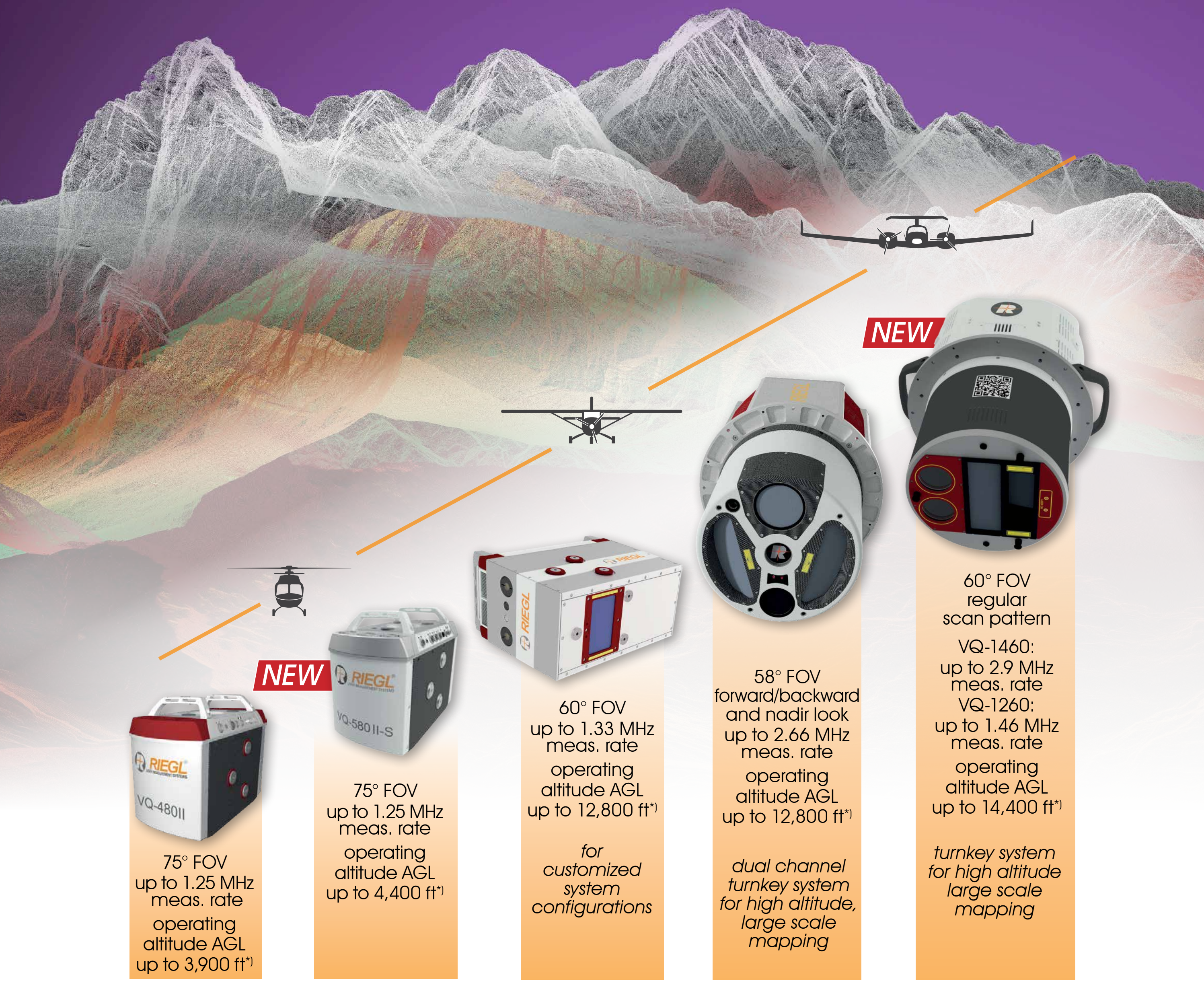

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