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Volume XXI, Issue 2, February 2025

THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Detecting and clearing explosive devices using small-scale customised drone

"We need to increase the visibility of Geodesy"

In Coordinates

10 years before...

mycoordinates.org/vol-XI-issue-02-February-2015

3D+t Acoustic fields modelling based on Intelligent GIS

Vasily Popovich, Yuri Leontev, Victor Ermolaev and Dmitry Chirov
St. Petersburg Institute for Informatics and Automation, Russian Academy of Sciences, St. Petersburg, Russia

Web &Wireless technology plays an important role in everyday life and affects the fundamental science and hi-tech. The approach described in this paper considers the development and implementation of the W2 concept and technology for the underwater acoustics' problems solving. Needless to say that the above approach demonstrates a fusion of different science and technology: W2, GIS, Intelligent GIS and underwater acoustics.

Positioning, Navigation, and Timing (PNT) Governance - Required Improvements

Dana Allen Goward
President, Resilient Navigation and Timing Foundation, USA

GNSS has become an essential, silent, utility, like running water. It is possible, with some discomfort, and reduction in safety and efficiency, for modern societies to do without it for short periods. Extended outages could be disastrous.

Survey requirements for river flood assessment and spatial planning

Enrico C Paringit
Chair, UP Department of Geodetic Engineering and Director of the TCAGP, University of the Philippines, Philippines

Louie P Balicanta
University of the Philippines, Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program, National Engineering Center (NEC), Philippines

Czar Jakiri Sarmiento
University of the Philippines, Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program, National Engineering Center (NEC), Philippines

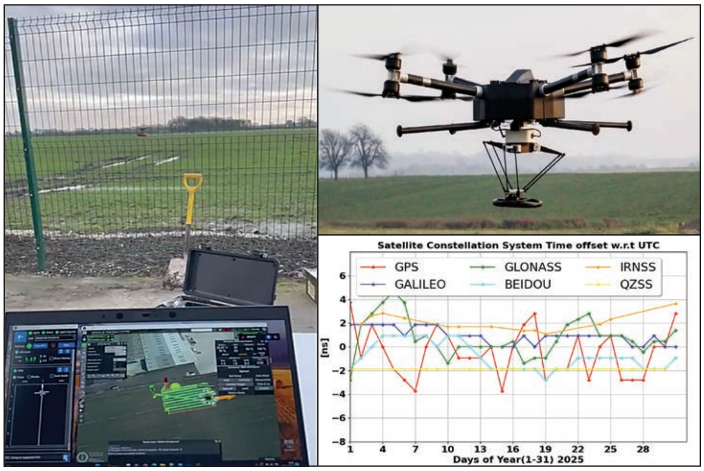
This paper discussed the different surveys employed in order to produce the data required to perform detailed flood hazard mapping and assessment. The flood hazard mapping exercise was able to dene in greater detail the flooding susceptibility of the four river systems based on a combination of various survey techniques employed on ground and in air. The newly generated spatial information serves as a valuable input for land use planning and zoning since it identifies decision zones where settlement and development activities must be regulated.

Tracking satellite footprints on Earth's surface

Narayan Panigrahi
Scientist, Center for Artificial Intelligence and Robotics, DRDO, C V Raman Nagar, Bangalore, India

Raj Gaurav
Navigation-System research enthusiast, Indian Institute of Surveying and Mapping, Survey of India, Uppal, Hyderabad, India

In this paper, a method of conversion of an inertial frame to non-inertial frame has been discussed. In this case we have taken a coordinate system TEME, for which no proper definitions available. We have opted first to transform TEME to PEF coordinate system using GMST, and then transform PEF to ECEF using polar motion coefcient. In this, time conversion method has been used and polar motion parameters have been taken from the http://www.celestrak.com/SpaceData.



In this issue

Coordinates Volume 21, Issue 2, February 2025

Articles

Columns

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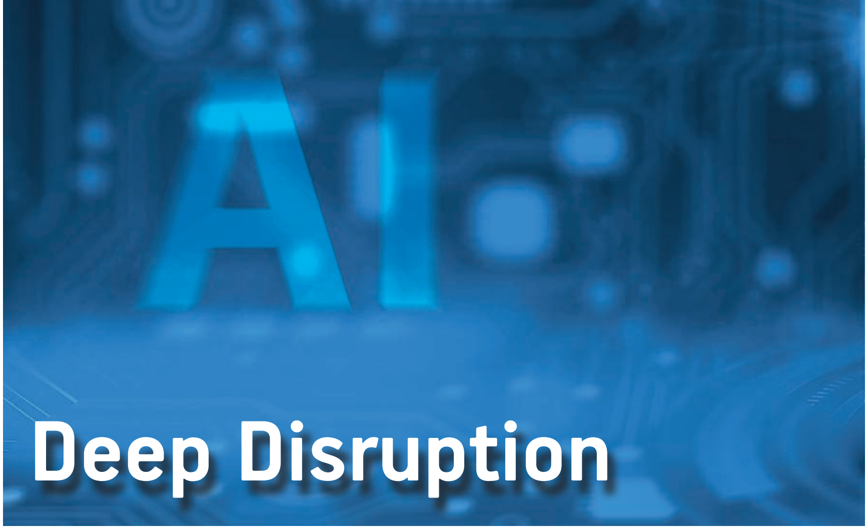

Deep Disruption

Traditionally, the development of large language models (LLMs),

Required immense computational resources,

Resulting into high costs, often in the tens of millions of dollars.

However, the recent advancements in AI have disrupted this paradigm,

Raising questions about sustainability, performance,

And the long-term viability of these models,

especially regarding computational costs associated with inference.

Innovative methods are proving that smaller,

More curated datasets, coupled with smarter training techniques,

Yielding similarly high-performing models at a fraction of the cost.

This shift represents a new frontier in AI development.

Where AI labs increasingly prioritize efficiency over sheer scale.

Bal Krishna, Editor
bal@mycoordinates.org

"We need to increase the visibility of Geodesy"

Says professor Chris Rizos in an interview with Coordinates magazine. He shares his insights on various topics, including the role of the International Union of Geodesy & Geophysics, as well as the importance and current status of Geodesy.

CHRIS RIZOS

Serving as the President of the International Union of Geodesy & Geophysics (IUGG) from 2023 to 2027. He is also an Emeritus Professor in the School of Civil and Environmental Engineering and a co-director of the Satellite Navigation and Positioning (SNAP) Lab at UNSW, Australia

As the serving president of the International Union of Geodesy and Geophysics (IUGG), how do you envisage global collaboration, especially in developing countries?

Global Collaboration is the *raison d'etre* of international scientific organisations such as the IUGG, established as they were in the aftermath of WWI. For its eight semi-autonomous international geoscience associations (representing most Earth and Space Science disciplines) the IUGG provides the platform upon which global and regional research collaboration can be launched. The IUGG makes it possible for scientists (acting as individuals or as representatives of research centres and government agencies) to propose and execute collaborative projects from local, through regional, to global scales. Formal engagement with developing countries (through government agencies, research institutes, and the like) has always been *problematic* due to scarcity of human (and other) resources in these countries. Yet many of the research topics of interest to IUGG scientists (and the projects they focus on) are extremely relevant to developing countries – for example measuring, monitoring and understanding changes in the Earth System due to climate change, natural processes and societal effects, many of which negatively impact on those communities and the environment. The IUGG (primarily through its associations), in the last decades, has made modest progress beyond treating developing countries simply as "open-air laboratories". We have found that the most effective means of encouraging the development of Earth and Space Science research capability is to sponsor travel grants for young scientists from developing countries to attend conferences and workshops. We believe that the individual that is given this opportunity to "rub shoulders" with their discipline's leading researchers will make the most of it, and in the process advance the research capability of their home country. It is estimated that 75-90% of the IUGG's budget is used to support young scientists from developing countries.

How do you envision the IUGG's evolving role in addressing emerging global challenges such as climate change, natural disasters, and sustainable development?

The IUGG's scientists are mainly focused on the Earth – solid, atmosphere and oceans – although some are engaged in "off-Earth"

> One development that is certainly going to require even greater degrees of "spatial enablement" is Automation of transport, logistics and mobility in general. Just consider the challenges of safe navigation, and spatial awareness, of autonomous land, air or marine platforms.

investigations, including other planets, and even distant galaxies. Because the IUGG is very much a scientist-driven organisation (at least as far as the research output, outreach and collaboration aspects are concerned) the research agendas of the various IUGG associations evolve all the time. Most scientists have "day jobs" that are very much focused on addressing Global Challenges – such as the sustainable extraction and consumption of natural resources, disaster risk reduction, changes in the Earth system (such as, but not restricted to, Climate Change), including a variety of anthropogenic impacts. Why is the IUGG's research agenda continually changing? Because the DNA of all scientists (and not just those associated with the IUGG) is to seek understanding of geoscience phenomena, through the application of the "scientific method", to create new knowledge. The Global Challenges listed above are a fertile source of problems for scientific attention.

There are not many experts and educators in Geodesy globally. Do you have any insights into why this might be the case? How do you think we could raise awareness and promote the field?

That is an interesting statement. In my opinion it is not strictly true. There are many scientists who work in Geodesy who never had a formal geodetic education (at undergraduate, or even postgraduate level). They are drawn to Geodesy for a number of reasons, including: the relevance of the geodetic problems or challenges, the opportunity to use cutting-edge space-based technologies, the application of advanced mathematics and associated computer algorithms, and the close links with other geoscience disciplines – which collectively are expanding our understanding of the Earth System. I therefore do not believe there is an education crisis. However, I do feel very strongly that we need to increase the *visibility* of Geodesy, and to promote it more to decision-makers and to the public in general. (Having said that, this awareness challenge applies to many scientific disciplines, and certainly is an issue that must be addressed in the geosciences.) In the case of Geodesy there is now a call for continued government investment in the global geodetic infrastructure.

Your career has spanned over four decades in the field of geodesy and GNSS. What key moments or advancements in the field have most influenced your work and the direction of the industry?

I must say that there is a significant element of *luck* in my career. I was lucky in having an extraordinary PhD supervisor in Professor Ron Mather. I was lucky that my PhD topic dealt with data analysis of a brand new space geodetic technology: Satellite Altimetry. I was lucky in having the opportunity to do postdoctoral work at the Deutches Geodetisches Forschungs Institut (DGFI), in Munich, Germany, under the mentorship of Professor Chris Reigber. But perhaps the greatest piece of luck was discovering GPS in the mid-1980s, and then being able to initiate GPS research projects at the University of New South Wales (UNSW), in Sydney, Australia. Becoming engaged in education, outreach and research activities on the precise positioning technology and applications of GPS at such an early stage has been a career boost. (I contend that Geodetic Surveying was the first civilian GPS application, that has required significant academic and commercial innovation.) My 40 years as an academic has introduced me to talented graduate students that I had the privilege of supervising, and to many colleagues in academia, government and industry. Being an "early GPS researcher" has opened the doors for me to become involved in many global organisations, and international committees and institutions, of which perhaps the most important have been the International Association of Geodesy (IAG), the International GNSS Service (IGS), and the International Committee on GNSS (ICG).

Your aim through your research has been to "spatially enable" all aspects of life. Can you elaborate on how this concept is being realized in real-world applications, and where do you see the most promising opportunities?

Many professionals are enthusiastic users of geospatial technologies, and they understand the enormous value to society of "spatially enabling" many functions of government, improving the operations of businesses, managing the environment and resources, and assisting citizens and society in their daily activities. The obvious ones are surveyors, civil engineers, geographers, architects, urban planners, and more. Increasingly the spatial "world-view" is recognised as being a *fundamental* one. Fundamental to improving the quality of our lives, to sustainable development, and to our measurement and monitoring of relationships and interactions between disparate objects and land features in the built and natural environments.

Such recognition is driving governments and large corporations to adopt practices that further the "spatial enablement" of all aspects of modern society. Today we *expect* to know where we are, where "things" are, how to navigate from A to B, what the spatial connections are, and how to use geospatial tools and data to make better decisions. It is an unmistakeable trend, though it is very difficult to make predictions on many future developments and opportunities. However, one development that is certainly going to require even greater degrees of "spatial enablement" is Automation of transport, logistics and mobility in general. Just consider the challenges of safe navigation, and spatial awareness, of autonomous land, air or marine platforms.

As a big picture thinker, you have watched Geodesy, rapidly evolve with its tools and datasets. How do you see satellite-based geodesy contributing to the global response to the challenges such as climate change, environmental shifts, and geohazards?

The geosciences represented by the IUGG's associations all have a set of common goals. These include measuring physical parameters that are the "fingerprints" of faint signatures of Earth System *changes*, understanding the fundamental causes of such changes, and addressing the impacts through engineered solutions such as early warning systems, scientific services, advice to decision-makers, and others. Geodesy provides the (mostly space-based) tools, the methodology, the framework, and the operational systems that can address many of the Global Challenges referred to earlier. I therefore believe that Geodesy can no longer be considered a *niche* geoscience discipline, but rather it is a *capability* used by geoscientists, by geospatial professionals, and, increasingly, by the general public. Its importance is not just its cool satellite-based tools – for Earth observation, or even GNSS positioning and timing – it is the *framework* by which every spatial tag or coordinate can be unambiguously connected to the Global Geodetic Reference Frame (GGRF). Geodesy's unique role is to provide the *foundations* for a "spatially enabled" society.

With the rise of intelligent transport systems (ITS) and autonomous vehicles, what breakthroughs are needed in GNSS to ensure safe and reliable navigation in these advanced systems?

As I mentioned in an earlier response, Geodesy provides tools, methodology, operational systems (such as the IGS), and a highly-stable framework (the GGRF). However, GNSS provides the unique capability to determine Position, globally, continuously to appropriately equipped users. Furthermore, as a result of many innovations over the last four decades, the accuracy of position (i.e. of coordinates expressed in the GGRF) can be "tuned" to an application requirement. The GNSS user hardware, software and algorithms, operational procedures, and service provider augmentation systems, can be selected to address accuracy requirements from dekametre (as in mobile phones), to metre-level (transport applications), sub-metre-level (mapping), centimetre-level (surveying, construction and precise navigation of autonomous platforms), down to sub-centimetre-level (geodesy, datums, meteorology). GNSS is the most important geodetic tool ever developed. However, by virtue of its versatility (see accuracy requirements above) GNSS has *revolutionised* many aspects of modern society. GNSS is the first-choice Positioning, Navigation and Timing (PNT) technology for all outdoor applications. Therefore, it is no surprise that GNSS is a core technology for autonomous vehicles, and ITS in general. There is currently no alternative to GNSS for precise Positioning and Timing, that is readily available on a global basis at reasonable cost. (Note that the Navigation task of PNT can be undertaken using non-GNSS technologies, such as imaging and radar systems, in a "sense-and-avoid" mode of navigation that also maps the moving platform's immediate environment using the principles of Simultaneous Localisation and Mapping – SLAM.) However, GNSS is vulnerable to intentional and unintentional jamming or spoofing, which can degrade its PNT solutions, or deny PNT capability entirely. The "hunt" is therefore on for a complementary or alternative technology to GNSS that can provide resilient PNT capability. That is, provide PNT solutions in environments where there are GNSS signal blockages, cyber attacks, or RF interference. The coming decade will see a number of technology and service options being offered. The most promising is using a constellation of ultra-small satellites in Low Earth Orbit (LEO) to *augment* GNSS, so as to increase PNT *resilience*.

> GNSS innovations in the coming decade include an increased focus on GNSS receiver, signal and measurement processing algorithm design to support high integrity and high accuracy applications. There is very likely to be continued interest in multi-sensor integration of the "GNSS plus" variety, including GNSS+LEO-PNT, and even of the perennial GNSS+INS (Inertial Navigation System) type, as the INS technology itself evolves.

There is very likely to be continued interest in multi-sensor integration of the "GNSS plus" variety, including GNSS+LEO-PNT, and even of the perennial GNSS+INS (Inertial Navigation System) type, as the INS technology itself evolves

Non-satellite-based systems such as Locata are becoming more prominent. How do you foresee these technologies complementing GNSS in critical applications like autonomous vehicles or indoor positioning? What are your views on e_Loran?

As I have mentioned above, the search for *resilient* PNT is driving the development of complementary GNSS PNT technologies. The deployment of CPNT technologies assumes the continued use of GNSS for all military and civilian applications when it is available, and its accuracy and continuity is *assured* (or can be "trusted"). However, there are environments where GNSS cannot be used, even when augmented with CPNT technologies such as LEO-based PNT. These include indoors, underground and where there are many (metallic) reflective surfaces that degrade GNSS or LEO-PNT signals due to "multipath". High accuracy PNT (Positioning at the centimetre-level accuracy, and Timing at the sub-nanosecond accuracy) is particularly challenging for autonomous vehicles in warehouses, open-cut mines, and container ports. CPNT technologies to address these challenges are unlikely to be the same as those intended to be used for resilient PNT in open-air operational environments. *Locata* was designed for the former, *eLoran* can be considered a candidate for the latter – although its accuracy is far less than can be achieved with even the most basic GNSS user equipment. (Personally, I see no sense in resurrecting *eLoran*, except if one is preparing for an "armageddon" scenario!) I acknowledge that I have been assisting in the development of the Australian *Locata* technology for over two decades, through joint projects, trials, graduate student research, and publications, hence I may be biased! Locata is an amazing invention as it tackles the CPNT problem at several levels. It has its own infrastructure of signal transmitting towers that are synchronised to picosecond-level. This means that the user positioning mode is in many ways identical to GNSS's "precise point positioning" technique. *Locata* has multi-antenna element multipath mitigation that is far superior to anything available on the market. However, *Locata* is a "local" PNT system, intended for "hot-spot" type deployments in, for example, container ports. Furthermore, its time transfer accuracy makes it a candidate for a non-GNSS terrestrial time-dissemination backbone for a city or country.

You've mentored over 35 PhD students. What advice do you have for young researchers entering the fields of GNSS and geodesy today, and what areas do you think hold the most potential for future research?

Geodesy offers many fields of research. New sensor technologies, on satellite missions, can map the Earth's solid, ice and ocean surface, and its changes over a range of time scales, information that can be used to improve our understanding of the Earth System, in both its natural state and as it is impacted by anthropogenic processes. The use of AI for geodetic data processing and pattern identification is an exciting research opportunity. As is sensor systems based on Quantum Principles. Furthermore, most of the geodetic tools and methodology can be applied to other planets and their moons! Even GNSS will be used for PNT applications on the Moon. GNSS-Reflectometry is an Earth Observation technique that uses reflected GNSS signals to sense the state and composition of the solid, ice or ocean surfaces. Resilient GNSS, especially LEO-based, is another topic ripe for academic research. There are also many CPNT research topics. Finally, research in Geodesy and GNSS fields also has commercial value, offering prospects to apply graduate research training in startup companies.

Looking ahead, what do you believe will be the most significant innovations in GNSS in the next 10-20 years, and how will they shape our daily lives?

Where do I begin? Lists of "mega-trends" are an obvious place to look for future applications that could benefit from *innovations* in GNSS. (Of course, given the utility of GNSS for military and security operations, we can expect considerable R&D to address this application space.) GNSS innovations in the coming decade include an increased focus on GNSS receiver, signal and measurement processing algorithm design to support high integrity *and* high accuracy applications. There is very likely to be continued interest in multi-sensor integration of the "GNSS plus" variety, including GNSS+LEO-PNT, and even of the perennial GNSS+INS (Inertial Navigation System) type, as the INS technology itself evolves. GNSS will therefore continue to be an indispensable technology embedded in our mobile phones, our automobiles, wearables, health monitors, and – as an "Internet-of-Things" (IoT) technology – in many mobile devices and objects, that may be valuable, critical sensors, or perishable (e.g. foods, medical supplies, etc). Robotic applications will be important, even on the Moon. Non-PNT applications of GNSS will mature, and GNSS will become also a highly efficient Earth Observation technology, using the principles of GNSS-Reflectometry and GNSS Radio Occultation, to sense not only the Earth's surface but also the Troposphere and Ionosphere.

Intelligent, automated, rapid, and safe landmine, improvised explosive device and unexploded ordnance detection using Maggy

In this study, a small-scale customised drone – the so- called Maggy – was developed to simplify and automate the procedures of cleaning explosive devices. We present here the first part of the paper. The conculding part of the paper will be publsihed in March issue.

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Abstract

Detecting and clearing legacy landmines, Improvised Explosive Devices (IED), and Unexploded Ordnances (UXO) using a force made up of humans or animals is extremely risky, labour-and time-intensive. It is crucial to quickly map millions of buried landmines/IDE/UXO, and remove them at a reasonable cost to minimise potential risks and make this labour-intensive task easier. Using unmanned vehicles and robots outfitted with various remote sensing modalities appears to be the ideal way to carry out this task in a non-invasive manner while employing a geophysical investigative method. In this study, a small-scale customised drone – the so-called Maggy – was developed to simplify and automate the procedures of cleaning explosive devices. It was instrumented with innovative intelligent automated techniques and magnetometer sensor technologies. Maggy's performance was assessed in field tests conducted in Latvia and the United Kingdom. The outcomes, obtained in the open-air minefields and the benchmark assessments, verify the viability of the technologies, methods, and approaches integrated into Maggy for the efficient and economical detection of legacy landmines and IDE/UXO. This research provides the related research community with fundamental design and implementation parameters (e.g. flight speed, flight altitude) in building and using magnetometer-integrated Unmanned Aerial Systems (UAS). The improved versions of the developed easy-to-use compact technology are aimed to be deployed by humanitarian demining teams to expedite their clearing operations safely and efficiently.

I. Introduction

Detecting and clearing legacy landmines (anti-tank (AT) and anti-personnel (AP)), Improvised Explosive Devices (IED), and Unexploded Ordnances (UXO) using a force made up of humans or animals is extremely risky and labour- and time-intensive [1]. When these explosives come into contact with, are near to, or are in the presence of a person or vehicle, they explode. In particular, AP landmines cause long-term casualties and psychological effects by mutilating, rather than killing. More than 1,000 deminers have lost their lives or suffered injuries while performing demining operations between 1999 and 2012 [2]. All around the world, there are approximately 100 million buried landmines [3] due to the low-cost manufacturing [4] and simplicity of deployment across wide regions. 61 states worldwide are severely impacted [5] by the slow demining process [6]; these include, but are not limited to, Croatia, Bosnia and Herzegovina, Serbia, Afghanistan, Montenegro, Libya, Syria, Iraq, and most recently, the war-torn regions of the west of Ukraine and Azerbaijan. By the end of 2005, Bosnia and Herzegovina declared that there was a possibility that over 4% of their territory was contaminated with landmines [7]. In 1997, two years after the war ended, 23% of Croatian territory was thought to be mine-suspected [7]. 10.413 people in Colombia, one of the nations most affected by landmines worldwide, lost their lives to landmines between 1990 and 2013 [8]. Over 35,000 amputees in Cambodia have been impacted by a landmine explosion [2]. The average number of people killed or maimed annually is 26,000 [9] and 80% of this figure is children [5]. Ten mines are placed for every mine removed, despite recent efforts to reduce their use [10]. The precise locations of legacy landmines that have been buried are unknown, and landmines can shift slightly depending on the features of the land and the time they were buried. Using conventional methods to remove millions of landmines/IDE/UXO would take more than a century [11] with potential risks and high costs [12], which will have a long-term, significant impact on these nations in a variety of ways. Their presence continuously puts communities in danger, obstructs economic growth, and makes it difficult for infrastructure, agriculture, and resettlement to have safe access to land. The development of a landmine/UXO/IDE detection system that is quick, safe, and economical is urgent. Land-based vehicles face a number of challenges, including accurate navigation over rough terrain despite being supported by various mechanisms like wheeled, legged, and dragged robots [13]. Furthermore, it takes a while to scan larger terrain with those slow, heavy vehicles. Autonomous drones have recently been deployed to accomplish a diverse range of missions (e.g. logistics [14], smart cities [15], agriculture [16]), due to their efficient and effective use. Drones can expedite surveying and provide better access to challenging terrain with tough and hard-to-reach topography and thick vegetation [17], [18], [19]. Unmanned Aerial Vehicles (UAVs) suited to covering a large area for the purpose of easing labour-intensive mine clearance have been used in numerous studies with different detection approaches. These studies are analysed in Section II.

Magnetometers consume very little power in addition to their affordable and lightweight features and drone applications can benefit from using magnetometers in a diverse range of applications efficiently and effectively. This work, by developing a magnetometer-integrated Unmanned Aerial Systems (UAS) has been focused on landmine/UXO/IDE detection, primarily, for supporting the humanitarian clearance challenges and constraints around the world – such as the need to operate in unforgiving, undulating terrain, which may be overground with vegetation. The contributions are listed below to make the novelty of this paper clear.

A bespoke, low-cost, small footprint, easy-to-use, and autonomous robotic drone – the so-called Maggy (Figs. 14, 15) – integrated with magnetometer sensor modalities (Fig. 10) was developed to detect landmines/IDE/UXO locations rapidly and safely. Low mass, small size, and lightweight Maggy with low energy consumption is capable of inspecting fields at low altitudes through pre-programmed routes with extreme height precision and terrain following mode for revealing the probable landmine/UXO/IDE spots.

A tablet/smartphone application (Fig. 16) was developed and integrated with Maggy to i) manage Maggy, ii) process real-time data streaming from Maggy to locate landmines/IDE/UXO, iii) perform detailed survey analysis considering varying magnetic fields (MF), and iv) communicate with the landmine/UXO/IDE clearing team for reporting exact landmine/UXO/IDE locations.

The developed small, lightweight and robust aerial platform can be carried in a backpack and rapidly deployed by humanitarian demining teams in supporting their humanitarian landmine/UXO/IDE clearance activities safely and efficiently.

This research provides the related research community with fundamental design and implementation parameters (e.g. flight speed, flight altitude) in building and using magnetometer-integrated UAS.

The rest of the paper is organised as follows. The literature survey is conducted in Section II. The developed approaches and techniques in this study are explored in Section III. The results within the experimental setup are presented in Section IV. Results and findings are discussed in Section V. Section VI draws conclusions followed by the limitations in Section VII. Finally, Section VIII provides directions for potential future works.

Related Works

Metal detector technologies, electromagnetic (e.g., ground-penetrating radar (GPR), microwaves, nuclear quadrople resonance (NQR), infrared (IR), electrical impedance tomography, X-ray backscatter, neutron methods, sound and ultrasound), acoustic/seismic, biological (e.g., rats and dogs, bacteria, bees, antibodies, chemical methods), mechanical methods (e.g., prodders and probes, mine-clearing machines) are the main non-invasive methods employed in landmine detection [10]. Among these, metal detectors are the most commonly used tools for detecting landmines in humanitarian demining [7]. The capabilities and limitations of metal detectors are analysed by Dieter et al. [7] for determining which detector is appropriate to be used under what circumstances. The ever-evolving technology of landmines poses a significant obstacle to clearance efforts [20]. Existing metal detectors require the user to be physically close to the scan area, and that presents a real risk of injury or fatality when the area has emplaced ordinance either buried or scattered on the surface. Such systems tend to give an audio warning when a detection is made, and it is not recorded or geo-stamped. Detecting new landmines is more difficult because they contain fewer or no metals [2]. Stated differently, there are numerous varieties of landmines composed of diverse materials, including plastic, glass, wood, and metal, and they come in a range of sizes [21], most of which are undetectable by conventional electromagnetic-induction (EMI) methods used in metal detectors.

A number of other diverse approaches have been employed to mitigate the shortcomings and constraints of the metal detectors. The use of GPR seems a viable option to support metal detectors and increase the detection accuracy of a demining system [9], [22], [23], [24] where it can detect a wide range of landmines, especially, in detecting non-metallic objects at depth, even though it is susceptible to various localised ground inhomogeneities and surface roughness [22], [20]. In addition to being sensitive to local inhomogeneities of the ground, the small electromagnetic (EM) radar cross sections for non-conducting materials make it challenging to detect buried explosives made of dielectric or polymer-based materials (plastics) [25], [26]. Moreover, regarding sensing capabilities, high-priced GPR systems have limitations due to strong random clutter at rough air-soil interfaces [27], the size of targeted objects (<10 cm) [28] and soil moisture and flight height [29]. To overcome these deficiencies, there have been numerous attempts to employ various other sensor modalities as mentioned earlier different from metallic detectors and GPR to reduce the false alarm rate (FAR), increase the chance of detection, and expedite the landmine/UXO/IDE clearing operations safely. Every technique used in these attempts has shortcomings. For instance, Lihan et al. [21] and Ishikawa et al. [30] assess dual sensor approaches that make use of both EMI and GPR sensors to compare the effectiveness of dual sensors and metal detectors. These approaches are particularly effective in differentiating between landmines and metal fragments and extending the detectable range in the depth direction. Donskoy et al. [31] use remote measurements of soil surface vibration (using laser or microwave vibrometers), processing of the measured vibration, and vibration (using seismic or airborne acoustic waves) of buried objects to extract the "vibration signatures" of mines.

Thanks to cyber-physical systems (CPSs) and enhanced Artificial Intelligence (AI) techniques, recent years have seen an increase in the intelligence of the "everyday things" in our environments considering Internet of Everything (IoE) [32], [33] enabling them to make decisions with an increasing degree of autonomy and little to no help from humans, leading to the development of advanced robotics systems. In addition to using different types of sensor modalities, there are various initiatives to speed up the demining process and prioritise safety using robotic systems. For instance, Aoyama et al. [3] propose a land vehicle robot with a mine detector; Sun and Li [23] propose a mine detection using a land vehicle on which a forward-looking GPR (FLGPR) is mounted. In particular, to more quickly detect landmines on larger fields, vision-based remote sensing (VBRS) modalities are becoming more and more popular as a

FIGURE 1. MANTA Mine Kafon[1]: GPR and metal detectors.

FIGURE 2. Binghampton University (NY) – De Mine Research Group[2]: Bigger and less manoeuvrable platform; real-time sensing and detection.

solution to the drawbacks of the currently in use of off-the-shelf conventional techniques. These methods are founded on various physical principles, e.g., vapor/builk detection, electromagnetic detection, and optoelectronic imaging [34]. Nonetheless, a number of factors, including the type of soil, weather, lighting, and ambient conditions, must be taken into consideration when applying these techniques successfully [34]. More specifically, over the past 20 years, spectral remote sensing technology has made great strides and is now being utilised more and more in lab-scale applications (such as forensic, biomedical, industrial, biometric, food safety, and pharmaceutical process monitoring and quality control) [35]. Increased and sustained agricultural yields, water resource management, food safety and quality evaluation, disease diagnosis, artwork authentication, forensic analysis of disputed documents, military target detection, and counterterrorism have all benefited from the use of hyperspectral imaging [36]. By exploiting this technology, Banerji and Goutsias [37] suggest combining an aerial minefield imaging system with multispectral (multiple wavelengths) sensors as part of a morphological approach to automatic mine detection. Anderson et al. [38] analyse the multispectral photos to look for landmines on the basis of histograms. Differentiating the thermal properties of the soil and the buried objects is how the detection is made [34]. Thanh et al. [34] suggest a finite-difference approximation of generalised solutions to the thermal model as a 3-D linear forward thermal model for buried landmines. Among the technologies in use, the dynamic thermal infrared technique (IR images of the soil surface obtained at multiple time instants) appears to hold promise for the detection of non-metallic landmines that are shallowly buried and for differentiating them from other buried objects by utilising the differences in thermal properties between the buried objects and the soil [39] [34], [39]. In other words, the existence of buried objects influences the soil's ability to conduct heat, leading to variations in soil temperature above the objects compared to areas that have not been disturbed; an IR imaging system situated above the soil area can measure this temperature signature [39].

FIGURE 3. Sensys R4 System[3]: Larger platform but offer full solutions and software.

FIGURE 4. F5 PRO quadcopter[4]: invested by NATO, 20-30 mins flight time, no real-time data processing.

FIGURE 5. Onboard sensors: Magnetometer and GPR.

The use of UAVs is clearly suited to covering larger minefields without the danger of triggering landmines/IDE/UXO during humanitarian clearing activities. The incorporation of UAS equipped with various sensor modalities into clearance operations has recently become popular. García Fernández et al. [40] propose a synthetic aperture radar imaging system for landmine detection using a GPR integrated with a drone. Measurements in controlled and real-world scenarios validate the algorithms and the UAV payload, demonstrating the viability of the suggested system. Mine Kafon integrated both a GPR and a metal detector with an aerial vehicle as shown in Fig. 1. García Fernández et al. [41] suggest using an aerial Synthetic Aperture Radar (SAR) imaging system to obtain complete three-dimensional (3D) radar images from below the ground. Schartel et al. [42] carried out airborne landmine detection with a circular synthetic aperture radar. Garcia-

TABLE 1. Properties of Fluxgate sensor — HWT3100-485.

#	Features	Properties
1	Output	MF and heading angle
2	MF range	-800uT — +800uT
3	Heading angle range	-180 — +180
4	Sensitivity	13nT/LSB
5	Return rate	can be adjusted between 0.2-100Hz
6	Components	Built-in sensor chips: 2*Sen-XY-f(pn13104) and 1*Sen-Z-f(pn13101) geomagnetic module; 1*Mag12C(pn13156) control chip
7	Resolution	16 bits for each axis
8	Voltage	5V—36V
9	Current	<10mA
10	Volume	83mm*25mm*25mm
11	Data interface	485 serial port (the specific level depends on the selection, the baud rate
12	Casing	Waterproof and vibration-resistance aluminium casing

Fernandez et al. [43] analyse airborne multi-channel ground penetrating radar for landmine/UXO/IDE detection. The use of GPR systems, with their large size and heavy weight, on UAS is extremely restrictive, especially, on lightweight drones with smaller payloads (Fig. 5). Badia et al. [4] suggest a blimp-based UAV outfitted with a widely tuned metal-thin oxide chemo-sensor through the use of a bioinspired detection architecture where employing trained animals is still one of the most widely used techniques for explosive detection. Colorado et al. [13] suggest a UAV-based system that recognises and processes images of partially buried landmine-like objects.

According to a market research report by MarketsandMarkets, the global magnetometer market was valued at around USD 2.44 billion in 2023 and was projected to reach USD 4.34 billion by 2032, growing at a compound annual growth rate (CAGR) of around 6.60% during the forecast period [44]. These figures indicate the market's significant size and potential for expansion. The active detection of small UXO by measuring electromagnetic responses is analysed in [45] using a magneto-inductive sensor array, in [46] using broadband electromagnetic induction sensors, and in [47] using fluxgate sensors. The detection and classification of subsurface UXO using a magnetic field with a magnetometer is analysed in [48], based on a set of landmine or UXO sensor signatures. It is concluded in these studies that since many target signatures are site-dependent and variable based on the features of UXO, obtaining trustworthy priori training data in advance of designing an algorithm is frequently challenging. Considering this conclusion, the techniques developed in our research employ field-dependent data sets, without requiring a priori training set. The self- and user-selective threshold classification and clustering mechanisms help reveal MF distinctive from the rest of the Area of Interest (AoI) as elaborated in Section III.

The integration of magnetometer sensors with small UAS is carried out by various studies to realize different objectives such as [49] and [50] in increasing the quality of magnetic field by reducing the permanent and induced interference magnetic field generated by the drone. We aim to increase the quality of the magnetic field in our novel drone and sensor integration design as explicated in Section III-B. The effectiveness of drones equipped with magnetometers in detecting buried metallic explosives, in particular, AP and AT landmines, was demonstrated in various studies [51], [52], [53]. We analysed the initiatives of using drone-mounted magnetometer systems in the market. The magnetometer-mounted UAS have been developed to provide an integrated solution to demining operations as demonstrated in Figs. 2, 3, 4. The features of these UAS are summarised in their legends. These systems are yet to provide an ideal compact system that the market demands as elaborated in Section V (Table 6). Millions of buried landmines still need to be found and removed manually, despite significant efforts to identify landmines using automated remote sensing approaches and using these manual techniques, it would take hundreds of years to fully demine all of these mines. It is now critically necessary to develop landmine/UXO/IDE detection and removal systems quickly [3] where their removal is very risky, expensive, and time-consuming [4]. The incorporation of aerial surveying supported by drones and multiple sensor modalities seems to be the most viable option to expedite the demining, specifically, in tough terrains. In this paper, regarding the previous promising studies on magnetometer sensor modalities, we have built a new integrated holistic system to detect landmines/IDE/UXO automatically in large terrains using UAVs. To the best of our knowledge, this research is the first attempt to determine the likely locations of potential landmines/IDE/UXO autonomously, rapidly and safely using a bespoke, lightweight, small and intelligent aerial-based, integrated, and easy-to-use compact drone (quadcopter) system equipped with a magnetometer sensing system and live sensor data telemetry link, which meets most of the market demands as explicated in Section V (Table 6).

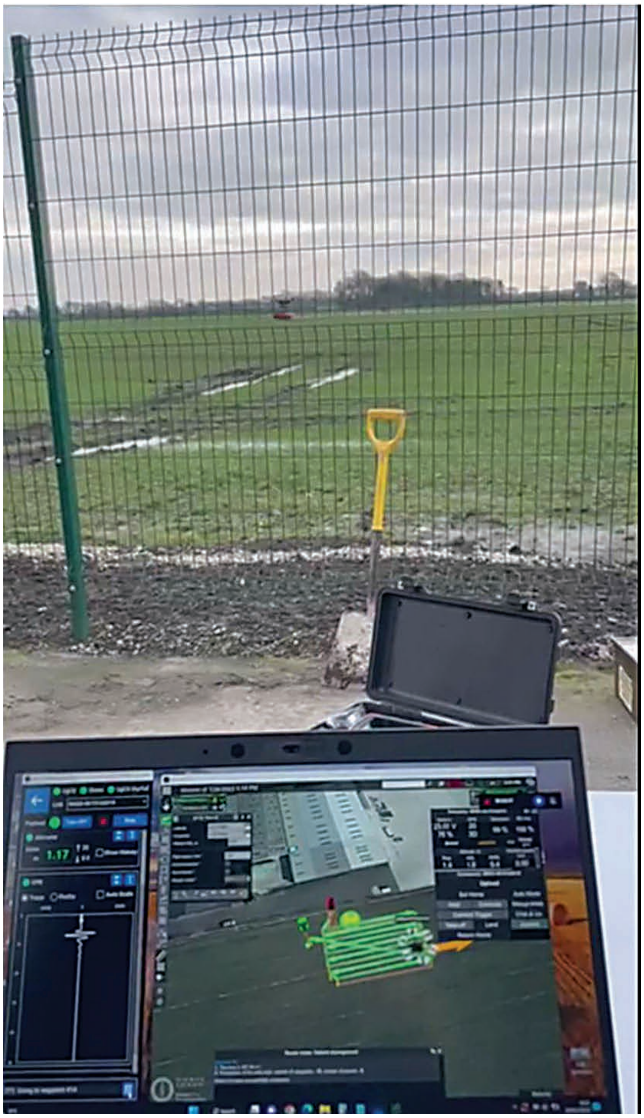

FIGURE 6. Autonomous mission monitoring in the UCLan landmine field. The drone (Fig. 5) is flying with an altitude of 1 m at a 1 m/s flight speed.

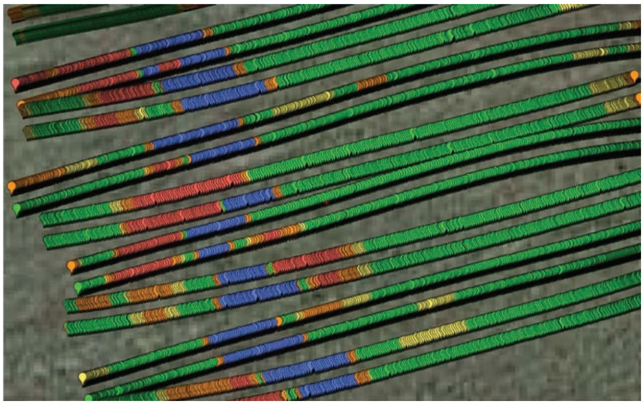

FIGURE 7. All scanned data points (Fig. 6) highlighted with 7 categorised colours which indicate the level of MF. Both magnetometer and GPR are actively acquiring data with no interference between them.

FIGURE 8. Landmine locations with very high MF points filtered from the scanned data in Fig. 7.

FIGURE 9. Examples for the plastic and metal landmines in different depths in the UCLan landmine field (Fig. 8).

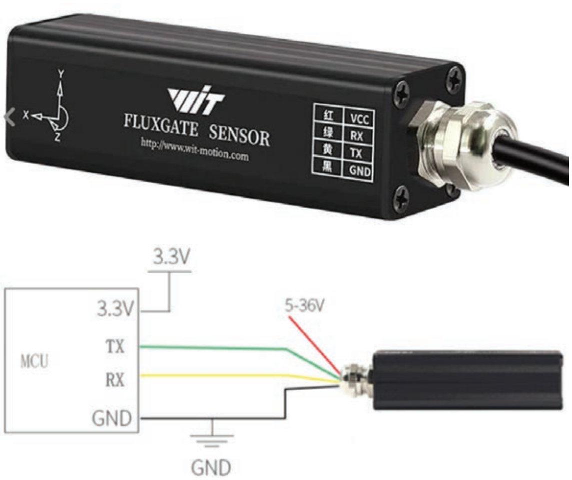

FIGURE 10. Fluxgate sensor with three-axis MF output. Model: HWT3100-485.

Methodology

A. Background

This research is based in The University of Central Lancashire (UCLan)'s Engineering and Innovation Centre, a 35m building bringing together additive manufacturing, software

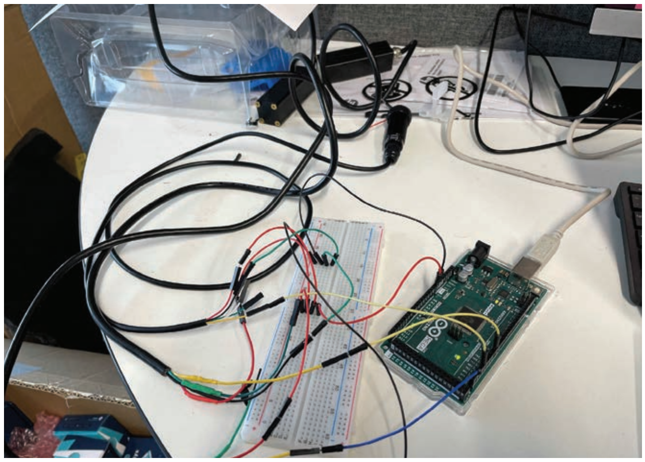

FIGURE 11. Integration of sensors with onboard Arduino.

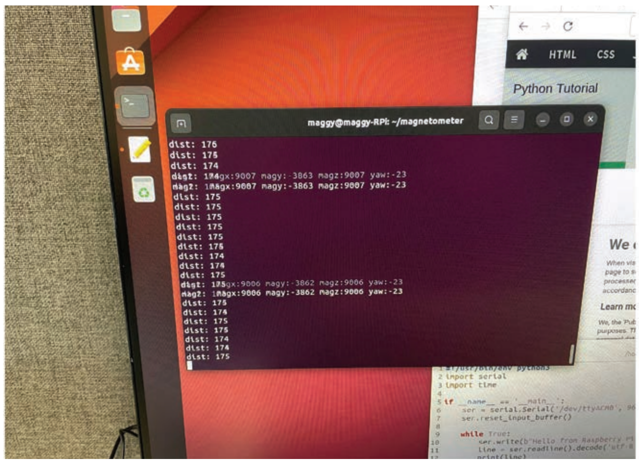

FIGURE 12. Acquiring the sensing.

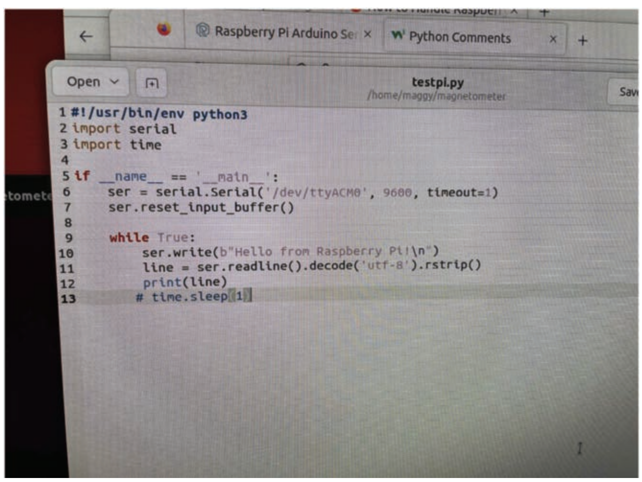

FIGURE 13. Programming of sensing using Python.

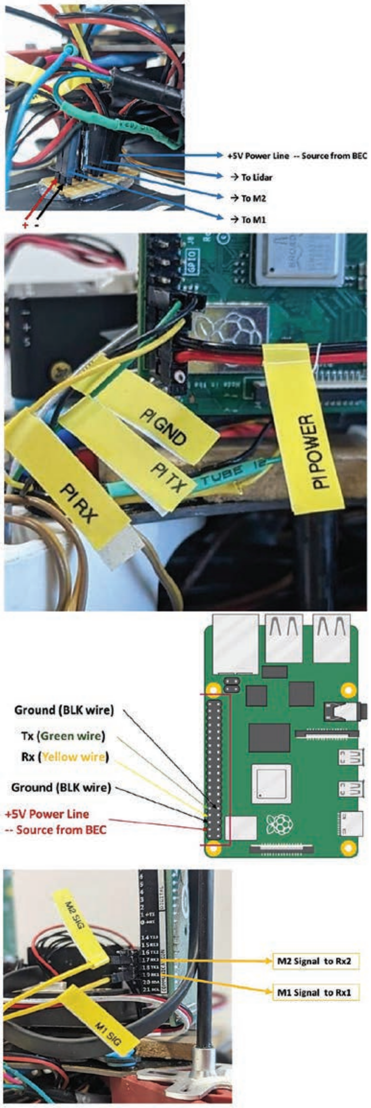

FIGURE 14. Inner component design of Maggy with detailed wiring diagram.

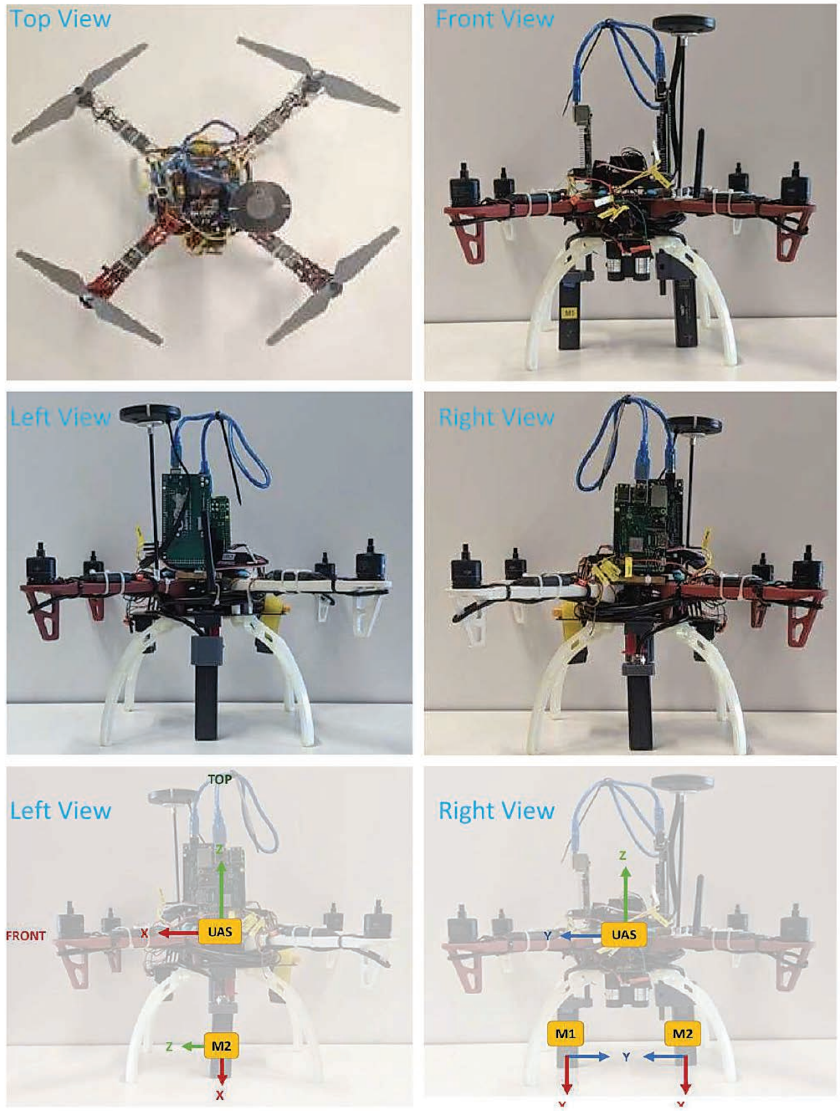

FIGURE 15. Outer design of Maggy.

TABLE 2. Features of Maggy in Figs. 14, 15 considering its drone components.

Component	Features
UAS/aircraft model name	DJI F-450
UAS battery packs	Tattu 4S 1800mah
UAS battery chargers	Overlander Charger
Transmitters model name	Futaba T8J
Transmitters battery packs	NiMH 4.8V
Transmitters battery chargers	Futaba Battery Charger
Ground station control model name	HP 15inch Laptop / Android Tablet + chargers
SiK telemetry	HolyBro ground side unit
Data communication	Netgear + charger
Data transfer	USB flash Drive, Arduino – Pi Cable
Propeller set	9X4.5
Software	QgroundControl, Wit-motion software

simulation technologies, advanced composites and a host of interdisciplinary engineering teams. UCLan has been testing multiple sensor modalities for 12 years in a diverse range of projects (e.g. [54], [55], [56], [57], [58]). UCLan received an investment of £ 1.3M in 2021 to procure drone equipment to support local businesses and enable new research.[5] Many commercially available geophysical ground scanning sensors were procured and bespoke ones were developed. These have been utilised and evaluated over the last few years in helping solve real-world problems intelligently. UCLan has developed many bespoke autonomous small, lightweight, compact quadcopters equipped with sensors for different types of objectives (e.g. for agriculture [59], [60], landmine/UXO/IDE detection [1], collision avoidance [17], beyond visual line of sight (BVLOS) teleoperation [61], [62]). UCLan has been collaborating with the Cambodian Army and several landmine-cleaning-based NGOs to develop new approaches and improve the pre-developed techniques for detecting and demining landmines. The Aerospace and Sensing Research (ASR) team at UCLan tested drone-mounted magnetometers with Cambodia's Armed Forces Peacekeeping Division.

The ASR team was previously funded by both the Global Challenges Research Fund (GCRF) in 2018 and the Internal Engineering Research Centre Fund in 2021 in developing landmine/UXO/IDE applications. The performance of particular remote sensing sensor modalities such as GPR, magnetometers, infrared (IR), a Longwave Infrared (LWIR) camera, and a multispectral camera has been evaluated in-field tests. The fusion of data obtained from the integrated GPR and magnetometer sensor modalities mounted on an autonomous UAS (Fig. 5) has already accomplished satisfactory results with very high accuracy rates in finding landmines [1] (Figs. 6), 8). Initial datasets using vision-based remote sensing sensor modalities (i.e. IR, LWIR camera, and multispectral camera) were collected in Croatia in 2018 [63]. Later, the developed sensor-integrated UAS were tested in Cambodia in larger mine-affected areas in cooperation with the Cambodian Army and NGOs to quantify the observed results in difficult scenarios. Two landmine sites (UCLan Hawkins yard and Myerscough site (Figs. 8, 9) were already designed with landmines/IDE/UXO for scanning by drones in Preston, UK. Recently, UCLAN and Qatar University have established collaboration[6] in developing drone-mounted sensor systems to support the landmine/UXO/IDE humanitarian clearing activities.

B. Design and Robotics Integration of Maggy

We planned to use a small single-board computer (SBC) on Maggy to process the internal management of its parts as well as the sensor components. Arduino and Raspberry Pi are both suitable to our design and development objectives. In this application, the Arduino board was selected to execute simple sensing operations from the sensors where i) it is cheaper than the Raspberry Pi, which helps us to accomplish one of our objectives – a bespoke drone as less expensive as possible and ii) it needs less current than Raspberry Pi does, which is important for us regarding the battery-constrained Maggy for the extention of flight time. This section consists of two subsections (Sections III-B1, III-B2), i) design and development of the drone – Maggy – with sensor technologies (Figs. 14, 15), and ii) development of the tablet/smartphone application (Fig. 16) to manage Maggy and process data streaming from Maggy to locate landmines/IDE/UXO.

1) Integration of Maggy with Sensors

The incorporation of the internal software and hardware components with the sensors into the bespoke Maggy system is explained in this section. Fluxgate magnetometer sensors were used to detect MF generated by the metallic parts of landmines, UXO or IDE. Magnetometer sensors should be integrated with UAS appropriately concerning the magnetic interferences relating to onboard electronics as elaborated in [64], [65], and [66] even though the small electronics of Maggy help reduce the interferences significantly. The magnetometers were integrated below a lightweight drone to minimise magnetic interferences, specifically, caused by the UAS (Fig. 17). The properties

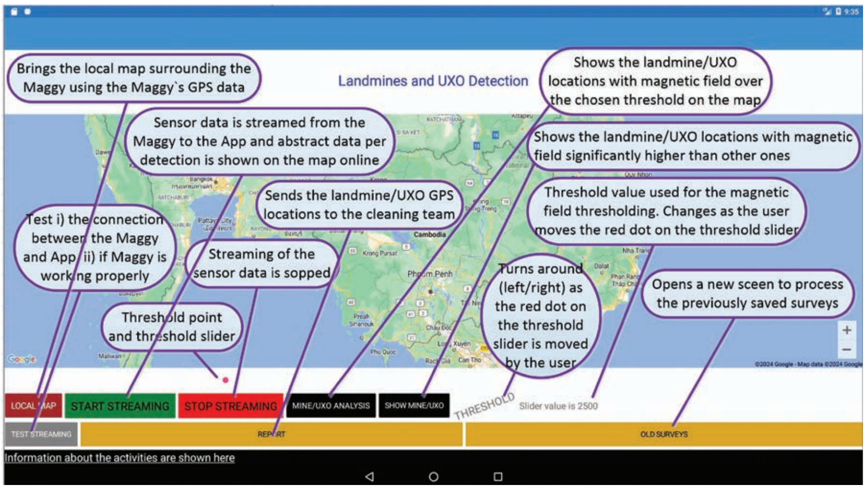

FIGURE 16. Main interface of the Android tablet/smartphone application and its functions.

TABLE 3. Particular features of Maggy in Figs. 14, 15 considering operational objectives and sensor integration.

Element	Feature	Description
Magnetometer.	FGM3D/75 Fluxgate	Two FGM3D/75 Fluxgate
Operational weight	880 gr	The operational weight when mounted to the UAV is 880g including the battery.
Power supply	1V, 1,950 mAh Li-Ion	Re-chargeable battery.
Connection 1	Bluetooth	Bluetooth module is implemented into the MagDrone device.
Connection 2	Fischer connector	The Fischer connector can be used as a telemetry port.
GPS receiver 1	Internal GNSS	The GNSS receiver contains a support battery for memorising the Almanach and the configuration. The Fischer connector is used as a telemetry port becomes the GPS input.
GPS receiver 2	External GPS	The Fischer connector can be used as the GPS input while the telemetry port is Bluetooth.
Sampling	200Hz.	All three axles of every sensor are sampled at 200Hz.
Data logger	SD card	The capacity of the SD card is 2GB . This capacity is enough for about 24 hours of uninterrupted recording.
Software	MagDrone Data Tool	The MagDrone device provides a telemetry port that allows for live data output and reception of start and stop commands.
Data	Binary raw data	Moving directions, tracks and overlapping. The data can be converted into a readable format using the MagDrone Data Tool
Offset correction	Temperature offset data	Offset correction data such as temperature offset data are stored. These data are applied to the data measured by the magnetometers.

of the magnetometer sensors shown in Fig. 10 are presented in Table 1. Two fluxgate sensors – magnetometers – are connected to Arduino using the serial port via the Modbus multiple connections as demonstrated in Fig. 11. One of the magnetometers is placed on Maggy to collect MF data via the Z direction and the other is placed to collect via the X direction. The sampling rate was adjusted to 10 Hz in order to reduce the noise (Fig. 17). Sensor data is read as shown in Fig. 12 and programming of sensing is executed using Python as displayed in Fig. 13.

$$\begin{aligned} &MF(uT) = (Maggy_{rawdata} * Sensitivity)/1000; \\ &\quad where\ Sensitivity = 13nT/LSB; \\ &\quad -800uT < Maggy_{rawdata} < +800uT; \\ &\quad 1000\ converts\ nT\ unit\ to\ uT\ (micro-Tesla); \end{aligned} \tag{1}$$

$$\begin{aligned} &MF_{XYZ} = sqrt(MF_X^2 + MF_Y^2 + MF_Z^2); \\ &\quad where\ MF\ is\ the\ magnetic\ field\ with\ respect\ to\ axis. \end{aligned} \tag{2}$$

$$\begin{aligned} &Maggy_{heading}(degrees) = atan2(mag_y, mag_x) * (180/pi); \\ &\quad where\ mag_x\ and\ mag_y\ are\ the\ magnetic\ field\ strength \\ &\quad values\ in\ the\ x\ and\ y\ axes\ respectively; \\ &\quad 180/pi\ converts\ radians\ to\ degrees; \end{aligned} \tag{3}$$

The general features of Maggy considering its drone components are presented in Table 2). The inner design of Maggy is demonstrated in Fig. 14. Each full battery can perform up to 4 min 30 sec at low speed flying (i.e. 1 m/s). An altimeter was incorporated into Maggy to make the flights accurate under 1 meter, enabling reliable terrain-following flight. The "position mode" is the easiest to fly with the centre stick configuration. Maggy uses a distance sensor (i.e. altimeter) for "position hold" below 1 m altitude. In "altitude mode", Maggy will drift with the wind and is sensitive to control input. The "transmitter timer" is set to 4 min and will start to beep to notify "low battery". The particular features of Maggy shown in Figs. 14, 15 considering operational objectives are explained in Table 3. By integrating wireless communications with antennas using telemetry radios for remote control, WiFi for real-time data transmission using a 5G Netgear Router and a drone flight controller for precise navigation – we can implement a provision of real-time data which opens up many operational advantages as elaborated in next subsection III-B2. X, Y and Z component directions of the magnetometers are processed as formulated in Eqs. 1, 2, 3) to result in the total magnetic strength/intensity. A Gaussian low-pass filter as well as a high-frequency pass filter are applied to the acquired signals (Fig. 17) to suppress the background noise and accomplish a satisfactory signal-to-noise ratio (SNR) (Figs. 27, 28), which help detect small-scale MF caused by the targeted explosives with metallic objects. The autopilot control system of Maggy was optimised for flight close to the ground, integrating a radar altimeter into the drone to enable terrain following flight at a distance between 50 cm and 1 m above the ground to maximise the sensor performance.

TABLE 4. Streaming attributes of each data point.

#	Attributes	Example
1	(GPS_RAW_LAT, GPS_RAW_LON, GPS_RAW_ALT)	(538126932, -28246376, 25240)
2	(GPS_FIX_LAT, GPS_FIX_LON, GPS_FIX_ALT)	(538126938, -28246368, 25546)
3	DIST_Sensor_height	52
4	(Local_Xm, Local_Ym, Local_Zm)	(-0.8917901515960693, -3.773503303527832, 6.130475997924805)
5	(Timestamp, Roll_Euler, Pitch_Euler, Yaw_Euler)	(778899, 0.019024385139346123, 0.020649636164307594, 0.2144695520401001)
6	(mag_ID, mag_x, mag_y, mag_z, mag_yaw)	(m1,6723,-3249,4605,-25)

2) Development of the Application

An intelligent tablet/smartphone application was developed using the Xamarin.Net development platform. The Xamarin platform enable us to create an application which can run on both Android- and iOS-based devices. The functionalities of the application are explained in Fig. 16. It was fully integrated with Maggy to i) manage Maggy, ii) process data streaming from Maggy to locate landmines/IDE/UXO, iii) perform detailed survey analysis considering varying MF, and iv) communicate with the landmine/UXO/IDE clearing team for reporting the exact locations of explosives. From a technical standpoint, the application establishes an agreed-upon communication link with Maggy using either a TCP or UDP connection. Preferably, a UDP connection is suggested to be used where each data point read by Maggy needs to be readily displayed on the application without stricter protocols as in a TCP connection. Maggy can be used in an automated manner where planned waypoints can be fed into Maggy using the UgCS system – drone flight planning software. Maggy transmits MF values with related information at each data point on its waypoints to the application. The flight information and MF data are streamed to the application to be processed and monitored in near real-time. The attributes of each data point are explained in Table 4 with an example. The streaming of data was coded using Python and the Python script codes of streaming (Maggy_UART.py) are provided in the supplementary materials for interested readers. The streaming is communicated through 5G Netgear Router's WiFi connection as mentioned earlier. The application readily processes these values using Eqs. 1, 2, 3 for MF classification and clustering based on the MF threshold chosen by the user as explained in Fig. 16 and shows landmine/UXO/IDE GPS locations on the local map with abstract information (Figs. 27, 28) as data is streamed from Maggy. The classification of MF values is carried out based on the distribution of the MF values obtained from various landmine/UXO/IDE devices considering the "no MF" values as exemplified in Section IV-A. Regarding the clustering, values below the threshold value are ignored and clustering is executed based on these values above the selected threshold. These algorithms are employed to classify the MF values as "very high MF" represented by "red"' colour, "high MF"' represented by "orange" colour, "low MF" represented by "yellow" colour, and "no MF" represented by "green" colour. This is demonstrated in Section IV, particularly, in Fig. 27. The use of the application with its functionalities is further explained in Section IV-B with real-field implementations.

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To be continued in next issue.

GNSS Constellation Specific Monthly Analysis Summary: January 2025

The analysis performed in this report is solely his work and own opinion. State Program: U.S.A (G); EU (E); China (C) "Only MEO- SECM satellites"; Russia (R); Japan (J); India (I)

Narayan Dhital
Actively involved to support international collaboration in GNSS-related activities. He has regularly supported and contributed to different workshops of the International Committee on GNSS (ICG), and the United Nations Office for Outer Space Affairs (UNOOSA). As a professional employee, the author is working as GNSS expert at the Galileo Control Center, DLR GfR mbH, Germany.

Introduction

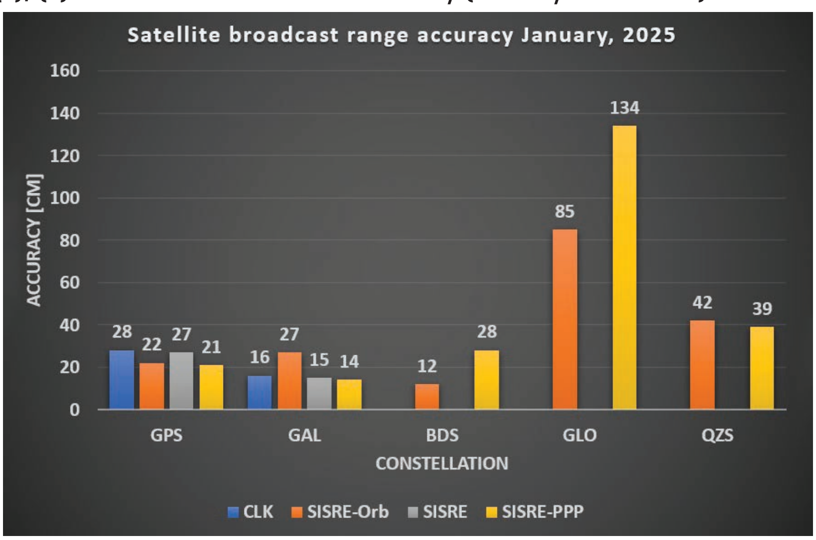
The article is a continuation of monthly performance analysis of the GNSS constellation. Please refer to previous issues for past analysis. Regarding applications, there was an interpretation and discussion in the last month's issue on the usage of GNSS PVT solutions for the Terminal Area Energy Management of spaceplanes, re-usable space vehicles and unmanned air vehicles. In this article it will be further elaborated with a real-data analysis combining GPS and IMU data.

Analyzed Parameters for January 2025

(**Dhital et. al, 2024**) provides a brief overview of the necessity and applicability of monitoring the satellite clock and orbit parameters.

a. Satellite Broadcast Accuracy, measured in terms of **Signal-In-Space Range Error (SISRE)** (**Montenbruck et. al, 2010**).
b. **SISRE-Orbit** (only orbit impact on the range error), SISRE (both orbit and clock impact), and **SISRE-PPP** (as seen by the users of carrier phase signals, where the ambiguities absorb the unmodelled biases related to satellite clock and orbit estimations. Satellite specific clock bias is removed) (**Hauschlid et.al, 2020**)
c. **Clock Discontinuity**: The jump in the satellite clock offset between two consecutive batches of data uploads from the ground mission segment. It is indicative of the quality of the satellite atomic clock and associated clock model.
d. **URA**: User Range Accuracy as an indicator of the confidence on the accuracy of satellite ephemeris. It is mostly used in the integrity computation of RAIM.
e. **GNSS-UTC offset**: It shows stability of the timekeeping of each constellation w.r.t the UTC
f. **GNSS-IMU Coupling**: Coupling of the GNSS and IMU is a standard procedure in avionics. The benefit of each technology is realized through various architectures and algorithms. It helps to have a robust navigation solutions even during satellite outages, and fault events.

(a), (b) Satellite Clock and Orbit Accuracy (monthly RMS values)



Note:- for India's IRNSS there are no precise satellite clocks and orbits as they broadcast only 1 frequency which does not allow the dual frequency combination required in precise clock and orbit estimation; as such, only URA and Clock Discontinuity is analyzed.

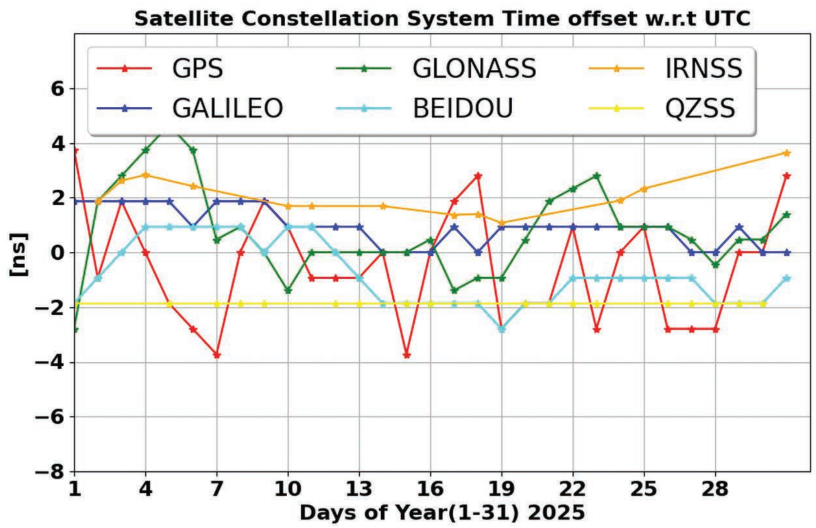
(c)-1 Satellite Clock Jump per Mission Segment Upload

Const	Mean [ns]	Max [ns]	95_Percentile [ns]	99_Percentile [ns]	Remark (Best and Worst 95 %)
IRNSS	3.52	658.68	5.69	23.24	Best I06 (2.94 ns) Worst I09 (7.65 ns) Big jumps for each satellite in multiple days; I10 had, unusually, large jumps; I06 performed better than before
GPS	0.41	32.13	0.92	2.31	Best G23 (0.46 ns) Worst G21 (2.67 ns) No large jump detected
GAL	0.09	30.11	0.18	0.42	Best E21 (0.15 ns) Worst E24 (0.21 ns). E29 had a large discontinuity of around 30 m on DOY 006

(d) User Range Accuracy (Number of Occurrences in Broadcast Data 01-31 January)

IRNSS-SAT	2 [m]	2.8 [m]	4.0 [m]	5.7 [m]	8 [m]	8192 [m]	9999.9	Remark Other URA values (frequency)
I02	3000	3	1	-	1	-	2	11.3 (1)
I03	-	-	-	-	-	-	-	-
I06	2862	144	-	-	3	-	-	-
I09	492	34	1	2	1	-	-	32 (1)
I10	816	3	-	-	2	-	-	-

(e) GNSS-UTC Offset



(f) GNSS-IMU Integration and Data Analysis

Note: The author is an experienced air navigation engineer with flight deck experience in assessing the navigation performance of the aircraft. The analysis below is based on the public resources and not directly from author's work due to ethic and contractual reasons.

In the article issued in January 2025 **(Dhital et.al, 2025)**, the application of GNSS in the navigation of aircraft, launcher and re-entry vehicle was discussed. A couple of real-life operational examples were provided to highlight the capabilities of GNSS for safe, secured and efficient navigation of such vehicles. This article focuses on the data analysis to provide further understanding of operational benefits provided by GNSS in the frame of GNSS and IMU integration. The results are correlated to the operational examples provide in the January's issue.

The fused solution of GNSSs (although only GPS is used in the aircraft FMS as of now) and IMUs provide reliable solution taking benefits of both GNSS and IMU. Using an open-source software "GINav" **(Chen et,al. 2021),** it is demonstrated that GNSS+IMU provides better solution than either of the individual solution. The complexity of the fused algorithm in the aircraft plays a greater role in the robustness of the solution. Even though, in commercial aviation, the aircraft have varying degrees of GPS and IMU coupling depending on the model, this article provides the analysis on the characteristics of only loosely coupled and tightly coupled GPS and IMU. The mathematical description and analysis are not the scope here, however, and the references **(Chen et.al, 2021), (Liu et.al, 2018), (Wang et.al, 2025), (Bento et.al, 2013)** and **(Goercke et.al, 2017)** provide a good detail on the topic.

The procedures for the data analysis are based on the following steps:

1. Only GPS is selected as the GNSS constellation, because only GPS is certified for aircraft FMS. The GPS solution is based on the Single Point Positioning (SPP).
   To compute position, velocity and attitude (roll, yaw and pitch). Note: the attitude values are also used in the fly-by-wire control of the aircraft lateral and longitudinal aerodynamics.
2. IMU stand-alone solution is computed through the mechanization equations
3. IMU aided by GPS solution is computed. This is based on loosely coupled mode where two separate Kalman filters are used for each of the IMU and GPS solution which are then combined.
4. Some epochs are refined to remove a couple of GPS satellites (total number

of satellites below 4). This means GPS standalone solution is not possible. (This is called Data modification 1)

5. Using the data from step 4, the IMU aided by GPS solution in loosely coupled mode is computed.
6. Using the data from 4, the tightly coupled IMU+GPS solution is computed
7. The innovation (residuals between the IMU predicted and GPS measurements) is computed for step 5
8. The figure of merit for above 5 and 6 is computed.
9. A fake GPS measurement data is used for a couple of epochs. (This is called Data modification 2)
10. The loosely coupled solution for using data from step 9 is computed. The innovation residual of the GPS filter is used for Chi-square statistics test.

Data source: The publicly available dataset from the github (GINav/data at main · kaichen686/GINav · GitHub), which is collected in a suburban environment around the university of Mining and Technology, China, on March 28, 2019 is used. The data collection platform is equipped with the Trimble R10 receiver and a tactical grade IMU, together with accurate reference solutions from NovAtel-SPAN-CPT system.

Data modification 1: The GNSS data is changed by removing couple of satellites (keeping number of satellites below 4) for some epochs to disable GNSS solution computation. This is to check the performance of LC and TC modes during satellite outages.

Data modification 2: The GNSS data is changed by adding fake measurement data for few epochs. This is to check the innovation residuals and chi-square statistics to detect anomalies and outliers.

Before starting the data analysis and interpretation, a very high-level understanding of the GNSS+IMU integration is provided below:

Dynamic Models

The dynamic model describes how the system state evolves over time. In GNSS/

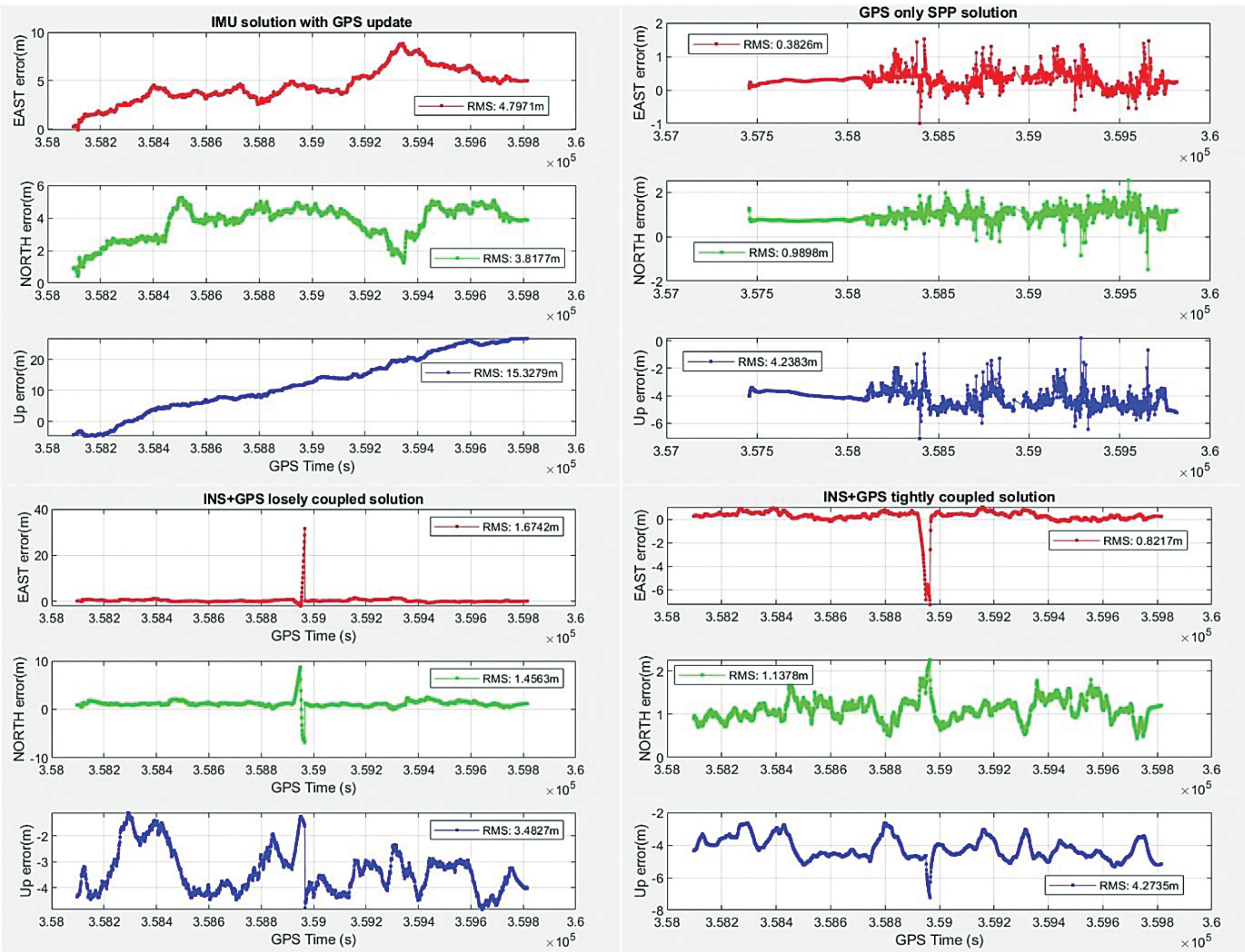


Figure F 1: The position solution accuracy for four methods: IMU alone (upper left), GPS-SPP (upper right), LC IMU+GPS (lower left) and TC IMU+GPS (lower right). The drifting nature of IMU is clearly visible in the solution. While better in accuracy, the GPS solution is noisy. Integration of IMU and GPS remove the disadvantages of both systems. For LC and TC solutions, the step 4 process is applied where couple of GPS satellites are removed (total satellites below 4). It is noticed that TC solution is more robust to the loss of satellites. In contrast, the LC mode relied only on the IMU solution and had slightly worse accuracy than TC solution.

IMU integration, the state vector typically includes position, velocity, attitude, and IMU biases (accelerometers and gyroscopes). The state transition model explains how these elements change over time, incorporating the effects of motion and sensor measurements.

IMU Mechanization

IMU mechanization involves using accelerometer and gyroscope measurements to update the position, velocity, and attitude of the aircraft. The position and velocity are updated based on the accelerations, while the attitude is updated using the angular rates from the gyroscopes. This process ensures continuous tracking of the aircraft's movement, even when GNSS signals are unavailable. The core of the mechanization process involves solving the equations of motion.

Accelerometers measure linear acceleration by detecting the Coriolis force acting on a vibrating mass inside the sensor. Similarly, gyroscopes measure angular velocity by detecting the Coriolis force acting on a vibrating mass inside the sensor. For sensors based on laser/optics, Sagnac effect is considered in the mechanization.

The dynamics model and IMU mechanization (which uses high grade laser/optical sensors) are a bit complex for aircraft. **(Bruggemann et.al, 2011)** provides some overview on it.

GNSS Measurement Models

GNSS measurements include pseudoranges, carrier phases, and Doppler shifts. These measurements provide information about the distance between the satellites and the receiver, which is used to update the state estimate. The pseudorange measurement model calculates the distance based on the time it takes for the GNSS signal to travel from the satellite to the receiver.

State-Space Model

The state-space model combines the dynamic model and the measurement model to estimate the state vector. The measurement update step involves comparing the observed measurements with the predicted measurements to calculate the measurement residuals (innovations). These residuals are then used in the form of a filter gain to correct the state estimate, improving the accuracy of the navigation solution.

Loosely Coupled vs. Tightly Coupled Integration

- Loosely Coupled (LC): In this approach, GNSS and IMU data are processed separately. The GNSS solution is used to correct the IMU solution. The EKF is implemented separately for GNSS and IMU and then individual solution is combined in another EKF. This method is simpler and less computationally intensive but may be less accurate in challenging environments where GNSS signals are weak or unavailable.
- Tightly Coupled (TC): In this approach, raw GNSS measurements are directly integrated with IMU data in the Kalman filter. The pseudorange and dopplers are predicted based on the IMU data and the last know GNSS satellites and bias values. This is than updated with the obtained measurements of pseudo range and dopplers. The method provides more accurate and robust navigation solutions, especially in environments with limited GNSS visibility, but it is more complex and computationally demanding.

Robustness of the Kalman filter:

In the LC mode, the IGG-3 robust model is used to down-weight or exclude outliers in the innovation residuals for the GPS/IMU mode. It calculates the standard residuals, applies robust factors to adjust the measurement noise covariance matrix, and removes measurements with high residuals, ensuring the integrity and robustness of the state estimation.

Results and Discussions:

In Figure F1, the characteristics of IMU only, GPS only and the IMU+GPS integration are demonstrated. The drifting

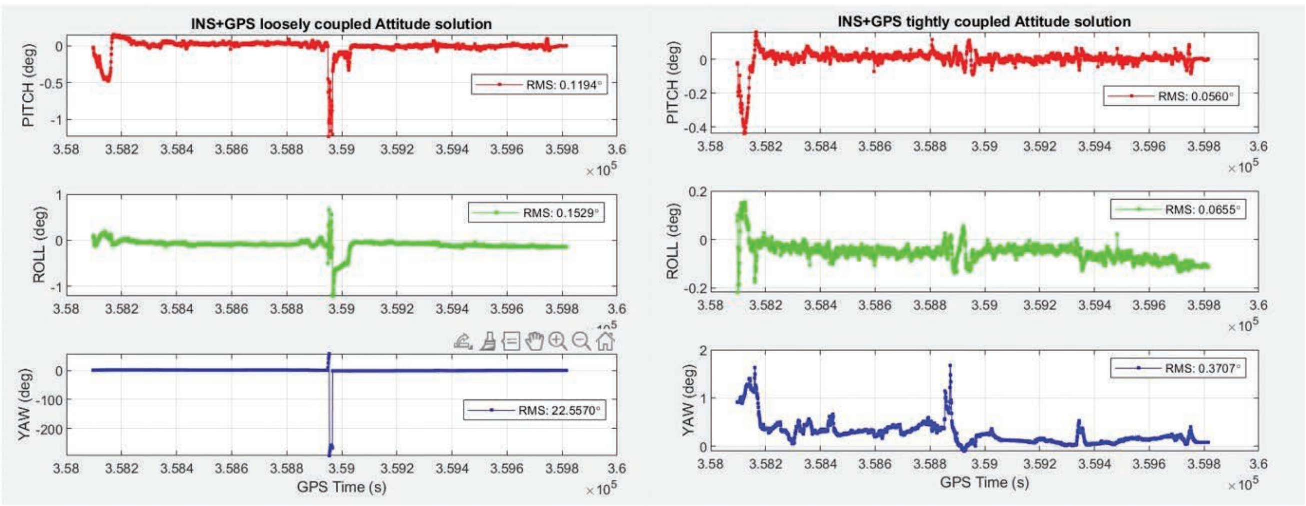


Figure F 2: The attitude solution generated by the LC algorithm (left) and the TC algorithm (right).

nature of the IMU, coming from unaccounted effects and biases, makes the IMU only solution not so reliable after few minutes. The GPS only solution (SPP) is better in accuracy (note that multi-constellation, multi-frequency and augmentation with PPP, RTK are way more precise) and is noisier. It is also noted that there is a solution outage around 35884 GPS seconds. By combining IMU and GPS, the solution has no outages. However, the solution for LC and TC looks a bit different. As the LC mode rely on the individual solutions of the IMU and GPS that are later combined in the Kalman filter, the absence of GPS solution during satellite outages prevents the update in the filter. During the satellite outages, the IMU only solution starts to drift until the GPS solution is available which re-aligns the IMU. In contrast, the TC algorithm uses only one Kalman filter where the IMU predicted pseudorange and doppler measurements are updated from the GPS measurements of pseudorange and doppler from the available satellites (even 1, 2 or 3 satellites aid in the update stage). This results in robust solution and better accuracy as seen in Figure F1 for the position solution and Figure F2 for the attitude solution.

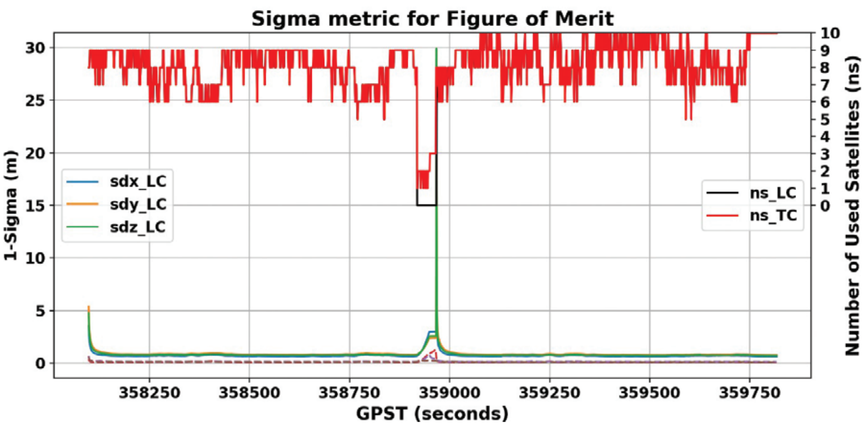


Figure F 3: The figure of merit from the predicted covariance. The 1-sigma value is poorer for LC mode and is also worse during the GPS outage. The final Horizontal Figure of Merit (1-sigma inflated by a scalar factor), as discussed in January's issue *(Dhital et.al, 2025)* in Figure F3 and F4, is based on the specific model used on the avionics. However, the concept and interpretation are similar. Such robust figure of merits (mostly offered by TC architecture even during GPS satellites loss) become important for fulfilling the required navigation performances in flight procedures.

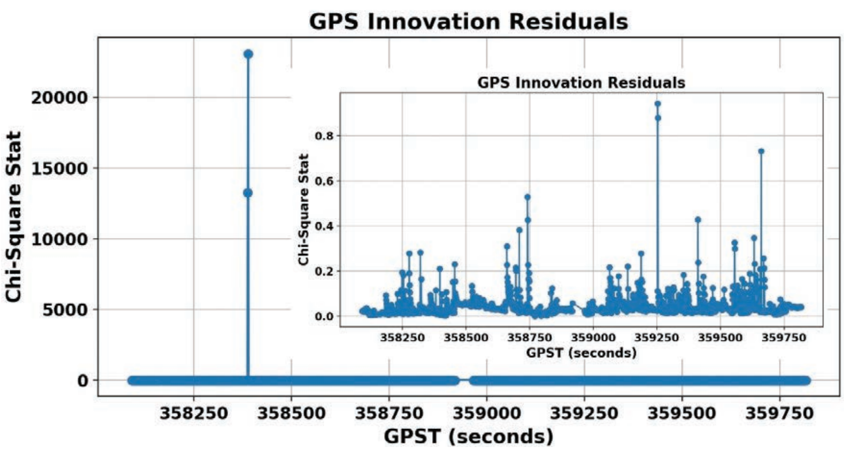


Figure F 4: The outlier detection based on the innovation residuals from the Kalman filter. The residuals are statistically analyzed by Chi-Square test. The data set is based on step 9 where fake GPS measurements were introduced. The Chi-Square value is very large and excluded from further processing. The inside plot is the Chi-Square value for other remaining epochs enlarged for better readability. Such innovation residuals can be tested to detect GPS outliers coming from interferences, noises, multipaths and spoofing.

The trust worthiness of the computed solution is a key in aircraft navigation to fulfil the required navigation performances. It is influenced by the implemented algorithms and from Figure F3, TC solution offers better trust worthiness in the solution as shown by the sdx, sdy, sdz (three components in position) 1-sigma value (dashed line very close to zero). The solid lines for sdx, sdy and sdz (shown in the legend as well) for LC are higher in values. It is also shown that the used number of satellites for TC mode is not zero during the loss of satellites (available satellites below 4) while it is zero for LC mode.

The robustness of the GPS+IMU integration does not only rely on the available satellites and measurements. Albeit not much application for aircraft, the urban navigation regularly faces tough environment that disrupts the quality of the used GPS signals. In addition, the ongoing GPS jamming and spoofing events throughout the world present a complex challenge for GPS+IMU algorithm. The outlier and anomaly detection based on the innovation residuals is a common practice. Figure F 4 and F5 show examples how such events can be detected and excluded in the solution. **(Curran et.al, 2017), (Bruggemann et.al, 2011),** and **(Tanil et.al, 2016)** provide various approaches and algorithms for such fault and anomaly detections using the GPS and IMU integration. Even though the data used in the analysis is not directly coming from the aircraft, the concept is analogous and for similar readings **(Schmidt et.al, 2010)** provides the impact of LC, TC solutions for different scenarios including jamming and fault events for aircraft navigation.

The impact of the fine tuning of the process noise and measurement noise for the used IMU and GNSS system was not analyzed, however, will be targeted in future issues. For understanding the noise characteristics of IMU sensors, **(Niu et.al, 2022), (Suvorkin et.al, 2024), and (Kj et.al, 2016)** are informative.

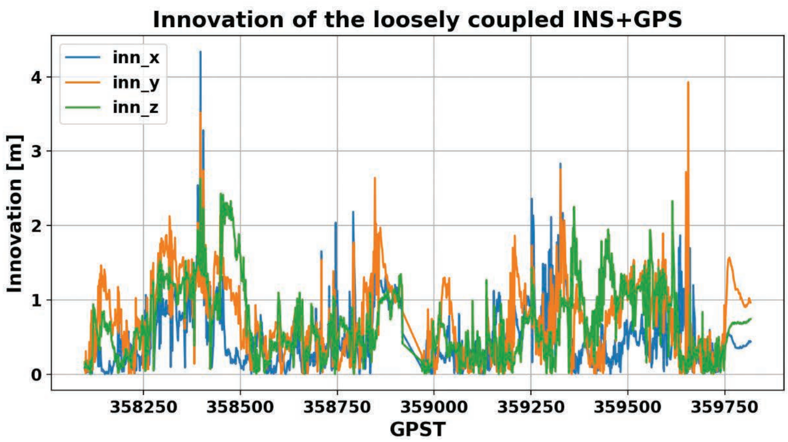


Figure F 5: The innovation of the Kalman filter where IMU and GPS solutions are combined. When the outliers and anomalies in GPS residual as explained in Figure F4 are not detected, this innovation metric is useful to detect any anomalies. For example, if the GPS solution is clearly spoofed where the GPS residual testing is not successfully, the innovation in the final Kalman filter can detect such discrepancy.

Only the GPS system is considered in above analysis and discussion, however, the interoperability of other GNSS enables robust solution. With multi-constellation and multi-frequency, the performance of the GNSS+IMU integration becomes stronger. While the use case in avionics was the focus in this article, the future articles will bring the analysis and discussions in autonomous vehicle, car navigation and robotics together with other sensors like LIDAR and camera that also enable Simultaneous Localization and Mapping (SLAM).

Monthly Performance Remarks:

1. Satellite Clock and Orbit Accuracy:

- The performance of GPS and Galileo are relatively stable and unchanged from previous month. The performance for Beidou, QZSS and GLONASS seemed to have dipped slightly. There were a couple of days with degraded orbits for QZZ. The orbit accuracy statistics of Beidou between DOY 17 and 22 degraded by few centimeters. The in-depth analysis of Beidou and QZSS orbit and clock will be performed in future issue to identify any potential faults.
- For Galileo, there was a rare satellite maneuver (E12 from DOY 022). In terms of clock, there was not any large discontinuity for GPS. However, Galileo E29 had a large clock discontinuity on DOY 006.
- For IRNSS, the clock for I06 appeared to be good than previous months. URA value for I09 has higher number of samples for 2.8 m than before.

2. UTC Prediction (GNSS-UTC):

All constellations show stable UTC prediction with minor variations. It is one of the best months in last one year.

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https://cddis.nasa.gov (Daily BRDC); http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/ (Precise Products); BKG "SSRC00BKG" stream; IERS C04 ERP files

(The monitoring is based on following signals- GPS: LNAV, GAL: FNAV, BDS: CNAV-1, QZSS:LNAV IRNSS:LNAV GLO:LNAV (FDMA))

Time Transfer Through GNSS Pseudorange Measurements: https://e-learning.bipm.org/login/index.php

Allan Tools, https://pypi.org/project/AllanTools/

gLAB GNSS, https://gage.upc.edu/en/learning-materials/software-tools/glab-tool-suite

Strategies for climate resilience: glacier retreat, water security in the Himalayan region

Climate change policies worldwide should prioritize addressing deforestation and promoting sustainable environmental practices.

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Abstract

Background: Climate change is an escalating global challenge with intense consequences for the environment and human livelihoods. Human-induced climate change, primarily driven by anthropogenic activities, presents a critical threat that necessitates urgent intervention. The rapid retreat of glaciers, especially in the Himalayan region, underscores the severity of this crisis. Covering approximately 33,000 square kilometers, Himalayan glaciers sustain nine of Asia's largest river systems, directly impacting the lives of over 1.3 billion people. Their retreat is one of the clearest indicators of climate change and its far-reaching impacts.

The Problems: By the end of the century, global temperatures are expected to increase by 1.4 to 5.8°C, largely driven by greenhouse gas emissions from fossil fuel consumption and industrial activities. This warming disrupts weather patterns, intensifies seasonal variations, and worsens water scarcity and food insecurity. Dry seasons are becoming increasingly arid, while wet seasons bring heavier rainfall, posing severe risks to ecosystems and communities dependent on climate stability. Persistent declines in water availability endanger agriculture, clean water access, energy production, and public health, further exacerbating challenges for vulnerable populations.

Recommendations: Earth observation technologies play a crucial role in tracking climate impacts, forecasting changes, and formulating adaptive strategies. Global collaboration is necessary to bridge resource gaps and promote shared responsibilities. Policies should emphasize the transition to carbon-neutral energy, curb greenhouse gas emissions, and harness scientific innovations for sustainable solutions. Meaningful dialogue between developed and developing nations is essential to strengthening collective climate resilience and driving informed action.

Conclusion: Scientific evidence underscores the pressing need to tackle climate change, which is closely tied to human activities. Governments, scientists, and policymakers must take proactive, people-centered, and environmentally responsible actions to minimize dependence on fossil fuels, embrace sustainable energy solutions, and uphold international agreements like the Kyoto Protocol. These efforts are essential for protecting the planet and ensuring a sustainable future for generations to come.

The context

According to geoscientists, global warming is contributing to an increase in the number and volume of Glacier-Lake Outburst Flood (GLOF) hazards in the Himalayan region. Some of these floods have exhibited discharge rates as high as 30,000 m^3/sec, traveling distances of up to 200 km (Richardson and Reynolds, 2000). Based on the average vertical lapse rate of 6.5°C per kilometer, various studies indicate that with a 1°C rise in air temperature, approximately 20% of the currently glaciated area above 5000 meters is likely to become snow and glacier-free. Furthermore, a temperature increase of 3°C and 4°C could result in the loss of 58% and 70% of glaciated areas, respectively. An increase in precipitation by more than 20% is likely to cause a significant increase in sediment delivery and more than 20% increase in annual sediment deposit could be expected in the scenario of a 50% increase in annual precipitation (MoPE, 2004).

These findings emphasize the serious consequences of global warming and climate change on Glacier Lake Outburst Floods (GLOFs). Large-scale GLOF events pose significant risks, not only to Nepal but also to neighboring regions like North India and Bangladesh, potentially causing widespread loss and destruction. Key climate change impacts in the Himalayan region include heightened GLOF hazards, greater variability in river runoff, increased sedimentation, higher evaporation from reservoirs, and disruptions to watersheds. Consequently, shifts in glacier melt and precipitation patterns are expected.

Urgent call to address climate challenges

For example, Nepal is home to a wide variety of species. A study has found that 2.4% of the biodiversity may be lost with climate change. Obviously climate change will affect agriculture. A majority of the people of Nepal depend on agricultural crops like rice, maize and wheat. Higher temperatures, increased evapo-transpiration, and decreased winter precipitation may result into droughts. It should be considered as an early warning for food security. (Uprety 2008).

With a predominantly agrarian economy where about 81 per cent of the over 26 million people of Nepal reside in rural areas - traditional, self-sustaining hill and mountain farming systems have been disrupted owing to increased population and fertile topsoil erosion combined with deforestation and environmental degradation. Migration from the hills and mountains to the fertile Tarai[1] region and haphazardly developed urban centers are increasing at an unprecedented scale. Consequently, the poor, uneducated, and unemployed people are compelled to make a living by settling in flood and landslide-prone areas in the hills, Tarai plains and urban areas which are now more vulnerable to disasters due to climate change and global warming. Lack of effective land use and settlement regulations have contributed to increased vulnerability to floods and other hazards caused by both natural and anthropogenic factors. Heavy reliance on tourism and agriculture makes Nepal's economy very susceptible to climate unpredictability (Poudyal Chhetri M. B., Bhattarai D., 2001).

Trends of warm days and warm nights are significantly increasing in the majority of the districts in Nepal. Warm spell duration is increasing significantly in the majority of the districts. Cool days are decreasing in the majority of the districts while cool nights are increasing in few north-western and northern districts and decreasing in few south-eastern districts significantly. Cold spell duration is also increasing significantly only in the far western region. It is noteworthy that maximum temperature trends are higher than minimum temperature trends in all seasons. The significant test shows maximum temperature trends are more robust than minimum temperature and precipitation trends. (Source: http://www.dhm.gov.np/)

According to a study carried out by Martin Vargic, a full-time student in Slovakia, there is enough ice in the Earth's polar caps to cause about 250-300 ft. (80 – 100 m) rise of the sea level. Result of such an event would be catastrophic to human civilization and the earth's biosphere. More than 75% of the world's population lives below 300 ft. above the sea level, including the vast majority of all large metropolitan areas. If current trends continue, 80% of the Himalayan glaciers - the water source for a sixth of the world's population - could disappear if the current rate of emissions is not reduced. (IPCC). Himalaya will have no ice by the year 2300 or even sooner. The lives of 2 billion people are at stake (WWF Nepal).

Given these observations, it is clear that climate change presents an escalating challenge with widespread and profound consequences. It is altering precipitation patterns, affecting the amount, intensity, frequency, and even form—such as shifting snowfall to rainfall in certain regions. These disruptions have significant implications for ecosystems, water resources, agriculture, and human livelihoods.

One of the most alarming consequences of these changes is the rising frequency and intensity of natural disasters. Events like floods, landslides, glacier lake outburst floods (GLOFs), and droughts are becoming more frequent and severe, posing serious risks to both lives and infrastructure. The increasing unpredictability of such events further complicates disaster preparedness and mitigation efforts, leaving vulnerable communities at even greater risk.

Beyond immediate physical destruction, these climate-driven changes have cascading long-term effects. They contribute to soil erosion, biodiversity loss, declining agricultural productivity, and increased sedimentation in rivers and reservoirs. These factors further exacerbate water management challenges, heightening risks to both food and water security.

Major climate change issues and way forward:

To evaluate the impact of climate change on water resources, institutions across the Himalayan region, especially in Nepal, encounter significant obstacles in conducting modeling studies. A major obstacle is the lack of reliable observational data necessary for accurately validating model results. Furthermore, limited human and technical resources further constrain progress in this field. Bridging these gaps could be achieved through initiatives such as satellite data sharing, regional training programs, and real-time exchange of observational data, all of which would improve the quality and scope of climate impact assessments.

It is crucial for governments in the region to implement strong climate change policies with a clear emphasis on impact adaptation. Effective adaptation measures must be planned to mitigate the negative effects of climate change on the region's socio-economic conditions. For successful adaptation planning, it is essential to understand how the regional climate may evolve in the future and how these changes could affect the hydrological regime of river basins. Climate modeling serves as a vital tool for predicting future climate trends, while hydrological modeling provides valuable insights into how these projected changes might influence river basin hydrology.

Performance can be significantly improved through close collaboration

> It is crucial to recognize that the adverse impacts of climate change, variability, and extreme events will hinder the achievement of national development goals unless adequate attention and funding are dedicated to mitigating these impacts.

among countries that currently conduct their activities in isolation. For instance, climatic scenarios can be developed at a regional scale, while individual countries can generate higher-resolution scenarios for national applications. Similarly, hydrological models can be run at the basin scale, while higher-resolution models can be applied at the catchment level by individual nations. This collaborative approach presents an opportunity for countries to share knowledge and expertise in developing regional climate change scenarios and basin-wide projections of water availability under changing climate conditions.

Throughout the disaster management cycle, the groups most severely impacted are often impoverished communities and individuals living in marginal or high-risk areas. These populations typically lack the necessary resources and infrastructure to cope with or recover from the negative effects of disasters. In Nepal and similar regions, disaster management systems mainly concentrate on response measures, which, although critical, fall short in addressing the wider challenges posed by climate change and vulnerability to disasters.

In order to build resilience, there is an urgent need to adopt a proactive framework that emphasizes preparedness and mitigation. This approach should involve identifying vulnerabilities, developing early warning systems, and implementing adaptive strategies tailored to local needs and environmental conditions. Government policies and plans must shift from a reactive stance, which addresses disasters after they occur, to a proactive one that anticipates risks and minimizes potential impacts.

Preparedness measures must include community education programs, capacity-building initiatives, and investments in disaster-resilient infrastructure. Enhancing agricultural practices is also essential, as climate change significantly affects crop yields, water availability, and food security. Promoting climate-smart agriculture—such as using drought-resistant crops, improving irrigation systems, and diversifying livelihoods—can reduce the vulnerability of rural communities to climate-induced shocks.

Additionally, integrating Disaster Risk Reduction (DRR) into national and local development plans ensures that policies across sectors align with the overarching goal of climate resilience. International cooperation and access to funding for disaster preparedness and climate adaptation play a crucial role in enabling this shift. By prioritizing preparedness, mitigation, and proactive policymaking, nations can significantly reduce the vulnerability of marginalized populations to climate change and related disasters, thus fostering long-term sustainable development.

Core message

As governments prioritize poverty reduction and other development objectives, investments in Disaster Risk Reduction (DRR) have consistently lagged behind. Consequently, disaster preparedness often receives minimal funding compared to the substantial resources required for disaster response and recovery. It is crucial to recognize that the adverse impacts of climate change, variability, and extreme events will hinder the achievement of national development goals unless adequate attention and funding are dedicated to mitigating these impacts. The increasing influence of climate change on precipitation patterns and the subsequent rise in disaster frequency underscore the urgent need for global action. Governments, scientists, and policymakers must collaborate to develop adaptive strategies, strengthen early warning systems, and promote sustainable practices to mitigate risks and build resilience against this growing global challenge.

Conclusions

Climate change policies worldwide should prioritize addressing deforestation and promoting sustainable environmental practices. Such measures would not only benefit millions of vulnerable individuals in developing nations but also contribute to global climate change mitigation efforts. By reducing deforestation and fostering ecological balance, proactive policies can facilitate the creation of carbon credit systems. In this framework, countries successfully implementing carbon dioxide mitigation programs can earn and sell credits. Developed nations, exceeding their emission limits under international agreements such as the Kyoto Protocol, could purchase these carbon credits to offset their emissions. This mechanism would provide financial support for forest conservation and sustainable land-use initiatives in regions like the Himalayas. This dual approach integrates environmental preservation with economic incentives, fostering collaboration between developed and developing nations to tackle the global climate crisis.

Endnote:

[1] Tarai is a flat and fertile land mass of Southern part of Nepal that extends from East to West. It covers 23 percent of the total land of Nepal.

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Voyant Photonics launches affordable CARBON LiDAR

Voyant Photonics has announced availability of “CARBON” FMCW LiDAR sensor, featuring the world’s first truly effective and affordable LiDAR on a chip with solid state beam steering. The silicon photonic chip is fingernail-sized and provides high-resolution, millimetre precision, object detection and static/dynamic segmentation up to. *www.voyantphotonics.com*

Funding from UK Space Agency to EnSilica

EnSilica, a chip maker of mixed-signal application-specific integrated circuits (ASICs), has been awarded funding from the UK Space Agency under its Connectivity in Low-Earth Orbit (C-LEO) program. It has been awarded £10.38 million ($12.8 million) throughout the next three years for a development project pioneered by EnSilica.

EnSilica will develop a family of semiconductor chips to support future generations of mass market satellite broadband user terminals. The terminals will be capable of connecting with various satellite constellations and will leverage advanced semiconductor technology. In addition, the project will provide a resilient source of chips, which will be independent and not tied to specific satellite service operators. *www.ensilica.com*

LiDAR survey for ‘One Map Hyd’ project

The Telangana government is set to consolidate all key information about Hyderabad into a single platform. The ambitious light detection and ranging (LiDAR) survey will cover a range of crucial infrastructure details, including road network, water supply, electricity, sewage, and even fire and traffic police networks. The aim is to improve urban planning, enhance infrastructure, and manage disasters.

LiDAR survey of the entire GHMC area and regions up to the outer ring road, covering approximately 2,050 square kilometres will be carried out. LiDAR is a remote sensing technology that uses light pulses to measure distances and generate precise, three-dimensional data about the earth’s surface and objects. By capturing detailed topographical information, the technology provides accurate insights that can be used for infrastructure planning, disaster management, and urban development.

In the future, the govt plans to launch a mobile app that integrates all data from the ‘One Map Hyderabad’ project, making it accessible to citizens and agencies alike. This digital platform will be crucial for improving services, such as door-to-door garbage collection, emergency response, and disaster management.

Last year, the GHMC initiated a comprehensive drone-based aerial GIS survey and door-to-door mapping of all properties within its jurisdiction. This effort aims to streamline property assessments and create a unique identification system for each property, improving service delivery and urban planning.

UAE signs agreement to develop EMA Lander

The UAE Space Agency and the Technology Innovation Institute (TII) has signed an agreement to design and develop the EMA Lander which will be aboard the MBR Explorer, and will be deployed to study the seventh asteroid Justitia, as part of the Emirates Mission to the Asteroid Belt (EMA).

Under this agreement, TII will lead the design, development and testing phases of the lander, as well as providing opportunities for startups’ participation in the development of the project, in line with the mission’s commitment of allocating 50% of the project to UAE based companies. *satelliteprome.com*

IIT Madras & ISRO develop semiconductor chip

Indian Institute of Technology Madras (IIT Madras) and ISRO have led the way in developing and successfully booting an Atmanirbhar aerospace quality SHAKTI-based Semiconductor Chip. The project is led by Prof. V. Kamakoti at Prathap Subrahmanyam Centre for Digital Intelligence and Secure Hardware Architecture (PSCDISHA) in Department of Computer Science and Engineering, IIT Madras.

The SHAKTI class of systems are based on RISC-V, an open-source Instruction Set Architecture (ISA), for designing custom processors. It is backed by Ministry of Electronics and Information Technology, Government of India, under its ‘Digital India RISC-V’ initiative (DIRV).

The ‘IRIS’ (Indigenous RISCV Controller for Space Applications) Chip was developed from ‘SHAKTI’ processor baseline. This development was part of the effort to indigenize semiconductors used by ISRO for its applications, Command and Control Systems and other critical functions. The ISRO Inertial Systems Unit (IISU) in Thiruvananthapuram proposed the idea of a 64bit RISC-V-based Controller and collaborated with IIT Madras in defining the specifications and designing of the semiconductor chip. *www.iitm.ac.in*

Judicial Review Sought Over Amendments to Geomatics Laws and Regulations in Malaysia

An application for judicial review has been filed with the High Court of Malaya regarding recent amendments to surveying laws and regulations. The applicant, the Institution of Geospatial and Remote Sensing Malaysia (IGRSM) representing the interests of its members and geomatics professionals impacted adversely by these amendments, is seeking to address concerns over the Amending Act and Amending Regulation that could significantly impact the geomatics industry.

Key Points of the Judicial Review Application:

1. Challenging Vague Definitions: The application questions the use of broad, undefined terms such as "geomatics survey" and "survey-accurate technique" in the new regulations. These ambiguities could lead to confusion and potential overreach in enforcement. With the amendments, it can now be an offence for persons who carry out the various types of geomatics surveys.

2. Inadequate Consultation: The applicant argues that the consultation process was flawed as a large number of stakeholders were not consulted. In a town hall meeting to discuss the changes, the draft regulations were not shared beforehand nor during the meeting with the stakeholders.

3. Request for Stay Order: The applicant has requested for a stay on the implementation of both the Amending Act and Amending Regulation. They argue that without this stay, many geomatics practitioners will be impacted negatively, and some forced to cease operations and could potentially face criminal charges if they continue to operate.

4. Concerns Over Impact: The application highlights worries that these amendments could severely affect existing geomatics professionals, potentially threatening their livelihoods without clear justification or safeguards.

5. Legal Basis: The applicant believes there are strong legal grounds for this judicial review, in particular that several constitutional protections such as the right to life, right to equal treatment before the law and right to property have been violated.

Background:

The concerns stem from a debate in Parliament, Dewan Rakyat sitting on 25 March 2024, and Dewan Negara on 4 April 2024, where issues were raised about the ambiguity of "survey-accurate techniques." Despite assurances that further specifications would be provided, the subsequent Amending Regulations failed to clarify these ambiguities.

What's Next:

The High Court has been requested to grant leave to consider this application for judicial review. The leave stage is a filtering stage where the High Court need only determine that the applicant has an arguable case. If granted, it could lead to a more thorough examination of the amendments and the potential striking-down of the key provisions in the amendments.

IGRSM and other stakeholders in the geomatics industry are hoping for a fair review of their concerns, and a resolution that ensures clarity and fairness in the geomatics laws and regulations. The hearing for the leave and stay has been fixed at the Kuala Lumpur High Court on 13 March 2025.

MBRSC, SPACEDATA to advance UAE digital twin tech for space and economy

Mohammed Bin Rashid Space Centre (MBRSC) has signed a MoU with SpaceData, a Tokyo-based startup to develop two key digital twin solutions. A digital twin is a virtual model or replica of a real-world object, system, or process, which can help entities test real-life situations and predict outcomes to make smarter decisions.

According to the MoU, SpaceData will create a high-fidelity lunar digital twin platform for space exploration. At the same time, to support economic initiatives, they will deliver a detailed Earth-based digital twin platform.

For the Emirates Lunar Mission, SpaceData will provide a simulation environment leveraging MBRSC's rover observation data for enhancing mission efficiency and accuracy in upcoming lunar exploration. It will also develop a digital twin environment to support lunar exploration training for UAE astronauts. This high-fidelity simulation will replicate lunar surface conditions, providing detailed three-dimensional spatial and physical environmental data. The training will enhance UAE astronauts' capabilities, ensuring safe and efficient exploration activities.

SpaceData will also develop a highly detailed digital twin of Dubai's urban environment. The platform will enable virtual tourism, transcending geographical and temporal limitations, and unlocking new opportunities for global tourism demand. Furthermore, by incorporating satellite and meteorological data, it will construct a disaster prediction digital twin for Dubai, focusing on large-scale disaster simulations to enhance safety. *mystartupworld.com*

The SoilFER Geospatial Platform launched at UNCCD COP16

The SoilFER Geospatial Platform was officially launched on December 5th at UNCCD COP16. This open-access platform offers comprehensive geographic information on the suitability of opportunity crops identified by the Vision for Adapted Crops and Soils (VACS). By integrating detailed data on soil properties and crop requirements, the platform serves as a valuable resource for farmers, policymakers, and scientists worldwide, enabling informed soil and crop analysis on a global scale. The crop modeling approach leverages decades of expertise from FAO and the International Institute for Applied Systems Analysis (IIASA), who collaboratively developed the Agro-Ecological Zones (AEZ) framework and database, grounded in extensive experience in land evaluation. This foundation is further strengthened by FAO's expertise in innovative digital solutions designed to align with end-users' priorities.

In Central America and sub-Saharan Africa, the Soil Mapping for Resilient Agrifood Systems (SoilFER) project stands out as a unique framework aimed at unearthing valuable information from soils to guide policymaking and fertilizer recommendations both at national and field scale.

The project's emphasis on strengthening capacities as well as empowering stakeholders with full ownership and control over the data and tools underscore its long-term ambition to sustainably equip both participating governmental institutions and farmers. By providing farmers with digital solutions based on the variability of soils, SoilFER promotes the efficient use of fertilizers, sustainable farming practices and the selection of major and opportunity crops as part of VACS, positively impacting soil health, agricultural livelihoods and enhancing the resilience of agrifood systems in the five beneficiary countries - Ghana, Guatemala, Honduras, Kenya, Zambia.

Northrop Grumman enhances US Navy Airborne Navigation

The U.S. Navy has selected Northrop Grumman to advance its airborne navigation capabilities by integrating its LN-251M, the upgrade of the LN-251 inertial navigation system (INS)/GPS. This new system incorporates M-Code technology, which provides an encrypted, military-specific signal with improved resistance to jamming, offering better protection against potential threats. *northropgrumman.com*

Japan launches navigation satellite into orbit aboard H3

Japan's flagship H3 rocket put a key component of Japan's satellite navigation program to eventually wean the nation off its dependence on foreign satellites into orbit on Feb. 2 on its fifth mission. The launch from Tanegashima Space Center in Kagoshima Prefecture marked the H3's fourth consecutive successful launch.

The H3 is the successor to the H-2A rocket and was jointly developed by the Japan Aerospace Exploration Agency and Mitsubishi Heavy Industries Ltd.

The Michibiki No. 6 is a positioning satellite that enhances the accuracy of location information for smartphones. It is the fifth spacecraft in the Quasi-Zenith Satellite System, a satellite network with multiple orbits designed to ensure that at least one satellite is positioned near the zenith over Japan at all times.

The development cost for three Michibiki satellites is approximately 100 billion yen ($642 million). Future plans call for an 11-satellite system, which is expected to improve smartphone location accuracy from the current 5 to 10 meters to within 1 meter. *www.asahi.com*

EUSPA launches GNSS and Secure SATCOM User Technology Report

The European Union Agency for Space Programme (EUSPA) has released its first GNSS and secure satellite communications (SATCOM) user technology report, offering an overview of recent developments in GNSS and SATCOM. This publication combines and expands upon previous GNSS user technology and secure SATCOM market and user technology reports, offering a comprehensive look at current trends and advancements in user technology.

The report examines the satellite industry's ongoing transformation, influenced by evolving security concerns, increased digitalization efforts, rapid progress in artificial intelligence (AI) and the emergence of the New Space sector. *www.euspa.europa.eu*

ISRO's NVS-02 orbit raise disrupted by valve issue

The Indian Space Research Organisation (ISRO) has been unable to perform the intended orbit raising operations for the NVS-02 satellite due to a valve malfunction. The NVS-02, the second satellite in the NVS series, was launched by the ISRO on January 29 as part of its landmark 100th launch from Sriharikota.

The space agency said that the orbit raising operations towards positioning the satellite to the designated orbital slot could not be carried out as the valves for admitting the oxidiser to fire the thrusters for orbit raising did not open.

The ISRO was supposed to carry out the orbit raising operations after the launch, but has been unable to perform the manoeuvres due to the glitch. The operations were to be executed by the Master Control Facility at Hassan in Karnataka. *www.thehindu.com*

CRPAs for PNT removed from ITAR list

The Directorate of Defense Trade Controls (DDTC) has changed the regulatory status of Controlled Reception Pattern Antennas (CRPAs) for position, navigation and timing (PNT). Starting September 2025, CRPAs will no longer be subject to the International Traffic in Arms Regulations (ITAR). Instead, they will be reclassified under the less restrictive Export Administration Regulations (EAR) list, which is under the jurisdiction of the Department of Commerce.

The rule, in part, removes items from the U.S. Munitions List (USML) "that no longer warrant inclusion." According to the rule, "certain anti-jam antennas no longer provide a critical military advantage, with increasing commercial utilization applicable to civil GPS resiliency." By removing CRPAs for PNT, "the Department intends to facilitate civil global navigation system resiliency."

The importance of CRPAs lies in their ability to protect GNSS receivers from interference and jamming. GNSS signals are inherently weak and susceptible to both deliberate and unintentional interference. CRPAs work by adjusting their reception pattern to create nulls in the direction of interfering signals while maintaining reception from desired satellite signals. This adaptive beam steering capability allows CRPAs to effectively eliminate signals from particular directions while preserving signals from others, making them a powerful tool in ensuring the reliability of GNSS-dependent systems. *www.federalregister.gov*

GPS III SV-07 becomes operational

The U.S. Space Force transferred Satellite Control Authority of the GPS III Space Vehicle 07 (SV-07) to the 2nd Navigation Warfare Squadron, Mission Delta 31, at Schriever Space Force Base, Colorado. The satellite became operational and available to global users on Jan. 22, 2025 — expanding the GPS constellation to 31 active vehicles. The transfer is the first instance in which the Satellite Control Authority moved from the acquisition program to the operations squadron within a single Delta, reflecting the new mission delta structure.

The space vehicle was launched on Dec. 16, 2024, from Cape Canaveral Space Force Station, Florida, aboard a SpaceX Falcon 9 rocket as part of a Rapid Response Trailblazer mission. The operation involved retrieving an existing GPS III satellite from storage, expediting integration and launch vehicle preparation, and swiftly processing the satellite for launch.

The entire process, from initiation to launch, was completed in approximately three months, significantly shorter than the typical six-month pre-launch processing timeline. This accelerated timeline was achieved through collaboration between multiple Space Force organizations and partner agencies.

The GPS III SV-07 satellite is equipped with M-code, designed to improve anti-jamming and anti-spoofing capabilities, enhancing secure access to military GPS signals. This launch contributes to the ongoing modernization of the GPS constellation following the launch of GPS III SV06 in 2023. Mission Delta 31, activated on Oct. 15, 2024, is responsible for providing, operating, and sustaining high-integrity positioning, navigation and timing (PNT) capabilities. It comprises three squadrons and one detachment, including the 2nd Navigation Warfare Squadron, which operates the GPS satellite constellation. *www.505ccw.acc.af.mil*

GPS jamming detection for military intelligence and security

The U.S. Space Force's Space Systems Command (SSC) has awarded a $1.9 million contract to Slingshot Aerospace to enhance its GPS jamming and spoofing detection capabilities. This contract, Positioning, Navigation and Timing – Secure Electronic Navigation Threat Intelligence and Location (PNT-SENTINEL), aims to improve the company's existing technology by incorporating advanced artificial intelligence and predictive analytics. *www.slingshot.space*

SandboxAQ Joins NATO's 2025 DIANA Cohort

NATO has selected SandboxAQ as one of approximately 70 companies to participate in the 2025 Defense Innovation Accelerator for the North Atlantic (DIANA) cohort. It will join the cohort's Sensing & Surveillance group, focusing on the development of its AQNav magnetic navigation system. It is designed to provide a secure navigation alternative that does not rely on GNSS, making it resilient against jamming and spoofing. The system utilizes SandboxAQ's proprietary Large Quantitative Models (LQMs), quantum sensors, and the Earth's crustal magnetic field to offer an all-weather, day and night, terrain-agnostic navigation solution for military and commercial applications. *www.sandboxaq.com*

Iridium looking into using small satellites with PNT capabilities

Iridium Communications is looking into using small satellites to demonstrate advanced Positioning, Navigation and Timing (PNT) capabilities, according to a recent statement by CEO Matt Desch during a small-sat symposium. He said small satellites could also support efforts to develop a VHF radio system for improving pilot communications with Aireon, which already provides aircraft surveillance services using hosted payloads on Iridium's satellites.

The company operates 66 Iridium Next spacecraft in low Earth orbit (LEO) for L-band connectivity services, plus additional spares, and expects the current constellation to perform well to at least 2035. At about 860 kilograms, Iridium Next satellites are significantly larger than the small satellites typically used for LEO communications, which tend to range from a few dozen to a few hundred kilograms. *Spacenews.com*

GMV to develop Galileo HAS data generator

The European Union Agency for the Space Programme (EUSPA) has selected GMV to develop a new version of the High Accuracy Data Generator (HADG) as part of Phase 2 of the Galileo High Accuracy Service (HAS) development.

This service offers free real-time precise positioning corrections to all Galileo system users. It seeks to improve the performance level of Service Level 1 (SL1) by deploying a new version of GMV's magicPPP algorithms for precise corrections calculation and expanding the ground station network. This aims to provide global coverage and enhance the accuracy and availability of the SL1 service. Additionally, it will implement a new Service Level 2 (SL2), a regional service available only in Europe that will transmit atmospheric corrections to reduce the convergence time required to achieve maximum accuracy at the user level. *www.gmv.com*

New HiPer XR GNSS by Topcon

Topcon Positioning Systems has launched the HiPer XR, its latest GNSS receiver for surveying, mapping, and construction applications. The new receiver supports all major satellite constellations, including GPS, GLONASS, Galileo, BeiDou, IRNSS, QZSS, and SBAS. It has advanced TILT (Topcon Integrated Leveling Technology) compensation featuring a calibration-free and magnetic interference-immune integrated IMU that provides up to 60 degrees of tilt for precision measurements in challenging positions. The sophisticated signal integrity protection, anti-jamming and anti-spoofing capabilities keep data reliable, even in areas with interference or tampered signals. *www.topconpositioning.com*

Low-noise chip-scale atomic clock

Microchip Technology has announced its second generation Low-Noise Chip-Scale Atomic Clock (LN-CSAC), model SA65-LN, in a lower profile height and designed to operate in a wider temperature range, enabling low phase noise and atomic clock stability in demanding conditions. It has developed its own Evacuated Miniature Crystal Oscillator (EMXO) technology and integrated it into a CSAC, enabling the model SA65-LN to offer a reduced profile height of ½ inch, while maintaining a power consumption of < 295 mW. *www.microchip.com*

Savvy Navvy launches "Savvy Integrated" for OEMs

Savvy Navvy has released Savvy Integrated, a comprehensive hardware and software integration platform specifically designed to provide advanced navigation solutions for original equipment manufacturers (OEMs) in the marine industry. It combines digital charting technology with hardware integration capabilities. It provides OEMs with a navigation solution featuring a comprehensive digital marine chart with real-time geographical data and seamless integration with multifunction displays. *www.savvy-navvy.com*

Taoglas unveils multi-band GPS/GNSS antennas

Taoglas multi-band GNSS antennas - Levity Series' AHP24510 (L1/L2/L-Band) and AHP54510 (L1/L5/L-Band) directional patch antennas are optimized for GPS, Galileo, GLONASS, and BeiDou satellite constellations. The L-Band capability means Levity Series antennas also work with high-precision GNSS correction services. Systems equipped with these services typically achieve better than 200 cm positioning accuracy, aided by comparing signals from different frequency bands so that receivers can correct for ionospheric delays and other errors. *www.taoglas.com*

Advanced Navigation to develop INS for Gilmour Space rocket launches

Advanced Navigation has secured grant funding from the Australian Space Agency through the Moon to Mars Initiative Grant. This funding will expedite the development of a space-grade high-shock inertial navigation system (INS) designed to endure extreme conditions during rocket launches.

The INS will support Gilmour Space Technologies, an Australian launch services company, in the development and launch of Eris Rockets and Elara Satellite platforms to low-Earth orbits (LEO). This collaboration aims to enhance Australia's sovereign aerospace capabilities and contribute to the growing space industry. *www.advancednavigation.com*

Xairos advances US defense with quantum timing technology

SpaceWERX, the innovation arm of the U.S. Space Force, has selected Xairos Systems Inc. for a $1.9 million Direct-to-Phase II contract to develop a fusion PNT system. This project aims to integrate quantum and optical synchronization of clock ensembles to address critical challenges faced by the Department of the Air Force (DAF).

Xairos Systems is collaborating with Luminous Cyber Corporation and Eritek on this initiative. The team has recently completed a Preliminary Design Review. The Air Force Research Laboratory (AFRL) shared that the collaboration is part of a broader effort by the AFRL and SpaceWERX to streamline the Small Business Innovation Research and Small Business Technology Transfer processes. *www.xairos.com*

Eos Positioning Systems improves mapping and asset management

Eos Positioning Systems (Eos) has become a member of the Municipal Information Systems Association (MISA) Canada's National Partner Program (NPP). This collaboration aims to enhance the capabilities of Canadian municipalities in utilizing GNSS technology for improved mapping and asset management.

The partnership between Eos and MISA Canada facilitates the digital transformation of Canadian cities and towns by bringing together municipal leaders and technology innovators. Eos specializes in providing high-accuracy GNSS technology to local governments, enabling them to maintain critical infrastructure and public services more effectively. *eos-gnss.com*

Leica Geosystems releases airborne bathymetric lidar system

Leica CoastalMapper is an airborne bathymetric lidar system designed for coastline and river surveying. The system offers a wider field of view and the ability to operate at higher altitudes. As a result, the CoastalMapper can survey coastlines and rivers 250% faster than previous sensor models. It features a combination of a high-performance bathymetric lidar module, a Leica TerrainMapper-3 topographic lidar and an imaging sensor, all integrated into a compact and lightweight sensor head. This allows the CoastalMapper to

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capture up to 1 million bathymetric data points and 2 million topographic data points per second while providing high-resolution imagery with a 5 cm ground sampling distance at typical flying heights. *leica-geosystems.com*

Unveiling AI-driven 3D navigation system

Mapbox and Hyundai AutoEver have developed an integrated AI-driven 3D navigation system with advanced driver-assistance (ADAS) capabilities. This system, powered by Mapbox 3D Live Navigation and MapGPT, operates on Hyundai Mobis' cockpit domain controller.

It offers 3D lane-level guidance, augmented reality overlays and real-time driver assistance. It integrates Mapbox's navigation technology with Hyundai AutoEver's software-defined vehicle platform and Hyundai Mobis' AR-enabled cockpit domain controller. MapGPT, an AI-powered location assistant, complements the navigation system. *www.mapbox.com*

Japan's space agency to advance earthquake damage estimation programme

Japan's Aerospace Exploration Agency (JAXA) has signed an agreement with Kumamoto prefecture to further develop a programme that estimates building damage caused by earthquakes using satellite imagery.

JAXA will utilise approximately 200,000 data on building damage from the 2016 Kumamoto earthquake to refine and enhance the accuracy of its technology, which is expected to be deployed nationwide. The programme, which is anticipated to be operational within a few years, will compare satellite images taken before and after an earthquake to assess the extent of structural damage within 2-3 hours of observation. It can function effectively during night time and adverse weather conditions. *www.siasat.com*


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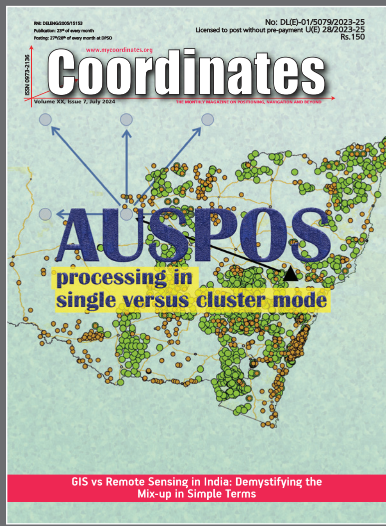
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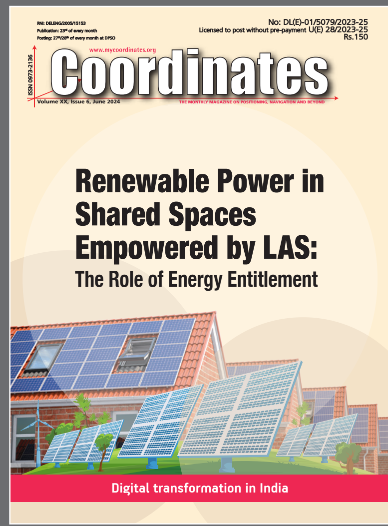
GIS vs Remote Sensing in India: Demystifying the Mix-up in Simple Terms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Renewable Power in Shared Spaces Empowered by LAS:
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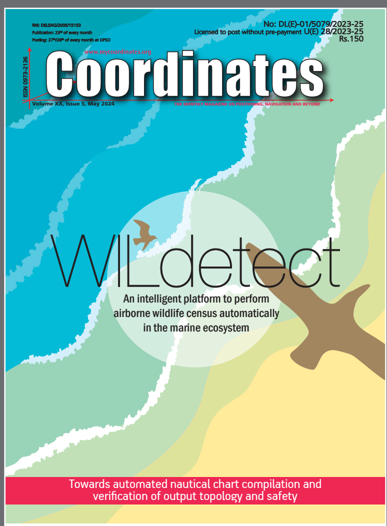
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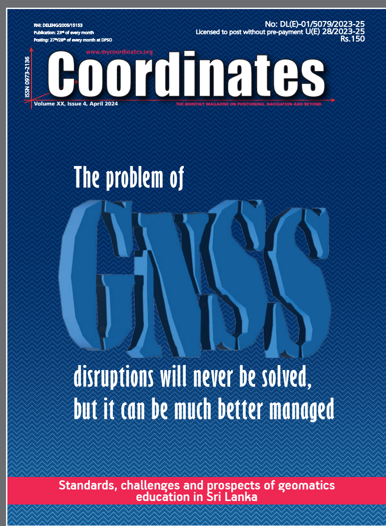
WILdetect
An intelligent platform to perform airborne wildlife census automatically in the marine ecosystem
Towards automated nautical chart compilation and verification of output topology and safety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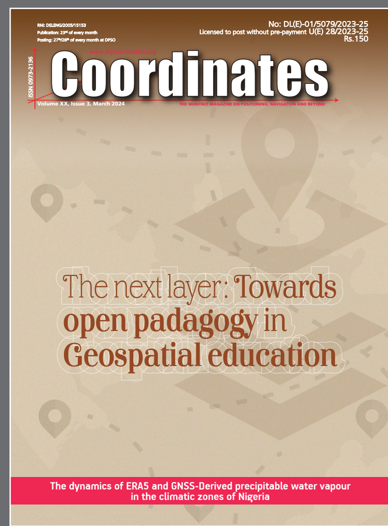
The problem of
GNSS
disruptions will never be solved, but it can be much better managed
Standards, challenges and prospects of geomatics education in Sri Lanka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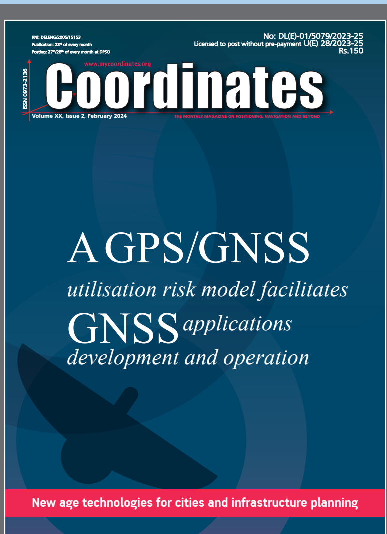
The next layer: Towards open padagogy in Geospatial education
The dynamics of ERA5 and GNSS-Derived precipitable water vapour in the climatic zones of Nigeria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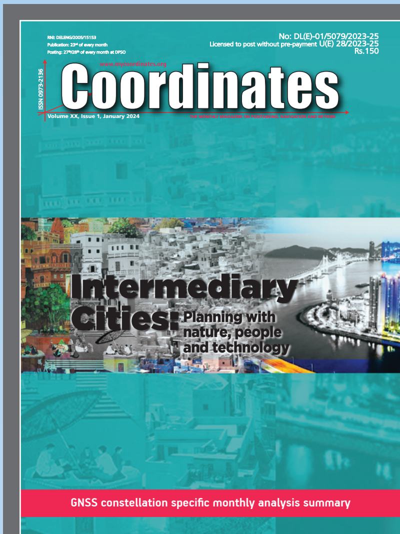
A GPS/GNSS utilisation risk model facilitates GNSS applications development and operation
New age technologies for cities and infrastructure planning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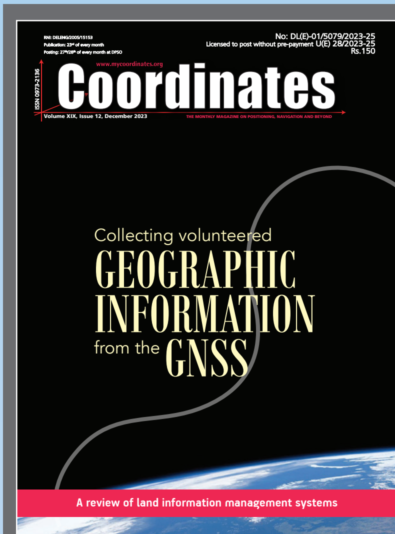
Intermediary Cities: Planning with nature, people and technology
GNSS constellation specific monthly analysis summary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Collecting volunteered GEOGRAPHIC INFORMATION from the GNSS
A review of land information management systems