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THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Dual frequency multi-GNSS smartphone in simple surveying

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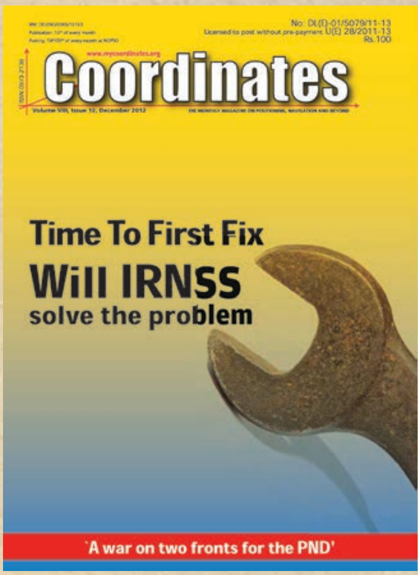

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Time To First Fix Will IRNSS solve the problem?

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

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

This article provides a top level description of methods to achieve fast TTFF and characterizes it using GPS and GLONASS L1 receiver, then generalizes the result for emerging systems such as the Indian Regional Navigation Satellite System (IRNSS). Using an example, the need for Fast TTFF in single frequency mode of operation is illustrated. A brief overview of receiver operations is first presented from a TTFF perspective.

Responding to the Great East Japan Earthquake

Toru Nagayama, Kazuo Inaba, Tamotsu Hayashi and Hiroyuki Nakai
Geospatial Information Authority of Japan

GSI conducted response activities at full strength against the tragic East Japan Great Earthquake. GSI's Geospatial information was well utilized by various people and organizations in disaster response activities. Meanwhile, new challenges were recognized through the experience, prompting continuous improvement of disaster response capabilities. As occurrence of natural disasters never ends, national mapping agencies or equivalent geospatial organizations in each country need to make their best efforts to provide stakeholders with necessary geospatial information products in emergency.

A war on two fronts for the PND

Zhong Ming Ng
Consultant, Point Consulting, Singapore

Going by the direction traditional PND manufacturers are taking, into both integration (into in-car systems) and evolution (into the connected PND) leveraging on their core competitive advantages, it is perhaps too early still to take the demise of the PND as a given – it may yet evolve or integrate into a 'new' product that could still prove to be competitive and relevant, especially given the clear flaws that are holding both the smartphone and the in-car unit back in the navigation market, where, after all, navigation and getting right, up-to-date, and easy-to-use directions is key.

Data integration and sharing for disaster management

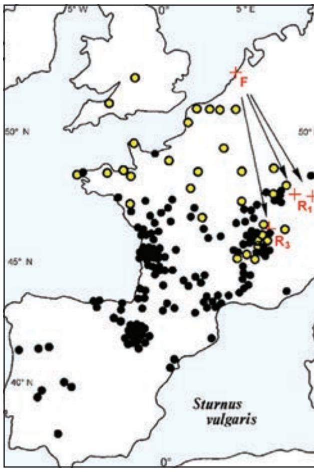
Director
Information Management Department , National Mapping and Resource Information Authority, Department of Environment and Natural Resources, The Philippines

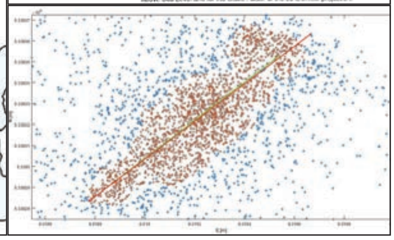
Project NOAH is the response of the Department of Science and Technology (DOST) to the call of President Benigno S Aquino III for a more accurate, integrated and responsive disaster prevention and mitigation system, especially in high-risk areas throughout the Philippines.

Datum transformations using exclusively geodetic curvilinear coordinates without height information

Dr Dimitrios Ampatzidis

The paper presents a method of transforming curvilinear coordinates from WGS84 to local datum and vice versa. The basic idea of the method lies on the connection between the translations of a Cartesian system and curvilinear differences on a particular spheroid.





In this issue

Coordinates Volume 18, Issue 12, December 2022

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Columns

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Editor Bal Krishna
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ENERGY SECURITY

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A world that is healthier and happier.

Bal Krishna, Editor
bal@mycoordinates.org

Positioning performance evaluation of a dual frequency multi-GNSS smartphone

This study examines the usage of dual frequency multi-GNSS smartphones in simple surveying tasks and as well as line documentation

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Guenther Retscher
Department of Geodesy and Geoinformation, Engineering Geodesy, TU Wien – Vienna University of Technology, Vienna, Austria

Abstract

Smartphones with dual-frequency multi-constellation GNSS (Global Navigation Satellite Systems) receivers are now available on the market. This study examines their usage in simple surveying tasks, such as data acquisition for GIS, e.g. for a tree cadastre, lantern cadastre, traffic signs, etc., as well as line documentation, such as for underground power lines. For the experiments, the Pixel 5 from the manufacturer Google LLC is chosen. Code and phase observations are recorded in different scenarios. Evaluation in post-processing based on these observations in Single Positioning (SPP) and Precise Positioning (PPP) mode are carried out. In the analyses, the main focus is led on the achievable positioning accuracies and resulting deviations from reference points serving as ground truth. Apart from these parameters, other criteria, such as the measurement effort and costs, quality, accuracy and repeatability of the measurements are investigated. The results of the experiments indicate that the Pixel 5, although it enables the recording of satellite data on two frequency bands, can only be used to a limited extent in practical surveying tasks because it does not meet the accuracy requirements on the centimeter level. The main reason for this is the quite low quality of the observations. With long observation times, however, results with a positioning accuracy of less than half a meter are achievable with the smartphone. Thus, the Pixel 5 is capable to achieve the requirements in terms of positioning accuracy and reliability for applications such as data acquisition for Geographic Information Systems (GIS) and especially in Location-based Services (LBS).

Introduction

Due to recent developments in the smartphone market, some smartphone models are nowadays available providing multi-constellation GNSS with signals on two frequency bands (see e.g. Barbeau, 2018; Darugna, 2021). They are also capable to record the raw data of the GNSS signals, which facilitates high performance real-time and post-processing applications. Thus, using these new models more precise positioning with GNSS has become possible. In this study, it is analysed if simple tasks of applied surveying, GIS (Geographic Information System) data acquisition or in LBS can be performed with these smartphones. Their usage saves time and cost, since no additional hardware has to be purchased, such as PDAs or dedicated GIS receivers. One current smartphone is selected for the experiments. It is the Pixel 5 of the American manufacturer Google LLC, which has been available since October 2020.

For the experiments, measurements were carried out on the roof of the Electrical Engineering Institute (EI) building of the TU Wien (Vienna University of Technology)(see Figure 1 on the left) and in a park in front of the main building (i.e., Karlsplatz) (Figure 1 right). In some of the tests, the smartphone is placed on a coordinative known reference point, i.e., a measuring pillar on the building roof or at known points of the control network available on Karlsplatz. Furthermore, measurements at Karlsplatz were performed in stop-and-go and kinematic mode where a user with the smartphone held in his hand walked along a straight trajectory with usual walking speed. The main purpose of the experiments is the analysis of the achievable positioning accuracies. The stop-and-go and kinematic measurements are used to simulate real measurement tasks such as data acquisition for GIS, such as for a tree cadastre, lantern cadastre, traffic signs, etc., as well as line documentation, such as for underground power lines.

In addition, a geodetic GNSS receiver from Spectra Geospatial, the SP80, (see Figure 1) is used as a reference station and placed in 12 meter distance from the smartphone on a second measuring pillar on the roof of the EI building. The SP80 receiver is capable to record GPS (L1, L2, L5) and GLONASS (R1, R2) data. In order to be able to use them, they are then converted to the RINEX format. The RINEX Converter 4.7.2 from Trimble is used for this conversion. Further data, such as the satellite ephemeris (RINEX navigation file) and clock corrections, are acquired from the CORS network EPOSA (see EPOSA, 2021) and the IGS (International GNSS Service). Post-processing of the raw data is carried out with the freely available Real Time Kinematic Library (RTKLib) software package. Furthermore Matlab routines are used to eliminate outliers, to calculate statistical parameters and transformations between different reference systems, such as from the WGS84 (World Geodetic System 1984) of GPS and the ETRS89 (European Terrestrial Reference System 1984).

RTKLib includes positioning algorithms for all common GNSS systems. In addition to the evaluation of the data in post-processing, the software can be used for positioning in real-time. In the course of this work, however, only the post-processing applications are used. The software package contains several subroutines. In this work, we use the applications RTKPlot and RTKPost. With RTKPlot, observations, navigation data and the solutions calculated with RTKPost can be visualized. In RTKPost the actual processing of the data takes place. The software includes different positioning methods. The methods Single Point Positioning (SPP), Precise Point Positioning (PPP)and the method static are used to calculate baselines.

Basics and approaches

Smartphone basics

The Google Pixel 5 smartphone incorporates a Snapdragon 765G processor from Qualcomm which allows the recording of multi-GNSS signals on two frequencies (Qualcomm, 2019). Table 1 provides an overview of the supported satellite positioning systems and frequencies. As can be seen dual frequency operation is available for the US Navstar GPS, European Galileo and Japanese QZSS (Quasi-Zenith-Satellite-System) satellite based augmentation system. For data logging an App from Geo++ GmbH, Germany, was used. The App is based on the freely accessible source code of Google's GPS Measurement Tool. With this App, raw GNSS observations in RINEX (Receiver Independent Exchange Format) format from the smartphone can be recorded. The RINEX Logger can record signals of all GNSS listed in Table 1. Apart from QZSS, other augmentation systems such as the European Satellite Based Augmentation System (SBAS) called EGNOS (European Geostationary Overlay System) are not supported.

Figure 1. Smartphone und reference receiver SP80 on two neighbouring measuring pillars on the roof of the EI building of TU Wien and mobile measuring set-up on Karlsplatz.

Table 1. : Supported GNSS and their useable frequency bands for the Google Pixel 5.

GPS	L1 / L5
GLONASS	R1
Galileo	E1 / E5a
Beidou	B1
QZSS	L1 / L5

Single Point Positioning (SPP) versus Precise Positioning (PPP)

Positioning with the help of SPP and PPP are an absolute position determination method. In the case of SPP, the position fix is obtained by code observation; for civil users with PRN (Pseudo-random Noise) code C/A (Coarse Acquisition). The accuracy of SPP is in the range of several meters. PPP is a method for reducing atmospheric error influences achieving more accurate positioning. In contrast to SPP, the position fix is more accurate, since the position determination is based on phase measurements of the carrier frequencies, e.g. from GPS L1 and L5 observations of the smartpohone. The code observations serve only to determine an approximate solution, which is necessary, since the phase measurement is ambiguous in contrast to the code measurement. The solution requires a certain convergence period, during which there must be no signal interruption. It is therefore of crucial importance that the observations are as uninterrupted as possible (Heßelbarth, 2011; Reußner, 2016). With PPP, accuracy in the centimetre range can be achieved. The broadcast ephemeris are not sufficient for this purpose. More precise satellite orbit data and satellite clock corrections are needed. These are provided by the International GNSS Service (IGS) on different accuracy levels, i.e, rapid and ultra-rapid orbits for real-time applications and final orbits for post-processing (Reußner, 2016). Thus, in this work the final orbits from IGS are used for the calculation of the PPP solutions.

Differential GNSS (DGNSS)

Another method for increasing accuracy is DGNSS. As with PPP, the position determination is based on both phase and code observations. Unlike SPP and PPP, this is a relative method, since the position is determined in relation to a reference station with known coordinates. This procedure therefore requires at least two GNSS receivers. One is operated as a rover, the other as a base (reference) station. While the base receiver is stationary, the rover is a mobile GNSS receiver. The correction of the measurement signals can be done either in post-processing or in real-time (so-called Real-Time Kinematic, RTK) during the measurement. In RTK, the correction data must be transmitted to the rover in real-time via a data link. This is usually done via the existing mobile network. In practice, it is often not necessary to set up an own reference station, since it is often possible to use an existing reference station network, so-called Continuously Operating Reference Station (CORS) networks. In Austria, such a network is operated by Energie Burgenland AG, ÖBB Infrastruktur AG and Wiener Netze GmbH. The station network, called EPOSA (Echtzeit Positionierung Austria), consists of 40 reference stations, which are distributed throughout Austria. The service provides both real-time data and RINEX data for post-processing. With the Austrian Positioning Service (APOS), the Federal Office of Surveying and Mapping (BEV) is providing another service with a similar function and its own reference stations. EPOSA is used in this work (EPOSA, 2021). If there is no reference station at an acceptable distance near the measuring area, it is possible to calculate a Virtual Reference Station (VRS) by interpolation from the surrounding reference stations (EPOSA, 2021).

Results of DGNSS solutions for the conducted long-term observations with the Google Pixel 5 are not presented here. They can be found in Retscher and Weigert (2022). Here the focus is led more on measurements with shorter observation periods of several minutes and down to seconds in the case of observations in the stop-and-go and kinematic mode.

Atmospheric error sources

In addition to satellite and receiver-specific errors such as orbit, hardware or clock errors, the atmosphere has a major influence on the accuracy of the determined positions. The effects of atmospheric refraction can be divided into the neutral atmosphere (tropospheric parts) and ionospheric parts.

The neutral atmosphere ranges up to an altitude of 90 km which are the ranges from the troposphere to the stratosphere to the mesosphere. The influence of the neutral atmosphere on the travel time depends on the meteorological conditions along the signal pathway and can be divided into hydrostatic (dry) and wet (or humid) fractions. Hydrostatic fractions account for 90% and wet fractions 10% of the tropospheric travel time delay. The hydrostatic components can be easily modelled on the Earth's surface using meteorological measurements (pressure and temperature) or through the use of standard atmospheric models and can therefore be modelled quite easily. For the wet fraction, the moisture content is largely determined by the water vapour content of the atmosphere along the signal path. This is subject to temporal and spatial fluctuations and is difficult to model (Reußner, 2016).

The neutral atmosphere is followed by the ionosphere. It passes into interplanetary space at an altitude of about 2000 km. The ionosphere contains the thermo- and exosphere. It contains large amounts of ions and free electrons, which significantly influence the delay of electromagnetic waves. The strength of this influence depends on the density of the free electrons along the signal path. To characterise this usually the parameter Total Electron Content (TEC) is used. Density, in turn, is influenced by the intensity of solar radiation and the geographic latitude and is subject to cyclical fluctuations. For example, the number of free electrons is ten times higher during the day than at night. The ionosphere is a dispersive medium for electromagnetic waves. This means that the propagation velocity depends on the frequency. This effect can be exploited to model the influence of ionospheric travel time delay. If the influence of the ionosphere is not eliminated, deviations in the order of several meters up to tens of meters for the measured pseudorange would occur. Although the satellites transmit several parameters modelling the state of the ionosphere, this non-negligible residual deviation remains. Dual-frequency observations can help in this respect as the ionosphere is dispersive. This means that the two frequencies travel with different propagation speed. Using the two frequencies recorded by the receiver linear combinations can be determined to reduce the effect of the ionospheric propagation travel time delays.

SPP solutions have significantly higher standard deviations than PPP. They resulted on the few meter level. For PPP, they are often less than one metre. The standard deviations of the GLONASS solutions are significantly larger than the ones of GPS.

Coordinate Systems and transformations

To determine the satellite-ephemeris, a globally uniform reference system is needed. This is provided by the WGS84 in the case of GPS, which is based on the International Terrestrial Reference System (ITRS). If a position is determined using GNSS, coordinates are obtained in WGS84, since the determined position refers to the position of the satellites. In many cases, it is necessary to transform the coordinates into a regional system. The European Terrestrial Reference System 1989 (ETRS89) is used in large parts of Europe because it represents a uniform and stable system for the Eurasian Plate. The ETRS89 was aligned with the ITRS in 1989. Since then, due to the continental drift, the Eurasian Plate has moved about 2.5 cm to the Northeast every year. The current positional deviation of the two systems is in the order of a few decimeters. The actual value is position dependent due to the additional rotation of the Eurasian plate. The ETRS89 is realized in Austria by the Austrian Positioning Service (APOS) (Höggerl et al, 2007; Killet, 2010).

Analyses of static and kinematic observations

In this section, the satellite availability and quality is briefly reviewed and then the main findings of the static long- and short-term observations and a detailed analysis of the kinematic observations are presented.

Satellite availability and quality of the static long-term observations

The Google Pixel 5 was able to observe GNSS signals from a total of 56 satellites over the whole observation period of 150 minutes in the static long-term observations. Of these, however, only 21 satellites were recorded on both frequency bands L1 and L5. Thereby the number of satellites observed was highest for GPS, but only about half could be observed on two frequencies. This is expected as only half of all available GNSS satellites in space broadcast L5 signals at the time of the experiments. In contrast, the number of Galileo satellites was smaller, but almost all satellites were able to receive both frequencies. Figures 2 and 3 show the satellite constellation of the GPS and Galileo satellites for the GPS frequency bands L1 (left) and L5 (right) and the Galileo E1 (left) and E5a (right), respectively, in the form of skyplots. In these plots the satellite motion, signal strength and the number of signal interruptions can be seen clearly. The signal strength is described on the basis of a colour scale, signal interruptions caused by cycle slips are marked by a red bar. Eight GPS satellites could be observed on only one frequency (see Figure 2). Many of these satellites are located more in the West. It is obvious that some of the satellites, from which only the L1 band could be observed, have a higher signal strength. The high number of cycle slips in the Pixel 5 observations is clearly visible. From the skyplots of the Galileo satellites in the frequency Galileo bands E1 and E5a presented in Figure 3 can be seen that all satellites could be observed on two frequency bands. Similar as for the GPS observations, cycle slips occur more frequently in the E5a band than in the E1 band. Overall, the signal quality of the Pixel 5 receiver is significantly lower compared to a professional geodetic GNSS receiver. The signals are considerably weaker and there are more frequent signal outages. In Retscher and Weigert (2022) the observations of the Pixel 5 with the nearby geodetic reference receiver SP80 placed on a second measuring pillar in a distance of only 12 m on the roof of the

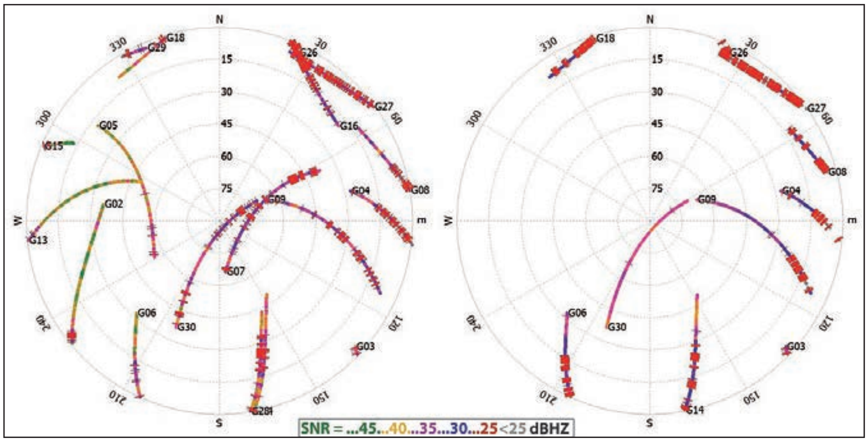

Figure 2. Skyplots showing the tracked GPS satellites of the Google Pixel 5 on L1 (left) and L5 (right) with coloured visualisation of the Signal to Noise Ration (SNR).

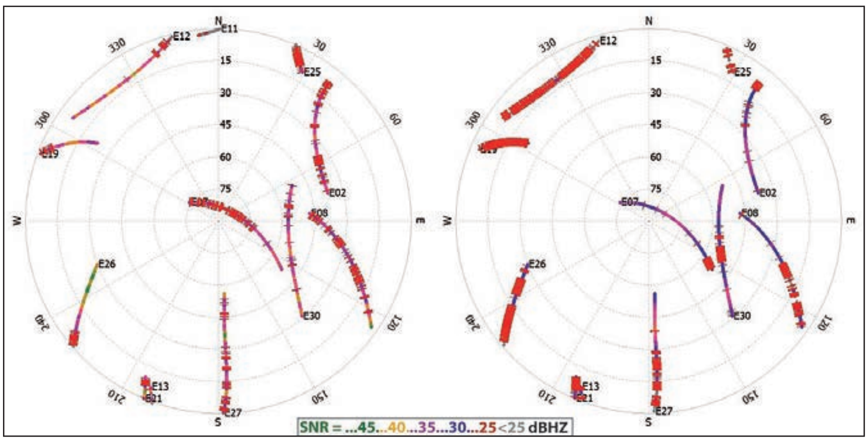

Figure 3. Skyplots showing the tracked Galileo satellites of the Google Pixel 5 on E1 (left) and E5a (right) with coloured visualisation of the Signal to Noise Ration (SNR).

EI building (see Figure 2) are compared. With the SP80, signal outages occur only at a very low elevation. While the signal strength of the reference receiver is highest at the zenith, the Pixel 5 still shows signal interruptions. Only in the West were relatively continuous signals with an SNR (Signal to Noise Ratio) of more than 45 dBHz.

Results of short static observation periods

Further measurements were carried out at Karlsplatz where a control point network including several reference points is available. These measurements represent typical real world measurement scenarios, such as GIS data acquisition, such as tree cadastre, lantern cadastre, etc. The Pixel 5 is mounted on a tripod and placed on known points (see Figure 1 on the right). Three surveys are carried out, each with 20 minutes of observation time. Different obstructions of the satellite signals are prevailing on the three chosen reference points N07, N08 and N09 of the control point network. While the points N09 and N08 are relatively in open space, N07 is located between several broad-leaved trees. Since the measurements have been carried out in winter, the trees do not bear any foliage. In the following, the calculated SPP and PPP solutions are presented and analysed.

SPP solutions

For the three reference points N07, N08 and N09, SPP solutions for the individual systems and a multi-GNSS solution are calculated. In the multi-GNSS solution, the individual systems are combined with Matlab. This is done for the entire observation period of 20 minutes. Table 2 shows the solutions for position N07, Table 3 for N08 and Table 4 for N09.

The number of calculated positions n varies greatly depending on the system used. The location also influences the measurement result. For reference point N07 the highest number of solutions (539) can be determined using GPS compared to the other points. For point N08, on the other hand, the lowest number (270) is determined with GPS. The number of solutions of the other systems also varies significantly depending on the point of view. Beidou delivers the most constant number of solutions. This varies only by 212 solutions between positions N07 and N09. Standard deviations are also subject to strong fluctuations and vary depending on the system and the point location.

The smallest 2D standard deviation (i.e., Std 2D in the Tables) of around 7.3 m is achieved at position N07 with Galileo. The largest positional standard deviation of around 67.1 m is again at point N07 with GLONASS. These GNSS and points also achieve the lowest (12.6 m) and largest (81.9 m) 3D standard deviations. In the following, the deviations from the known coordinates of the reference points are analysed. The results of Helmert's point position error (i.e., Dev 2D) differ by a few meters depending on the system and the point of view. The lowest deviation is achieved with GPS at point N08. It is only 0.36 m and is at the same time the solution for which the fewest individual solutions have been identified. The GPS solution for which the most solutions are available (N07, n=539) achieves an inaccurate result with a deviation of more than 18 m. This means most likely that more outliers in the data have influenced the result significantly. With more than 20 m, only the GLONASS solution for position N09 is less accurate. When the height component is included in the deviation, the best results are achieved with the multi-GNSS solutions. For points N08 and N07 these are just over 10 m, for point N09 a deviation of 24.6 m is achieved. Overall, the multi-GNSS solution achieves position deviations of about 4 m on all points.

Table 2. Comparison of the SPP solutions over a 20-minute observation period for the reference point N07.

SPP	20 Min	17.12.2020 11:10 - 11:30			N07						
	n	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	539	17.235	32.911	48.135	37.151	60.804	4.450	18.117	-16.983	18.655	25.228
GLONASS	369	40.812	53.238	46.900	67.082	81.851	-0.957	16.274	-30.079	16.302	34.212
GALILEO	534	10.999	12.478	28.7971	16.634	33.256	-2.992	-3.392	-10.669	4.523	11.588
BEIDOU	480	12.002	8.954	31.268	14.974	34.668	5.832	-0.032	9.885	5.832	11.477
Multi GNSS	1922	16.862	21.407	38.651	27.250	47.292	1.337	4.161	-9.739	4.371	10.675

Table 3. Comparison of the SPP solutions over a 20-minute observation period for the reference point N08.

SPP	20 Min	17.12.2020 10:46 - 11:06			N08						
	n	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	270	9.248	23.738	28.934	25.476	38.551	-0.217	0.288	-21.455	0.361	21.458
GLONASS	837	11.863	18.469	20.655	21.951	30.141	-9.349	4.618	-16.314	10.427	19.362
GALILEO	915	2.909	6.661	10.3231	7.268	12.625	-0.474	0.263	-11.376	0.542	11.389
BEIDOU	554	8.535	2.329	16.608	8.847	18.818	2.353	6.511	9.703	6.924	11.919
Multi GNSS	2576	7.427	9.129	17.754	11.768	21.300	-2.108	2.709	-9.441	3.433	10.045

Table 4. Comparison of the SPP solutions over a 20-minute observation period for the reference point N09.

SPP	20 Min	17.12.2020 10:20 - 10:40			N09						
	n	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	393	10.129	11.289	12.889	15.167	19.904	-3.714	3.512	-12.201	5.112	13.229
GLONASS	640	16.821	17.708	39.453	24.424	46.401	-6.824	4.670	-14.565	8.268	16.748
GALILEO	276	12.318	38.452	31.6746	40.376	51.318	-7.085	-19.078	-45.453	20.351	49.801
BEIDOU	342	5.165	7.840	17.423	9.389	19.792	2.185	-8.563	-37.729	8.837	38.750
Multi GNSS	1651	11.915	14.093	26.506	18.455	32.297	-3.977	-0.830	-24.258	4.063	24.596

PPP solutions

In the following, PPP solutions are calculated for the three reference points. As in the case of long-term measurement, no solutions can be estimated for Galileo and Beidou because of their low signal quality. For GPS, two carrier frequencies can be included in the calculation. For GLONASS, only the frequency R1 is available. Broadcast ephemeris are used. Figure 4 shows plots of the determined numbers of solutions for point N09 (left) and N07 (right). The distribution of the solutions for position N08 is similar to that for position N09 and is therefore not shown here. The GPS solutions are shown in green and the GLONASS solutions in blue. If PPP solutions cannot be determined, the employed software package RTKPost automatically calculates SPP solutions. These are represented in red in the Figure. There is a distance of several meters between the GPS and GLONASS solutions at N09. At N07 this distance is even larger. Observations from point N07 have a lower quality and many SPP solutions are estimated only. Similar as for the SPP solutions in section 3.2.1, Tables 5, 6 and 7 summarise the PPP results for each reference point. In addition to the number of identified solutions per system, the quality (Q) of the solutions is also given in percent. Q describes the proportion of PPP solutions. The remaining solutions are SPP solutions.

At the reference points N07 and N08 much more solutions are achieved with GLONASS than with GPS. Especially at N07, where Q is only 17.6% for the GPS results. Overall, GLONASS solutions are of a higher quality than GPS solutions. With GLONASS, 100% PPP solutions can usually be calculated, even on point N07. Using GPS this result is not achievable. The quality of the solutions has a major influence on the standard deviations. The solution with the lowest quality (GPS; N07; 17.6%) also has the largest standard deviation (in 2D 45.5 m; and in 3D 79.6 m). The smallest standard deviation is achieved with GLONASS for point N08. This is about 2 m in 2D and about 3 m in 3D. The total deviations from ground truth are similar. The results with a low quality have a large deviation. This reaches for the reference points more than 27 m. The best result can be achieved with the GPS solution for position N09. The deviations are about 4 m in 2D and 12.9 m in 3D. The multi-GNSS solutions vary by several meters depending on the reference point. For the position, results for the standard deviations are obtained between 4 and 13 m, the total deviation from the known reference point coordinates is between 16 and 26 m.

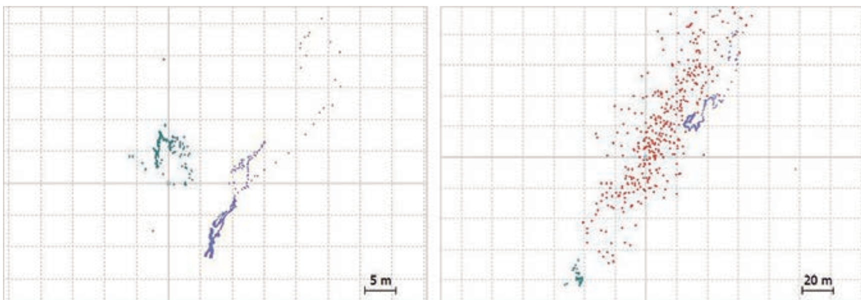

Figure 4. Comparison of PPP solutions for GPS (turquoise) and GLONASS (purple); on the left is point N09, on the right N07. Solutions for which only one SPP solution could be determined are shown in red. Note, the different scale of the grids.

Table 5. Comparison of the PPP solutions for GPS and GLONASS over a 20-minute observation period at point N07.

PPP	20 Min	17.12.2020 11:10-11:30	N07									
	n	Q [%]	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	380	17.6	21.585	40.022	65.366	45.472	79.627	9.174	25.459	-19.463	27.062	33.333
GLONASS	340	99.8	3.993	3.895	4.806	5.578	7.363	-20.501	0.810	-34.893	20.517	40.478
Multi GNSS	720	56.4	16.829	21.529	29.141	27.326	39.949	-8.518	8.700	-22.311	12.176	25.417

Table 6. Comparison of the PPP solutions for GPS and GLONASS over a 20-minute observation period at point N08.

PPP	20 Min	17.12.2020 10:46-11:06	N08									
	n	Q [%]	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	189	84.4	1.596	4.636	9.613	4.903	10.791	-1.046	-11.199	-27.989	11.247	30.164
GLONASS	797	100.0	0.839	2.018	2.059	2.185	3.003	-8.731	2.052	-13.874	8.969	16.521
Multi GNSS	988	95.6	2.024	5.097	4.762	5.484	7.263	-8.017	-0.169	-15.723	8.018	17.650

Table 7. Comparison of the PPP solutions for GPS and GLONASS over a 20-minute observation period at point N09.

PPP	20 Min	17.12.2020 10:20-10:40	N09									
	n	Q [%]	Std E	Std N	Std U	Std 2D	Std 3D	Dev E	Dev N	Dev U	Dev 2D	Dev 3D
GPS	245	99.0	1.090	2.581	1.753	2.802	3.305	-1.097	-4.159	-12.044	4.301	12.789
GLONASS	556	100.0	2.289	2.414	2.770	3.326	4.328	-5.251	6.537	-17.473	8.385	19.380
Multi GNSS	799	99.9	2.582	4.404	3.065	5.105	5.955	-3.898	3.641	-15.642	5.334	16.527

Compared to long-term observations, the 20 minute observations are much more imprecise. Thus, if the requirements in terms of positioning accuracies are high, longer observation times are needed with PPP.

Measurements along a straight trajectory

For application scenarios such as line documentation, e.g. for underground power lines, or the approximate recording of trajectories, measurements are carried out along a straight line with a total length of 95.86 m on Karlsplatz. The measurement scenario is such that a user walks at a slow pace with the smartphone in his hand along a predefined line both ways in the outward and in the return direction between the two known reference points N07 and N09. Every five meters a short stop with a duration of several seconds is made. Thus, the measurements can be seen as pseudo-kinematic or in stop-and-go mode.

With RTKPost the GPS, GLONASS, Galileo and Beidou solutions for the outward and return journey were calculated. The resulting 8 position files are transformed, merged and plotted with Matlab (Figure 5). A total of 3,497 positioning solutions are available. The resulting point cloud is widely scattered. The course and direction of the track can be roughly estimated in the form of a cluster. There are many faraway outliers and it is not possible to make precise statements about the path taken. Consequently, the results need to be further processed. For this purpose, an adjusted straight line is laid through the point cloud. This can then be compared with the calculated distance between the two known reference points. With Matlab, a neighbourhood analysis is performed to eliminate outliers and more distant points. For each point, the number of neighbours within a defined radius is determined. If the number falls below a predefined limit, the point is not included in the calculation. The radius and the limit are determined by experimentation. The adjusted line should be optimally adapted to the known straight path. The best result was achieved with a radius of 5 m and a minimum number of 30 neighbours (Figure 6). A total of 1,491 points are eliminated (blue) and 2006 points are included in the compensation (red). The adjusted line is shown in red and the ground truth in green in Figure 6. The actual distance can be easily reproduced by the straight line. The estimated adjusted line, however, has a slightly lower slope. This results in an increasing distance between the two straight lines. The maximum distance obtained resulted in 0.97 m. A problem is the start and end point of the determined trajectory. The adjusted line is too long and extends more than 10 m beyond the distance between the known points serving as ground truth (Retscher and Weigert, 2022).

In addition to the SPP solutions, the PPP solutions are estimated. As with previous measurements, PPP solutions can only be calculated for GPS and GLONASS. A total of 1,142 individual solutions of the two systems are available for the round trip. This data is processed with Matlab similar as with the SPP solution. The unprocessed point cloud of the solutions gave similar results as the SPP solutions shown in Figure 5. There are fewer points in total than in the SPP solution. The point density along the reference line is lower and there are many outliers. Despite the variation of the radius and the boundary during the neighbourhood analysis, a good adaptation to the actual distance is not achieved. The deviations of the two lines are many meters apart. The main reason for the lower accuracies is here that only GPS and GLONASS can be used instead of all four GNSS as in the SPP solutions.

Summary of the main results and conclusions

Various experiments were carried out in this study, such as long-term measuremenst of 150 minutes, several practical measurements over an observation period of 20 minutes as well as stop-and-go and kinematic measurements. In this paper, short-term static observations and a straight trajectory measured in stop-and-go mode are analyzed. The measurement data were evaluated using the positioning methods SPP and PPP. The main findings and results are summarized in the following, with reference to the criteria investigated, i.e., measurement effort and costs, quality, accuracy and repeatability of the measurements.

Measurement effort and costs

The effort for the measurements is quite low. For equipment, only a mounting device for the mobile phone and a tripod are required for long-term observations on reference points depending on the measurement task. Especially if PPP is chosen as positioning method, longer observation times should be chosen, as the quality of the measurement data varies considerably over time.

Signal quality

Compared to geodetic GNSS receivers, the quality of the observations is significantly lower. The recorded satellite signals are weaker and there are frequent signal outages, which also occur for observations in the zenith. Obvious from the tests is that the satellites with strong L1 signals from GPS could not always be observed on the second frequency L5. Most of the Galileo satellites could be received on both frequencies, however,

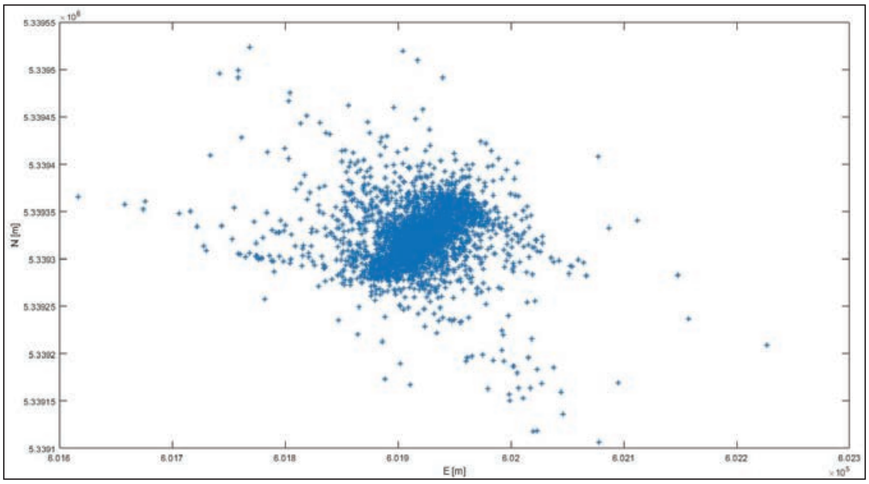

Figure 5. Point cloud with SPP solutions along the route to be investigated. The point cloud includes solutions for the round trip, as well as for all four GNSS.

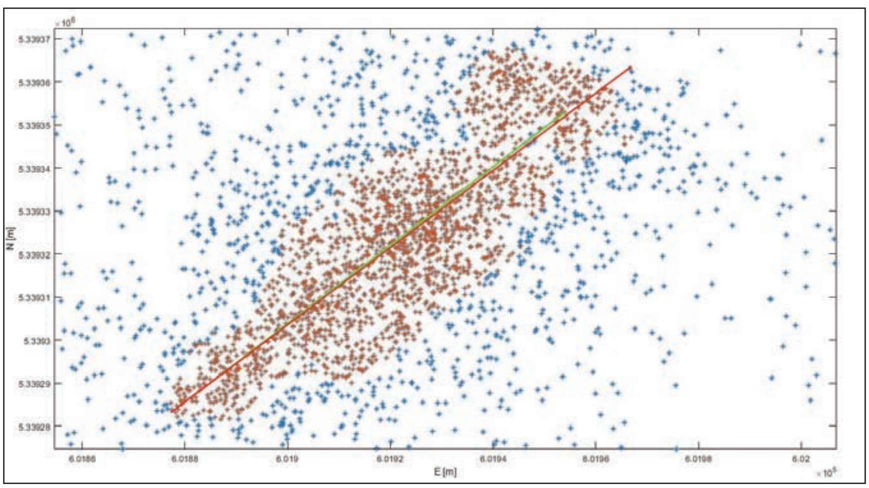

Figure 6. Adjusted line of the point cloud along the straight route. The distance calculated from the known coordinates is shown in green. The distance calculated with the help of the neighbourhood analysis from the points is shown in red. The red points have been included in the calculation of the adjusted line (Source: Retscher and Weigert (2022).

Observations on two frequency bands can only be made currently for GPS and Galileo with the Google Pixel 5. In this case, however, the observation data of the second frequency band L5 was of lower quality in the conducted experiments, so that unfortunately evaluation of both frequency bands is only possible to a limited extent.

the signals of the bands L5 and E5a are weaker overall than the signals of the bands L1 and E1. The high number of signal outages and the often low signal strength indicated by the SNR make further evaluation difficult. PPP solutions can only be calculated for GPS and GLONASS. However, this is often not possible for the entire observation period. At these points, RTKLib automatically switches to SPP mode. The fact that a dual-frequency receiver is installed in the Pixel 5 can therefore only be used to a limited extent in our experiments.

Achievable positioning accuracies

As expected, SPP solutions have significantly higher standard deviations than PPP. They resulted on the few meter level. For PPP, they are often less than one metre. The standard deviations of the GLONASS solutions are significantly larger than the ones of GPS. If one considers the deviations from the ground truth from the coordinates of the reference points, the results could not be generalized as significant differences in achievable accuracies occurred for the individual methods. Clear differences of the results can only be seen for GPS in the long-term measurement. Both Galileo and Beidou provide SPP results with higher positioning accuracy for long-term measurements. However, these cannot be compared with the other solutions, as no PPP processing is possible for Galileo or Beidou. If the different GNSS are combined, SPP can achieve results with a deviation of less than half a meter in dependence of the chosen observation time period. The combined solution of all four systems is not always the best, however, as it is strongly influenced by the very inaccurate GLONASS results. However, position deviations of less than 30 cm could be achieved with different GNSS combinations (see also Retscher and Weigert, 2022).

For the observations over 20 minutes the differences between the results are in the range of several meters for both methods SPP and PPP. The results vary significantly between the different GNSS combinations and the chosen reference points. Because of the high variation, it is difficult to say which system and method can be used to obtain the more accurate results. The SPP multi-GNSS solution, consisting of all four systems, can guarantee a positional deviation of less than 5 m for all three reference points on Karlsplatz. The PPP dual-GNSS solutions, consisting of GPS and GLONASS, provide a positional deviation of similar quality depending mainly on the length of the observation period.

SPP and PPP solutions were also calculated for the measurement along the chosen trajectory. From the point cloud of the SPP solutions, an adjusted straight line could be estimated, which represents the true trajectory well. The maximum deviation of the measured and true distance is less than one meter. However, the adjusted line resulted in a longer distance than the true distance of few meters which causes that the start and end point cannot be estimated precisely from the measurements.

Repeatability

In the paper of Retscher and Weigert (2022), the long-term observation for GPS were also divided into measuring intervals of 10 minutes each and position solutions were calculated using the methods SPP and PPP, using both broadcast ephemeris and final orbits from IGS for the PPP calculation. The standard deviations for these solutions remain largely constant in the intervals. However, the accuracy varies significantly regardless of the method used. The measurement results therefore show poor repeatability for the short observation periods of 10 minutes. A major dependence on the prevailing satellite constellation in these 10-minute periods is seen. Further analyses are required for different length of observation periods.

Final outcome discussion

Observations on two frequency bands can only be made currently for GPS and Galileo with the Google Pixel 5. In this case, however, the observation data of the second frequency band L5 was of lower quality in the conducted experiments, so that unfortunately evaluation of both frequency bands is only possible to a limited extent. Due to the high number of signal outages, a position determination based on phase observations was not possible for all satellite systems. In most cases, they could only be made for GPS. The results depend also on the chosen ephemeris data. If IGS final orbits are also used for PPP, the accuracy is significantly higher.

Whether the Google Pixel 5 or a similar smartphone is currently suitable for solving measurement tasks in surveying depends essentially on the requirements of the application. If accuracies of less than half a meter are sufficient, smartphones can replace PDAs or receivers for GIS data acquisition. However, if short observation times are required, the deviations often amount to several meters. The in the literature reported cm-accuracies for the PPP with comparable smartphone models could not be confirmed from the experiments.

These are mostly based on extensive calibrations for the smartphone GNSS antennae to determine the phase center variations, see e.g. in Darugna (2021) and Wanninger and Heßelbarth (2020), and are therefore not always for practical usage in GIS and LBS applications.

Outlook on future research questions

For the future work, we will concentrate on the following research questions:

- Which results can be achieved for different observation time periods with PPP?
- How do the other GNSS and the SPP multi-GNSS solutions behave during the measurement?
- How do the L5 observations look like for different satellite constellations?
- How long is the convergence period of PPP solutions as a function of the observation time?
- Which positioning accuracies can be achieved in real-time?
- Which positioning accuracy is achieved in real-time positioning with the CORS RTK services?
- Do similar problems occur with comparable smartphones?
- Are the accuracies to be achieved comparable for different smartphones?
- Does the App used for data acquisition have an impact on the results?

Acknowledgement

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Usage of NaviC system has increased in India

The Government of India has informed that the usage of Indian Regional Navigation Satellite System (NaviC system) has increased in India. NavIC finds utilization in national projects like public vehicle safety, power grid synchronization, real-time train information system, fishermen safety, etc.

Other upcoming initiatives viz. common alert protocol-based emergency warning, time dissemination, geodetic network, unmanned aerial vehicles, etc. are in the process of adopting NavIC system. Many mobile phone models in the country are already having NavIC compatibility. Department of Space is constantly engaged with the manufacturers of mobile phones and chipsets to support them technically for adding NavIC compatibility in their devices.

Russia launches final GLONASS-M navigation satellite into orbit

Russia added another piece to its GLONASS satellite-navigation network on November 28, 2022. A Soyuz rocket rocket topped with a GLONASS-M satellite lifted off from Plesetsk Cosmodrome in northwestern Russia Monday at 10:17 a.m. EST (1517 GMT; 6:17 p.m. Moscow time). The spacecraft was successfully delivered to its target orbit and has received the designation Cosmos 2564, according to Roscosmos, Russia's federal space agency. *www.space.com*

NGA seeks feedback on how to improve Earth modeling

The National Geospatial-Intelligence Agency (NGA) is seeking information from the GNSS community on upgrades to its Stardust program. Stardust develops models of the Earth used in geomatics. The upgrades will result in modernization of geomatics information technology systems and infrastructure. The update includes migration of models to the cloud.

Stardust is run by the NGA Foundation GEOINT Integrated Program Office, partnered with the Foundation GEOINT Group (NGA/SF) within the Source Operations and Management Directorate.

Use only horizontal ground distance [not grid distance] dimensions in land surveys

In Australia, all land dimensions are only horizontal ground distances and all surveying and mapping coordinates are only on 6^0 UTM projection. Comparatively simple and unconfused, this Australian coordination practice has proven itself over the last 50 years and can claim to be the best survey coordination and mapping system in the world

John Read
FIS NSW, Emeritus Surveyor [Retired]

Abstract

The anomaly of having two nearly identical units of linear measurement has led the USA to discontinue the use of the "US Survey Foot" after 1/1/2023, This then leaves the "International" foot as the only standard unit of linear measurement in the USA. However, the USA also has two nearly identical ways of stating dimensions in land surveys. Either Grid distances on their SPCS coordinate projection plane [usually at Sea Level] or Horizontal Ground Distance [where measured and used] are stated as dimensions. The continuation of this anomaly and duplexity prompts this Paper.

Back in the 1970's, in New South Wales, Australia, the reverse situation arose. Then, the surveying profession proposed a similar to SPCS coordination system that required Projection [Grid] distance [instead of the established horizontal ground distance that everyone was using] as dimensions on survey and title plans. Also, so that the proposed grid distance dimension approximated horizontal ground distance, they required a 2^0 zone UTM projection [in addition to the established 6^0 UTM mapping projection]. This Paper recounts the rationale used to ultimately reject the NSW proposal.

In Australia, all land dimensions are only horizontal ground distances and all surveying and mapping coordinates are only on 6^0 UTM projection. Comparatively simple and unconfused, this Australian coordination practice has proven itself over the last 50 years and can claim to be the best survey coordination and mapping system in the world.

1. Introduction

Upon the colonisation of New South Wales in 1788, all land was "taken" as Crown land [Public domain] and was leased or granted for settlement by metes-and-bounds visible marking and written description. Surveyors used circumferentors and compasses with reference to magnetic north for bearings and used a Gunther's chain for measurement of boundaries. Later [1872] after the use of theodolites became mandatory and when a long, thin, steel riband or wire came into use, there was a significant improvement in the precision of surveys. Chains required regular standardisation to ensure accuracy. Together with the concise, simple and easily understood Torrens title system [introduced by the Real Property Act in 1863] real property was defined by precise boundaries physically identified on the ground and described in simple and easily understood terms. For nearly 100 years [in the 1970's] this NSW survey and land title system underpinned property values and had proven itself to be reliable and trusted.

1.1 NSW trigonometrical surveys and mapping

Trig surveys and mapping in NSW had a haphazard past because of changing budgetary priorities. Consequently, Australia was caught unprepared during World War 2 and aerial surveying and mapping then became a military priority. In 1945 the National Mapping Council was established and resources optimised to meet Commonwealth, Military and State topographical mapping needs. Universal Transverse Mercator [UTM] projection was used with map sheets based on the International Map of the World [IMW] 6^0 longitude by 4^0 latitude sheets. The Australian Geodetic Datum [AGD] and the Australian Map Grid [AMG] were established in 1966 and were applicable in the 1970's.

1.2 Coordinated cadastre

The NSW colonial cadastre was a patchwork of parcels where new parcels generally abutted existing parcels, using their abuttals for boundary origin and azimuth. Crown land portions and allotments were plotted on County, Parish, Town and Village maps and, after 1863, subdivision lots were plotted on Registrar General charting maps, together making up a mosaic of parcels for cadastral maps. The 1985 review of the state survey system established a Digital Cadastral Database [DCDB] which digitised data [1984-1994] from AMG maps, aerial photos and calculated from surveys. This met most community need for coordinates without survey precision. It should be noted that the DCDB is graphical in nature, is used for administrative purposes, and has no legal weight in land boundary definition.

1.3 Boundaries and survey coordination

Boundary location is a matter of law whereby precedence is given to where boundaries are visible, identified or marked on the ground. The plan of survey records, in a convenient form, particulars of the survey of that boundary. In survey coordination, all other evidence of boundaries [visible, natural, marked, relocated from monuments, occupations and measurement] precede that of [invisible] coordinates. However, survey coordination provides point reference to underpin the coordinated cadastre and provides positional recovery where boundaries are destroyed by natural disasters such as bushfires and floods.

Survey coordination does not remove the obligation on the part of the surveyor to accurately mark boundaries on the ground as permanently and visibly as possible and to state the boundary information on the title plan that is clear and easily understood. For any legal credence in boundary definition, coordinates (and their datum) must be stated on the relevant survey or title plan.

1.4 The NSW survey integration proposal

The NSW Survey Integration proposal was timely. It was claimed to be *"the first comprehensive system of surveys in the state"*. It sought to replace [1] magnetic north, true north and azimuth from abuttals with grid north and [2] to integrate ad-hoc surveys with control surveys and a coordinated cadastre. It also [and this was a matter of subsequent dispute] proposed coordination copied from similar 'narrow zone' coordinate systems from overseas. It proposed that: [a] all stated land, survey and title dimensions be Projection [or Grid] distances on a coordinate projection plane [at sea level] and [b] proposed a 'narrow' 2^0 zone wide Integrated Survey Grid [ISG} so that [Grid distance] dimensions would be mathematically consistent with the proposed [ISG] coordinates. This was additional to the already existing horizontal ground distance dimensions and 6^0Australian Map Grid [AMG].

The NSW proposal had support of the Surveyor General, academic surveyors, surveying professional bodies and the heads of most government Departments. This, and its use overseas, gave it credibility. Further, any argument against the matter under dispute was seen as opposition to the proposal as a whole, and was ignored by its NSW proponents.

Ultimately grid distance dimensions were opposed, and then [1975] rejected, so that all dimensions in surveys and land titles remained and continued as horizontal ground distances in Australia. Once this decision was made (and the need for grid distance dimensions on plans and their closeness to ground distances was no longer an issue), the existing 6° UTM (AMG) map projection should have also been used for survey coordination. Nevertheless, the 2^0 zone ISG was introduced and practised in NSW for 20 years (until 1995) when the *geodetic* 6°-zone AMG was replaced by the *geocentric* 6°-zone MGA. From then, and for the last 25 years, all survey and mapping coordinates, the DCDB and all maps have been based on the 6°-zone MGA (first MGA94 and now MGA2020).

This background information is included with the hope that the reader will forego the presupposition, generally accepted with the NSW proposal, that the grid distance dimension and 'narrow zone' coordination practised elsewhere around the world was the only means of survey-precision position reference. This paper argues against the statement of grid distances as dimensions in survey and land titles as they often differ with horizontal ground distance and other dimensions where measured and used. It also asserts that it is advantageous to state horizontal ground distance dimensions with an orientation to grid north and the already existing 6°-zone UTM mapping coordinate system, particularly in relation to modern surveying equipment producing more precise measurements and modern computer software simplifying and speeding up the calculation of coordinates. As horizontal ground distances and 6°-zone UTM maps already exist globally, this Australian system could be established worldwide, simply by doing away with the duplexity of grid distance dimensions and their 'narrow zone' coordination.

2. An initial explanation

In mapping, all distances on the projection plane are grid (or projection) distances, being in standard linear units on that plane. Distance on the ground, where measured and used, is in standard linear units at ground level. Consequently, grid distance dimensions (in 'narrow zone' coordination) vary from place to place and height to height with the distance measured at ground level by (1) a scale (projection) factor and (2) a height (above sea level) factor. These are combined as the 'grid-to-ground' conversion factor between grid and ground distances.
As mathematical consistency of data is required in calculation, this must be in standard linear units, either on the projection plane or at ground level, with the 'grid-to-ground' conversion between them. (*Mathematical consistency is when data or units of calculation are of the same uniform standard measure.)* This conversion is ignored in many 'narrow zone' coordinate systems where grid distances are stated as 'substantially equal', 'near enough', 'quasi-' and/or 'pseudo-' horizontal ground distance dimensions.

In surveys, precision and accuracy of measurement is important and expected of a surveyor. The surveyor makes adjustment (not corrections, unless there is an error) to replicate the exactness of the standard linear units of their measurement. All measurements are adjusted to the horizontal or level at its mean height. This is known as "horizontal ground distance" (also called site or terrain distance) and is defined as *"the distance on the horizontal plane at the mean elevation of its measurement"*.

The matters of dispute between the NSW Survey Integration proposal and the alternative existing horizontal ground distance dimension – 6^0 AMG coordinate proposal were:

[a] mathematical consistency and
[b] what to show on plans.

Copied from overseas practice [1] the NSW 2° 'narrow zone' coordination proposal required the mathematical consistency of data for calculating coordinates, thereby showing both projection [grid] dimensions and coordinates, on plans. This requires a 'narrow zone' projection to minimise the size of the 'grid-to-ground' conversion factor so when grid distance is stated as a dimension on plans, it approximates horizontal ground distance and measurement.

By comparison, [2] the existing alternative preserves the fundamental mathematical consistency of data between measurement and dimension. This means that horizontal ground distance dimensions and projection coordinates are shown on plans, but it requires the calculation of the 'ground-to-grid' difference between them for coordinate calculation. Unlike the NSW proposal with approximate dimensions, the existing alternative ensures the exactness of dimensions with measurement in standard linear units where measured and used.

So, the choice in the 1970s NSW Survey Integration debate was either:

1. introduce the overseas practice of mathematical consistency of the coordinate calculations derived from measurement, but stating grid dimensions on plans that [often] <u>disagree</u> with those measurements; <u>or</u>
2. maintain the long accepted mathematical consistency of horizontal ground distance dimensions with measurement and calculate the projection coordinates from measurement, but then, state on plans, dimensions that <u>agree</u> with those measurements.

3. Horizontal ground distance land dimensions, only and always

According to the Oxford Dictionary, a dimension is a measurable extent of any particular kind, such as length, breadth, depth or height. The word comes from the Latin *dimensis* meaning "a measuring" and the old French word *dimetiri* meaning to "measure out" and, hence, has a direct nexus with measurement. It is the written statement of a measurement.

Over many years the standardisation of units of measurement has been refined to the extent that standard linear units can be reproduced with exactitude. The dimension should replicate that exactitude as measured in standard units. Every country maintains national linear standards (in Australia, by the National Measurement Institute) and every surveyor must verify their measuring equipment with baselines certified from these standards. Consequently, every measurement (and dimensions derived from these measurements) should replicate the "most scrupulous exactness" of the standard linear unit.

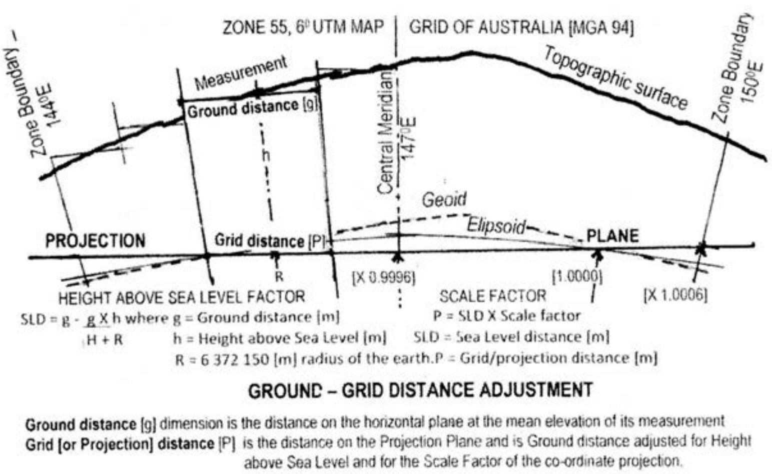

Figure 1: Ground distance to grid distance adjustment

Horizontal ground distance is the survey measurement and land dimension that a surveyor determines and what the public understands and expects. In this context, the deliberate departure [no matter how small] of grid distance from horizontal ground distance dimension at its location, would seem to be a specious practice by surveyors. Being 'near enough' is contrary to the professionalism expected of surveyors and the competence, precision and exactitude of the measurement surveyors make, and the dimensions that they then state.

3.1 Advantages of using Horizontal Ground Distance dimensions

Horizontal ground distance is stated in standard linear units, i.e. metres in Australia. Its use (instead of grid distance) is supported by the following five reasons outlined in the following subsections.

3.1.1 Measurement and usage support Horizontal Ground Distance dimensions

Usage (practically all development is built on the horizontal plane where their measurement is made), calculation, and convenience of record commonly support horizontal ground distance as the dimension in land measurement, surveys, property plans and titles.

3.1.2 Horizontal Ground Distance dimensions are mathematically consistent with all other dimensions in standard linear units

Horizontal ground distance maintains mathematical consistency with existing and other dimensions and their inter-related systems of area, volume, etc. In this context, this mathematical consistency is particularly important in design when construction materials and products are manufactured or prefabricated off-site. Incidentally, grid distance dimensions are the *only exception* to this mathematical consistency and the statement of dimensions in standard linear units where they are measured and used.

3.1.3 Horizontal Ground Distance Dimensions are mathematically consistent with measurement at specific locations, heights and surfaces

It would be illogical for metes and distance relative to bounds, distances to and from monuments, strata and strata titles, and titles restricted to often 50' (15.24 m) from the surface, to be shown by standard linear unit dimensions at any other place (i.e. the projection plane or at sea level) than the location, height and surface to which such distances and areas are referred to, measured and used.

3.1.4 Horizontal Ground Distance dimensions do not change with Coordinate Systems

Unlike grid distance, horizontal ground distance does not change, irrespective of the zone width and coordinate system used. (Grid distance dimensions can vary, and be an issue, when more than one zone width or coordinate system is used, as in the 2°-versus-6° zone debate regarding the NSW proposal.)

3.1.5 'Narrow Zone' Projection Coordinate Systems, State Plane Coordinate Systems and Low Distortion Projection Coordination acknowledge the significance of Horizontal Ground Distance

Specifically, the important function of horizontal ground distance is acknowledged by those systems designed to limit the difference between their grid (or projection) distances and the horizontal ground distance. However, the fundamental consideration is not an 'acceptable' amount of difference, but the need to have a difference, *any difference*, between the [grid distance] dimension shown and the horizontal ground distance measurement of what exists.

The statement of horizontal ground distance allows dimensions to be readily measured and used [1] without any need for 'grid-to-ground' calculation, [2] without the imprecision of (often) approximate grid distance dimensions, [3] without coordination, and [4] without a 'narrow zone' projection. This is what most users [and surveyors] want.

4. Grid distance land dimensions, not now and not ever

4.1 Use and Statement of Grid Distance dimensions on 'Narrow Zone' Projection Planes

Initially, in plane coordination, dimension and measurement were the same, and there was mathematical consistency with plane coordinates. Naturally, this mathematically consistent relationship could not be maintained over larger land areas and greater height differences, so measured (horizontal ground distance) data had to be multiplied by a 'ground-to-grid' conversion factor for coordinate calculation on the projection plane (Figure 1).

The introduction of mapping coordinates using UTM maps and survey coordinates using State Plane Coordinate Systems [SPCS] in the 1930s was revolutionary at the time and continued to underpin the 'narrow zone' NSW Survey Integration proposal of the 1970s. The validity of calculation requires mathematical consistency of all data used in the calculation. This is irrefutable and forms the basis of support for the mathematical consistency of grid distance dimensions and coordinates.

However, this created a paradox where the precision of the 'ground-to-grid' conversion applied when initially establishing coordinates from measurement, did not apply in reverse when the comparatively imprecise grid distance dimensions used in 'narrow zone' coordination was stated on plans. That is, without the 'grid-to ground' conversion, the stated grid dimension was imprecise and mathematically inconsistent with the measurement from which it was derived. Also, grid distance dimensions required 'grid-to-ground' calculation every time for the more precise Horizontal ground distance dimension was needed, even if coordination was not used.

Essentially, *the real issue was whether, or not, grid distance should be shown as dimensions on plans*. The NSW 'narrow zone' coordinate supporters argued that it should, otherwise the mathematically inconsistent data would invalidate coordinate calculations. So, instead of mathematical consistency of stated dimensions with horizontal ground distance, they proposed a 2° 'narrow zone' projection to reduce the scale (projection) factor of the 'grid-to-ground' difference to an 'acceptable' limit for mathematical consistency of the grid distance dimensions stated on plans with grid distance projection coordinates.

The NSW Survey Integration proposal claimed that, with a 2°-zone projection plane, grid distance dimensions would "significantly equal" ground distance in the "vast majority of cases" and that the scale (projection) factor was within an "acceptable" limit of 1:8000. <u>Yet, in this:</u>

- Allowance was not made for the often-greater height (above sea level) factor;
- Overstatement of measurement often occurred;
- Tolerance was still needed for the maximum error in measurement to not exceed 1:12,000.

However, this action to narrow the zone width to ensure that the grid distance approximated horizontal ground distance detracts from the essential issue of why grid distances need to be stated as dimensions in the first place.

4.2 Statement of mathematically inconsistent data on plans

The 'narrow zone' coordination practice of mathematical consistency of calculation data is used to justify the statement of grid distance dimensions on plans. This was to prevent any calculation error due to different and inconsistently stated data. Yet, unless clearly declared otherwise, confusion and error can occur when grid distance dimensions replace the more-expected horizontal ground distance dimension, especially as their similar size and same mode of statement tends to hide the difference. However, *dimensions and coordinates are stated differently, in different modes*. In this way, both horizontal ground distance dimensions and grid distance coordinates can be shown on the same plan (with a calculable difference) and (although mathematically inconsistent) without confusion, simply by stating [1] horizontal ground distance in dimension form and [2] grid distance as coordinates and in coordinate form.

Coordinates can be stated either as or in:

1. Coordinate mode at the relevant point on the plan (and potentially in *italics*), or
2. An (accompanied?) schedule of coordinates referenced to relevant points, and/or
3. To dispel any confusion, a horizontal ground distance conversion statement with
   a. the multiplication factor for conversion from ground to grid, and
   b. the applicable static coordinate datum (e.g. MGA94 or MGA 2020), acknowledging that, for title clarity, data and statements on title plans must be kept to a minimum.

Adoption of the different modes of statement allows both ground (dimension) and projection (coordinate) data to be shown on the same plan [1] without confusion, [2] without 'near enough' approximate grid distance dimensions, [3] without the need for 'grid-to-ground' conversion for measurement and [4] without an additional 'narrow zone' coordination system.

4.3 Calculation of mathematically inconsistent data in Coordination

In 'narrow zone' or State Plane Coordinate Systems, either (1) grid distance is deemed 'near enough' for use as a dimension or (2) a 'grid-to-ground' conversion is applied to the grid distance when the more-precise horizontal ground distance dimension is to be determined, measured and used. However, there is another option: (3) The 'grid-to-ground' conversion can be made with the coordinate calculation with data conversion, becoming part of coordinate calculation; a calculation that must be made anyhow. <u>This is supported by the six reasons outlined in the following subsections:</u>

4.3.1 Conversion, only when required, with the obligatory coordinate calculation.

Data conversion should be carried out only when it is required, with coordinate calculations.

Grid distance and coordinates on the projection plane cannot be measured and must be calculated. Therefore, it makes sense that the data conversion should be calculated, as required, with the obligatory coordinate calculation.

Ensuring that calculating data is

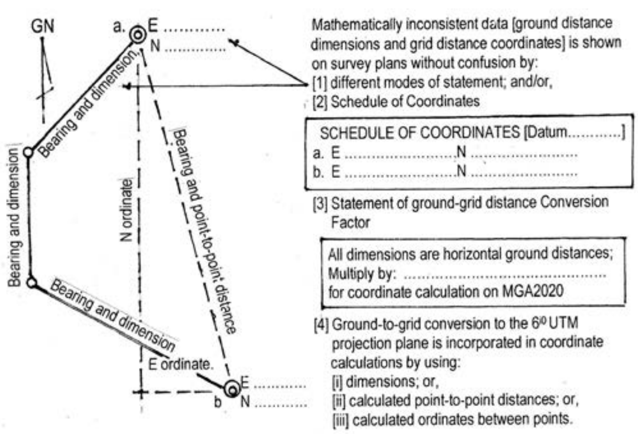

Figure 2 Statement of mathematically inconsistent data on survey plans without confusion

mathematically consistent is not a problem [or issue] for the mathematically competent professional surveyor. Therefore, it seemed odd that in the 1970's NSW Survey Integration proposal, NSW surveyors, known for precise measurement, should advocate mathematically consistency but with often imprecise, 'near enough' dimensions. Subsequently, this proposal was rejected in favour of mathematical consistent calculation between the stated coordinates and the stated horizontal ground distance dimension. Also, for coordinate calculation, a Combined Conversion Factor and coordinate datum were stated on all survey plans. This way, conversion with coordinate calculation has been practiced for 50 years without confusion. During this time computers and software have made the calculation almost automatic, and the use of more precise measuring equipment [(EDM) along with new techniques [GPS, GNSS, etc.] have made measurement and dimensions more precise. As a result, the mathematical consistency calculation as part of coordinate calculation and the statement of horizontal ground distance dimensions should become mandatory. Conversely, the identical, but anomalous and inexact grid distance dimension, should be deprecated.

4.3.2 Choice for 'Grid-to-Ground' conversion with the Coordinate calculation

'Grid-to-ground' conversion with the coordinate calculation offers a choice in calculation method and can be carried out without involving dimensions, by alternatively using [1] 'point-to-point' working or [2] East and North ordinates between points. This is especially relevant when comparatively few coordinates are stated or used.

4.3.3 Less risk of mistake and error

There is less confusion and less risk of mistake and error when only horizontal ground distance dimensions are stated on plans than when grid distance dimensions can otherwise be stated. Apparently, there have been incidents where off-site materials, prefabricated structures and other items made in standard linear units did not fit on-site when grid distance dimensions, being identical, were stated on plans and were mistaken for the usually expected horizontal ground distance. Similarly, with only horizontal ground distance dimensions, there is not the need for 'grid-to-ground' conversion of grid distance for when dimensions are to be measured and used. Furthermore, there is advantage and convenience in calculation by having both grid (coordinates) and horizontal ground (dimension) data on plans with a common grid north orientation and with a statement of a Conversion Factor for calculating between them. Duplexity, mistake and error does not occur in Australian practice.

4.3.4 Functional uselessness of Grid Distance dimensions

The projection plane is assumed for the special purpose of coordinate position referencing in surveying and mapping. For convenience of calculation and mathematical consistency of stated data, grid distance dimensions and projection coordinates are shown on 'narrow zone' coordination projection planes. However, because stated grid distance (dimensions) vary from place to place and height to height in its conversion to horizontal ground distance (and because it cannot be actually measured at sea level), [1] it does not perform the function of a dimension in land measurement. Also, as it is not stated in coordinate form, [2] it does not perform the function of position reference. Thus, unlike horizontal ground distance dimensions and projection coordinates, which (as separate stand-alone entities) function in their own right, grid distance dimensions are functionally useless by themselves. To be of any use, in reality, grid distance dimensions must be multiplied by 'grid-to-ground' conversion for horizontal ground distance land dimensions, and by trigonometrical functions for coordination. Also, as part of the coordinate calculation, with 'point-to-point' or ordinate calculation, grid distance (as a dimension) is not required at all. In fact, Grid distance, if used in dimension form, is really a transitory, non-essential component in coordinate calculation.

By being the <u>only exception</u> to horizontal ground distance dimensions in standard linear units where measured and used, its similar 'near enough' size makes it not only deceptive as a dimension, but it also requires its own superfluous 'narrow zone' coordination system. There is no justification for this duplexity. Again, grid distance, and its "narrow zone" coordination, should never be used and it should be deprecated from surveying practice.

4.3.5 Difference between Grid and Ground Distance becomes a calculating quantity only

By stating horizontal ground distance (instead of grid distance) dimensions on plans, the matter of the "closeness" of the difference between them, and the need for 'near enough' grid distances and 'narrow zone' widths, is no longer an issue. Without the need for grid distance dimensions, the 'ground-to-grid' difference becomes a calculating quantity *only* in coordinate calculations, and so can be larger than the 'near enough' magnitude needed in State Plane Coordinate Systems, Low Distortion Projection coordination and other 'narrow zone' coordination.

4.3.6 Using any Projection Zone Width

When horizontal ground distance is stated as the land dimension, any (or just one) zone width can be used. Stated conversely, horizontal ground distance dimensions maintain their direct nexus [or mathematical consistency] with measurement *without* the need for 'grid-to-ground' conversion and *without* it placing limits on the choice of zone widths and coordinate systems.

5. The use of the 6° UTM coordinate system

As previously mentioned in section 1.1, the 6° UTM projection coordinate system was introduced for mapping in the 1930s, was used during World War 2, and then, with the International Map of the World [IMW] mapping, is now universally used for worldwide mapping. Consequently, as any zone width can be used with horizontal ground distance dimensions, it is hard to argue against using the existing and established 6° UTM mapping system for survey coordination as well. This is supported by the four reasons outlined in the following subsections:

5.1 One Coordinate System for all land Spatial Position Reference purposes

Ideally, there should be *one* coordinate system for *all* uses. Surveying is only part of a wider application in areas such as cadastres, information systems, databases, mapping, and military and emergency location services. Although positions for these other uses may not be required to the precision of surveys, they must be underpinned by precise survey control. On the other hand, coordinate cadastre reference is only part of surveying practice. It is used for the determination and reference of unique absolute position as part of control, cadastral and boundary re-establishment surveys. In the coordinated cadastre, property surveys, boundary marks, monuments, relative position and dimensions have greater legal status, significance and substance to the surveyor (and user) than absolute coordinate values, especially as the coordinates cannot be seen. However, (GNSS-derived and MGA) coordinates can supplement other evidence in the location of lost property boundaries.

5.2 Avoiding Coordinate confusion

Using only the 6° UTM coordinate system (MGA) for all coordinate and mapping purposes overcomes the need and confusion of calculating, and showing on plans and maps, State Plane Coordinate Systems, Low Distortion Projection systems and other 'narrow zone' coordinate systems. Apparently, such duplication and confusion occurred during the 25 years when the 2°-zone ISG [as well as 6^0 AMG] was used in NSW.

5.3 Overcoming the discontinuity of smaller coordinate systems

The much larger 6° by 4° UTM zone size (or 600 km by 450 km) and, with ½ ^{0} overlaps, (700 km by 550 km) overcomes the discontinuity and confusion of many smaller and/or 'narrow zone' coordinate systems. For instance, NSW is covered by three 6° MGA zones compared to the [used from 1975 to 1995] seven 2° ISG zones.

5.4 Allowing for Project-Specific survey coordination.

The use of the 6° UTM system for survey coordination does not preclude use of project-specific survey coordination at the mean horizontal ground distance plane (i.e. Low Distortion Projection coordination, centreline and cross sections, datum lines, set out for offsite prefabricated structures and other forms of coordination or survey at a height and/or orientation convenient for the project) provided that it is appropriately integrated to the 6° UTM survey and mapping coordinate system.

6. The ideal dimension and coordinate system

6.1 Ground Distance dimension – 6° UTM Survey and Mapping Coordination System

One underlying and easily overlooked reason for the adoption of the horizontal ground distance dimension – 6° UTM coordinate system in Australia was that *both already existed*. They just needed to be used in survey integration. This also applies worldwide. By outlawing grid distance dimensions (and phasing out its 'narrow zone' coordination), the 6°-zone UTM coordinate system used worldwide for mapping can also be used for survey coordination and survey integration. In Australia, the horizontal ground distance dimension – 6° UTM (MGA) system provides:

- One homogenous national datum and one common spatial data system.
- A complete and unambiguous dimension and coordination system for all uses.
- Direct compatibility with Global Navigation Satellite System (GNSS) observations.
- Less confusion by not having two different dimensions and two different coordinate systems.
- Reduction in conversions required between different dimensions and coordinate systems.
- Reduction in the number of zone borders and their associated overlap issues due to the wider 6° UTM zone width.
- Compared to the duplexity of dimensions and coordinates, obvious cost savings …

The foregoing is made more realistic with the advances in surveying and measuring equipment, GNSS technology, computers and software since the 1970s (when the NSW Integrated Survey dispute occurred) and from many years before when State Plane Coordinate Systems were implemented elsewhere.

6.2 Benefits of the Australian 6° UTM Survey and Mapping Coordination System

The benefits of the Australian 6° UTM survey and mapping coordination system far outweigh its cost in comparison with also having the duplicate NSW Survey Integration proposal. The 1970s decision to continue with horizontal ground distance dimensions was incisive by avoiding the confusion and calculation with the NSW proposal's statement of grid distance dimensions. Also, with resulting benefits, Australia converted from imperial to metric units on 1 July 1972. Yet, especially with

> The benefits of the Australian 6° UTM survey and mapping coordination system far outweigh its cost in comparison with also having the duplicate NSW Survey Integration proposal. The 1970s decision to continue with horizontal ground distance dimensions was incisive by avoiding the confusion and calculation with the NSW proposal's statement of grid distance dimensions.

satellite-based positioning and computer software, the major benefit was having all mapping, databases and all survey coordination unified on the one, existing 6° UTM projection coordination system. This finally occurred in 1995 when NSW adopted the Australia-wide 6°-zone MGA system. This avoided the confusion, calculation and cost of duplicate survey dimension and mapping coordinate systems. In doing so, the Australian experience shows that it is never too wise, and never too late, to benefit from the change. So, considering the reasoning in this paper, and the improvements in technology since the 1970s, it would be beneficial to make the change by banning grid distance dimensions and instead state horizontal ground distance dimensions, and by doing so, also benefit by having a coordinated cadastre and mapping system based only on the existing 6° UTM mapping projection.

7. The incongruity of having both grid and ground distance dimensions in the USA.

After 130 years, [on 1/1/2023] the USA will no longer use the "US Survey Foot" as a standard unit of linear measurement. For over 60 years the US has also used the "International" Foot. The "folly" of having two nearly identical versions of the unit of linear measurement had become apparent, resulting in the confusion of dual definition, evidence of [unintended] error and costly blunders. This led to the recent bold action to deprecate the "US Survey Foot" so that the "International" Foot then becomes the only standard unit of linear measurement in the USA.

In a similar context, the USA also has two nearly identical ways of stating dimensions in land surveying. Following the introduction of the State Plane Coordinate System [SPCS] nearly 90 years ago, land measurement dimensions have been stated as grid distance on the coordinate projection plane, usually at sea level, instead of [and the only exception to] the more common and usual horizontal ground distance in standard linear units where measured and used.

In SPCS2022, the surveying profession in some States of the USA raised the elevation of their projection planes above sea level to reduce the height factor in the "grid to ground" adjustment. This was to make the stated grid distance dimension closer to horizontal ground distance. However,

[1] this action actually highlights the intrinsic value of the statement of horizontal ground distance dimensions that replicate the measurement in standard linear units at its location.

[2] Further, by still having the nearly identical, variable, and different grid distance [rather than horizontal ground distance] stated as dimensions on survey plans perpetuates the similar duplexity and confusion that prompted deprecation of the "US Survey Foot".

[3] All that's needed is to apply the same "bold" action used to deprecate the "US Survey Foot", to also [boldly] deprecate the statement of grid distance dimensions so that horizontal ground distances would then become the <u>only</u> linear dimension stated on USA survey and title plans.

8. Summary and concluding remarks

From a cadastral perspective, this paper has explained and promoted the use of horizontal ground distance dimensions and the Australian 6° UTM survey and mapping coordination system throughout the world. <u>In summary, it has outlined in the following:</u>

- From 1788 (and the initial settlement of NSW) the primary function of the cadastral surveyor was to physically locate and mark deed boundaries on the ground. Further, it's the visible evidence of the property boundary in the field (and not invisible coordinates) that the public wants and the law relies upon in settling boundary disputes.
- Copied from overseas, the 1970's Survey Integration proposal introduced survey control, the coordinated cadastre, and grid north into survey practice. However, its proposal for grid distance and 2^0 zone coordination was disputed, and then dismissed.
- Instead, emphasis was given to the importance of land, survey and title dimensions (horizontal ground distance) being stated in standard linear units where they are measured and used. This (and not distance down on a projection plane at sea level) is what the public wants. (The USA [and overseas] surveyor's grid distance dimension is the <u>only exception</u> to this precept)
- It was explained that grid distance dimensions are functionally useless in themselves, and that their statement as an (often) deceptively approximate dimension is an anomaly, unnecessary and should be deprecated. For cadastral surveys, grid distance

dimensions should not be used, ever.

- It followed that 'narrow zone' coordinate systems elsewhere that are based on and use grid distance dimensions should also be phased out and replaced.
- Instead, it was recommended to use the successful Australian practice (the Australian 6° UTM survey and mapping coordination system), which applies *only* horizontal ground distance dimensions and *only* 6° UTM coordination (initially AMG66, MGA94 and now MGA2020).
- As its basis (i.e. horizontal ground distance dimensions and 6° UTM coordination) already exists and is used throughout the world, this Australian best-practice could easily replace the confusion and duplication (i.e. grid and ground dimensions, "narrow zone" and 6° UTM coordination) that applies where 'narrow zone' coordinate systems and 6° UTM mapping are both used.
- By combining horizontal ground distance dimensions and 6° UTM coordination, *one* unified worldwide system of survey dimensions, coordination and mapping could be established. [Over the last 50 years EDM, GPS and the geocentric MGA maps have been introduced seamlessly into this unified system in Australia]
- Less confusion, less calculation and considerable cost savings and benefits would result from using *only* horizontal ground distance dimensions and *only* 6° UTM coordination.

All the foregoing just goes to show that you cannot take anything for granted, even with the most credible of sources and supporters. But, by 'thinking outside the box' in the 1970s NSW Survey Integration dispute (and with the decision of the NSW Registrar General), Australia can claim to have the best survey coordination and mapping system in the world.

9. References

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This paper has been adapted from a larger paper written for a NSW surveyor readership and published in the proceedings of the APAS2022 Conference, available at www.apas.org.au.

ISRO launches Earth Observation Satellite-6 (EOS-6)

The third generation Indian satellite for monitoring the oceans, formally named as Earth Observation Satellite-6 (EOS-6) was launched on November 26, 2022 by the Indian Space Research Organization (ISRO) in partnership with Ministry of Earth Sciences (MoES) among others, from its First Launch Pad (FLP) at Satish Dhawan Space Centre (SDSC), Sriharikota.

The ocean observing mission is a follow up to OceanSat-1 or IRS-P4 and OceanSat-2 launched in 1999 and 2009, respectively. The satellite was launched aboard the proven launch vehicle PSLV (Polar Satellite Launch Vehicle) on its 56th flight (24th flight of the PSLV-XL version). Designed as PSLV-C54, it also accommodated other small satellites along with Oceansat-3.

The Oceansat-3 was placed in the polar orbit at the height of about 740 kilometers above sea level. While at ~1100 kilograms, it is only slightly heavier than Oceansat-1, for the first time in this series it houses three ocean observing sensors viz Ocean Color Monitor (OCM-3), Sea Surface Temperature Monitor (SSTM), and Ku-Band scatterometer (SCAT-3). There is also an ARGOS payload. All these sensors have their own importance for India's blue economy aspirations.

The advance 13 channel OCM with 360 m spatial resolution and 1400 km swath will observe the day side of the earth every day and will provide crucial data on distribution of ocean algae which is the base of the food chain within marine ecosystem. The OCM-3 with high signal-to-noise ratio is expected to provide improved accuracy in daily monitoring of phytoplankton having wide range of operational and research applications including fishery resource management, ocean carbon uptake, harmful algal bloom alerts, and climate studies.

The SSTM will provide ocean surface temperature, which is a critical ocean parameter to provide various forecasts ranging from fish aggregation to cyclone genesis and movement. Temperature is a key parameter required to monitor health of the coral reefs, and if needed, to provide coral bleaching alerts. The Ku-Band Pencil beam scatterometer onboard EOS-6 will provide high resolution wind vector (speed and direction) at the ocean surface, something which any seafarer would like to know of, whether its fishermen or shipping company. The data of temperature and wind is also very important for assimilation into ocean and weather models to improve their forecast accuracies. ARGOS is a communication payload jointly developed with France and it is used for low-power (energy-efficient) communications including marine robotic floats (Argo floats), fish-tags, drifters, and distress alert devices useful for conducting effective search and rescue operations. *pib.gov.in*

Animal navigation: How animals use environmental factors to find their way

Migratory animals have innate programs to guide them to their still unknown goal. Highly mobile animals with large ranges develop a so-called navigational 'map', a mental representation of the spatial distribution of navigational factors within their home region and their migration route. Readers may recall that the first part was published in November issue. We present here the concluding part.

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4 The course to the goal

The mechanisms of determining the course to the goal, that is, the direction that is to be pursued to reach the goal, are less well known than the compass mechanisms, although there has been considerable progress during the last decades. Again, birds, in particular homing pigeons, are the best studied group, but also marine turtles and the desert ant *Cataglyphis* have been studied in detail.

For most animals, a frequent task is to orient within their home range, i.e., to return to a resting place, their burrow, their nest, etc. In this case, for the first step of the navigational process, the animals have the option to use various informations collected during the outward journey. Animals that cover larger distances, e.g., birds, can also establish a learned system based on remembering the spatial distribution of several environmental factors, the so-called navigational '*map*'. Another task is to reach a yet unknown goal in migration—for this animals have to rely on innate programs.

4.1 The use of information obtained during the outward journey

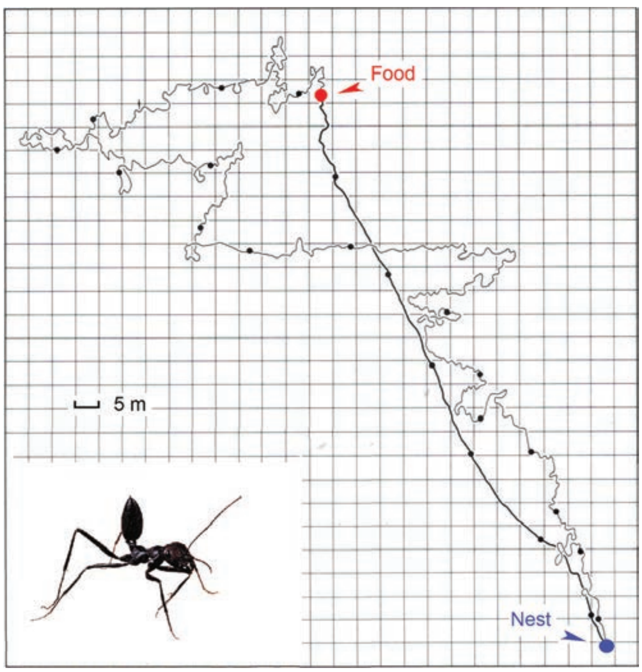

Fig. 4 Outward paths and return path of a foraging desert ant *Cataglyphis*, illustrating path integration. The outward path (thin line) is characterized by searching around; after the ant found a food item, it returns on a more direct route (thicker line). The small circles indicate the position every 1 min. The outward path is 592.1 m long and took 18.8 min, the return path is 140.5 m long and took 6.5 min (after [215], modified)

When returning to a specific place, such as a burrow or a nest, animals can theoretically rely on landmarks, following the sequence of landmarks they observed during the outward journey in reverse order. Many animals have been shown to respond to landmarks, in particular in the vicinity of their nest (e.g., [125,126] a.o.). However, it is difficult to demonstrate that this strategy is used during natural movements, and clear evidence is not available. If the outward journey has not been on a straight route, following a sequence of landmarks backwards has the disadvantage that the return paths is not the most direct, but shows the same windings and detours.

Another strategy would be to record the direction of an outward journey with a compass and reverse this direction to head home. If the outward journey was not straight, but consisted of frequent changes in direction, the animal must consider the various compass directions and the respective distances of the parts of path and integrated them, to obtain the net direction of the outward journey. This strategy—*path integration* [127]—has been observed in desert ants: Leaving their nest, they start to search around for food, with winding paths covering a certain area—after having found a food item, however, they carry it back to their nest on the direct route (Fig. 4)[127]. Experiments have shown that the ants use their skylight compass, integrating all the twists and turns of the outward journey (for details, see [128]). They also have a rather precise idea of the distance to home—after covering that distance, they start to systematically search around [129]. Path integration may be combined with landmark memories to guide ants and bees back to their nest (see e.g., [130–132], which is a very effective, safe strategy. Little is known about other animals, but it may be assumed that many make use of this strategy.

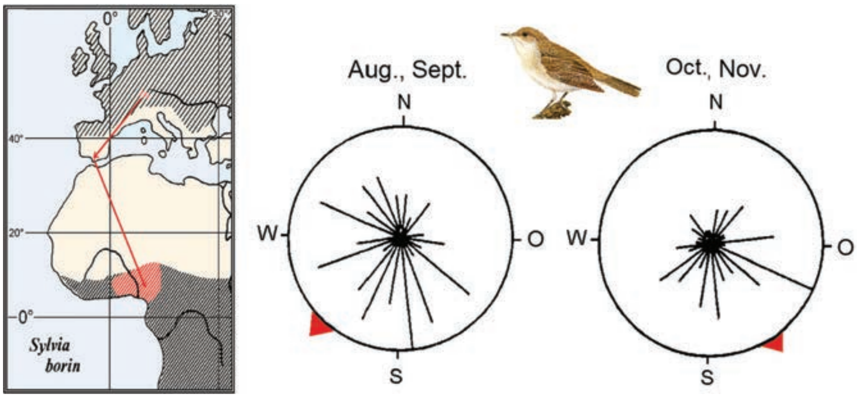

Fig. 5 The innate migration program of garden warblers, *Sylvia borin*. (Left): birds from southern Germany migrate via the Iberian Peninsula to their African wintering areas (marked red). (Right): the headings of hand-raised birds tested during their first autumn migration, showing the shift in direction from SW during August and September to SE in October and November (from [137], modified)

Experiments with young, inexperienced homing pigeons indicate that for determining the heading home, they also rely on information obtained during the outward journey. The first spontaneous flights escape analysis, but young birds can apply path integration also when passively transported, using their magnetic compass to record the direction of the outward journey. Displacing them in a distorted magnetic field caused disorientation, while staying in the same distorted field after arrival at the release site had no effect [133]—having access to magnetic compass information during displacement proved crucial. This effect could only be observed in young, inexperienced birds, however; experienced pigeons apparently change their navigational strategy and do not need this type of outward journey information any longer [134]. Yet to what extent they may additionally use it when available is unclear.

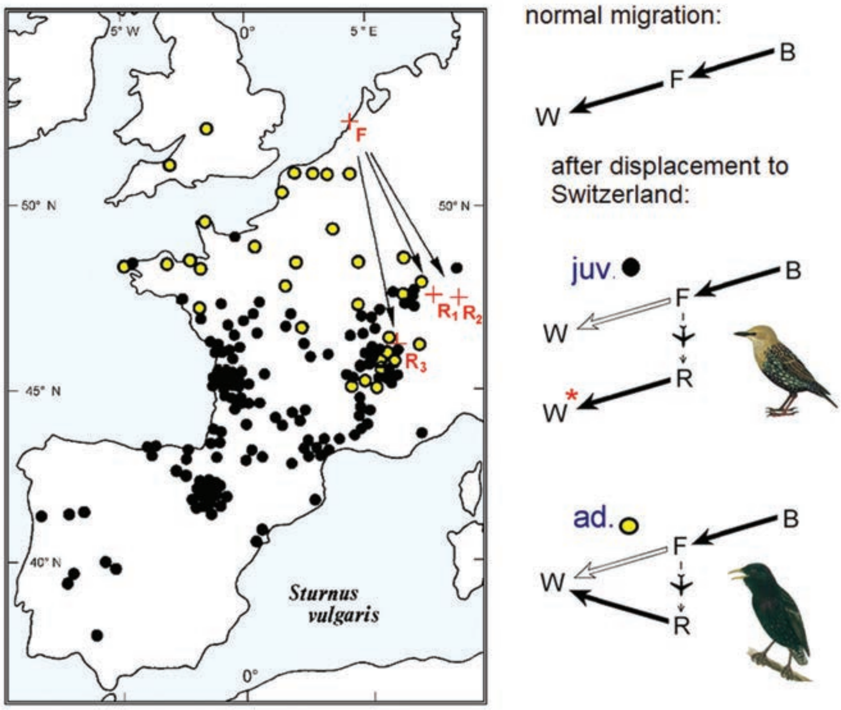

Fig. 6 Displacement experiment with starlings, Sturnus vulgaris,migrating from the Baltic area to winter in Northern France and Southern England. The birds were caught as transmigrants in Holland and displaced by airplane to Switzerland. (Left) The original data [138]; (right) Scheme showing the different behavior of juvenile (black dots) and adult (yellow dots) migrants

Relying on route information and path integration is an efficient strategy over short distances, as it does not require any previous knowledge. Yet over longer distances, it has the disadvantage that small mistakes may accumulate, and there is no way to correct these mistakes relying on outward journey information alone.

4.2 Migration: reaching a still unknown goal by innate programs

Many animals start migrating immediately after they are born. With mammals like caribous or gnus and zebras, but also with whales, the young ones stay with their mothers and follow them to the regions where they have to go—here, parental guidance leads them along traditional routes. This may also apply to some bird species that migrate as families in flocks. Other young animals, however, have to start migrating alone, and they are endowed with innate programs that guide their movements.

In migratory birds, the innate program consists of directions and distances to the wintering area of their species/ population. The direction is genetically encoded with respect to the magnetic compass and celestial rotation: Birds handraised without ever seeing the sky, tested during autumn migration in cages in the geomagnetic field headed into their migratory direction ([e.g., [135,136] a.o.); they even change direction if their migration route is not straight (Fig. 5) [137]). Birds handraised under a rotating planetarium sky or an artificial "sky" with an arbitrary pattern of little light dots headed away from the center of rotation [122,124]. When migratory birds were caught during migration and displaced several 100 km perpendicularly to their migration route, young birds migrating for the first time continued in their migratory direction, ending up in a different region (Fig. 6)—not knowing their goal yet, they could not yet navigate toward it. Adult birds that had already stayed in the wintering area the year before, in contrast, compensated for the displacement (see below); they changed course and headed directly toward their winter quarters ([138,139] a.o.).

Newly hatched marine turtle spontaneously move from the beach into the ocean, guided by visual cues, heading toward the brightest part of the sky. After having reached the water, they start swimming into the incoming waves, probably detecting their direction by their orbital movements, and later maintain this direction by their magnetic compass. Hatchling loggerheads, *Caretta caretta* (Cheloniidae) from Florida then enter the Atlantic gyre where the stay the next years (see [140] for details). Innate directional responses to certain combinations of magnetic intensity and inclination ensure that they stay inside favorable marine areas ([141] a.o.).

Fishes like Pacific salmons and eels migrate only twice during their life—from their birthplace to the region where they spend most of their life and later back to their birth place; they also follow innate programs for their migration. Sockeye Salmon, *Oncorhynchus nerka* (Salmonidae), leave their hatching site in little streams and creeks, responding to currents and heading in specific directions by magnetic and celestial cues, first to reach a nursery lake and later to migrate downstream toward the ocean (for details, see [142]).These innate programs are specifically adapted to the stream systems where they live [143]. When in the ocean, specific magnetic conditions elicit swimming in particular directions to make them stay in their normal habitat [144]. Eels, born in the ocean, migrate to spend most of their life in fresh water. European eels, *Anguilla anguilla*, born in the Sargasso Sea, follow the current of the Golf stream, but this passive transportation is supported by active swimming, presumably in directions indicated by their magnetic compass. When in brackish water, they enter an estuary and move upstream, swimming actively against the current for various distances into fresh water [145].

Marine turtles as well as salmon and eels return to their birthplace to lay their own eggs. They imprint on their hatching site and store the respective conditions in their memory. Marine turtles probably rely on the local magnetic conditions [146], whereas salmons imprint on the odors of their natal creeks [147].

4.3 True navigation: use of local, site-specific information: the 'Map'

Many animals return after passive displacement over various distances; they are capable of true navigation in the sense that they can head towards a specific goal from unfamiliar sites. The mechanisms they use are largely unknown; they have been analysis to some extend only in birds, in particular in homing pigeons.

In the middle of the last century, navigation by astronomical factors was suggested for birds: Matthews forwarded the *Sun navigation hypothesis* [148], and Sauer interpreted his planetarium results with migrants as indicating true navigation by stellar cues [149]. The clockshift experiments (see above), however, clearly show that shifting the internal clock affects the compass only,

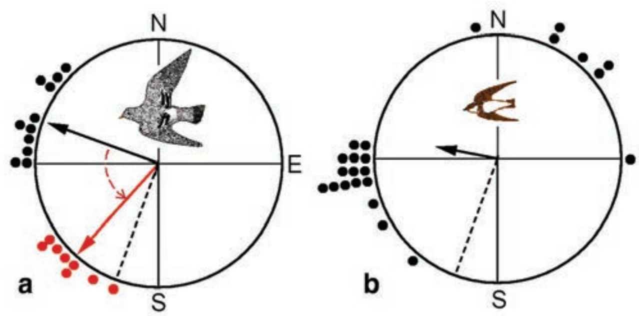

Fig. 7 Vanishing bearings of a pigeons and b bank swal-lows from a colony near the loft, released at a site 143 km away; the home direction 200◦is indicated by a dashed radius. Both species showed a marked clockwise deviation from the home direction, indicating that they used the same navigational factors and interpreted them in a similar way. In a, the black dots mark bearings of untreated control birds and the red dots those of pigeons whose internal clock was 5 h advanced. The clock-shifted pigeons, although vanishing closer to the home direction, returned much later, and more got lost (data from [150])

while the bird determined their location and the home course correctly (e.g., [72], see above). The planetarium experiments by Emlen ([116], see above) identified the birds' use of stars as compass orientation. This indicates that the factors birds use for true navigation are not astronomical, but geophysical in nature.

4.3.1 The concept of the navigational 'map'

Pigeons return when displaced to unfamiliar distant sites from the area of their direct experience they usually leave these sites heading into directions not far from their home direction—this indicates that they can interpret the local factors more or less correctly, even if they have never been there before. It suggests that these factors have the nature of *gradients*—birds familiarize themselves with the course of these gradients in their home area and can extrapolate this knowledge when they are at an unfamiliar site. They compare the local values of the gradients with the remembered values from home. If a pigeon has experienced that, e.g., factor A increases toward north and at a given site it encounters values of A that are larger than within its home range, it knows that it is farther north and consequently has to head south to return. Wallraff [150] described this model in detail, assuming that the birds' navigation is based on at least two, possibly more gradients that enable birds to determine their position relative to home, and from this derive the home course.

The birds' headings often deviate somewhat from the true home direction, with these deviations being characteristic for a given site—the so-called *release site biases* (Fig. 7). These deviations are attributed to local irregularities in the distribution of the navigational factors [151]; they are normally not very large and do not prevent birds from returning—obviously, the initial error is later corrected.

The 'map' is a learned system, based on experience. Young birds acquire the respective knowledge during spontaneous flights in their home range. When homing pigeons are regularly released at the loft, in about their third months of life, they start to venture further away from their loft, often staying out of sight for more than an hour. It is to be assumed that during these flights they are aware of their flight directions by a compass and observe how the potential navigational factors change with distance in the various directions, thus establishing their navigational *'map', a directionally oriented mental representation* of the spatial distribution of the navigational factors in their home region. This applies to migratory and sedentary birds alike. Young migrants roam around in their home region before their start migration—e.g., young bank swallows, *Riparia riparia* (Hirundinidae) from a colony at the southeastern English coast were found to move all over England, several as far north as Scotland, before they left for fall migration [152]. A study with handraised migrants showed that only birds that had had the chance to fly around at the release site for some time could return to that region next spring; birds that had been released after the onset of migration and left right away did not come back [153].

While all birds probably establish a 'map' of their home region, migrating birds also experience the distribution of 'map' factors during their first migration, establishing a 'map' of their migration route. This is documented by the observation that from their second migration onward, migrants are able to compensate for displacements—they abandon their traditional migratory direction and head directly toward their goal—their breeding ground or wintering area (see Fig. 6)(e.g., [138,139]). Tracking displaced migrants showed that in species with long migration routes, some birds also headed to intermediate feeding areas and from there join the traditional migration route for the rest of the journey [154].

4.3.2 The nature of the factors included in the navigational 'map'

The nature of the factors used for true navigation is still a largely open question. A number of factors have been suggested, among them some with global gradients

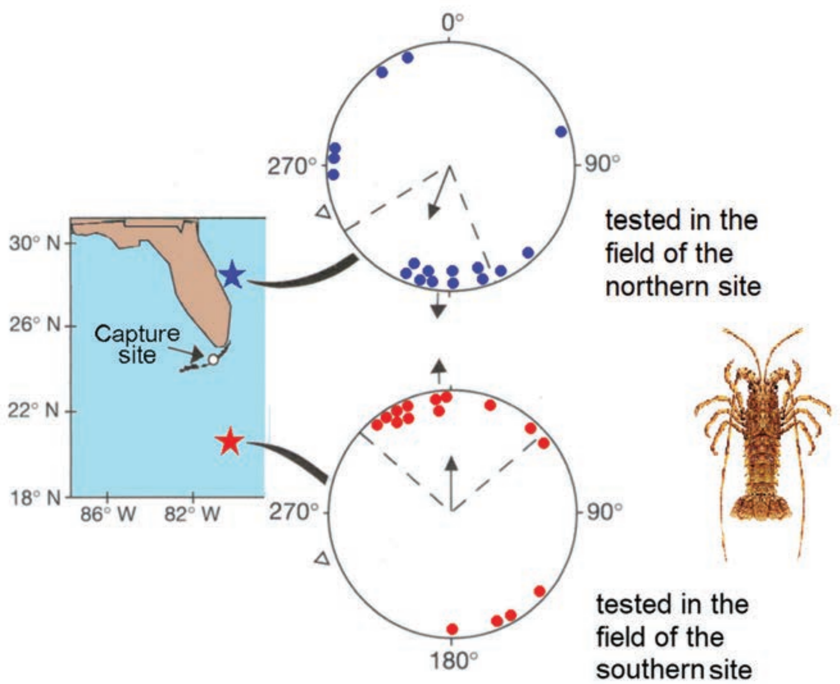

Fig. 8 Spiny lobsters, captured at the Florida Keys, tested at the capture site in the geomagnetic field of a site in the north and a site in the south. The lobsters behaved as if they had been displaced and preferred directions that would have brought them back from the simulated sites to the capture site (data from [171] , modified)

like magnetic factors (see [155] a.o.) or gravity [156] , but also factors of more regional importance like infrasound [157] and odors (see e.g., [158,159]). Most of these con siderations involve the navigation of birds (see [160]for review).

Magnetic factors: Magnetic factors are the ones that are best supported by experimental evidence so far. They involve total intensity and inclination, both forming global gradients running roughly north/south from pole to pole. In many parts of the Earth, the angle between the two gradient directions is sufficiently large to form a bicoordinate 'map' [161]. Magnetic declination was also considered as a navigational factor [162], but later experiments did not support such a role [163,164].

The first indications for the use of magnetic factors came in the late 1970s from the observation that pigeons released in a strong magnetic anomaly seemed disoriented and departed in random directions [165]; similar findings were reported from magnetic anomalies in other regions [166–168]. The use of magnetic factors is also supported by the observation that pigeons treated with a brief, strong magnetic pulse to interfere with the receptor system for magnetic intensity (see below) showed significant deviations from untreated controls at some sites more than 80 km away [169]. In caged migrants, the pulse caused a significant shift in direction that lasted about 3 days, followed by ca. 1 week of disorientation before the birds resumed their normal migratory headings [170]. Treatment with such a pulse had a similar effect on freeflying migrants, but only on experienced birds; young migrants on their first migration (which is still controlled by the innate migration program) remained unaffected [171].

The best evidence for the use of a magnetic 'map', however, comes from magnetically simulated displacements. The first such experiment was performed with the spiny lobster, *Panulirus argus* (Decapoda), at the Florida Keys. When displaced, lobsters tested in arenas, showed directional tendencies to compensate for the displacement, heading toward the capture site. Tested at the capture site in a magnetic field as it occurs north of that site, they headed southward, whereas lobsters tested in a field as found south of that site headed northward (Fig. 8), i.e., in directions that would have brought them back from the respective sites to capture site [172]. Similar results were obtained with green sea turtles, *Chelonia mydas*, at the Florida coast, tested in the magnetic fields found ca. 340 km north and south of the capture site ([173]; see also [174]: They, too, compensate for the simulated displacements.

Corresponding experiments with caged migrating birds likewise showed that displacements can be simulated by testing birds in a magnetic field of a distant site. Reed warblers, *Acrocephalus scirpaceaus* (Muscicapidae) caught during spring migration at the Kurish Spit near the Baltic Sea showed northwesterly headings toward their breeding area in Southern Finland; tested in the magnetic field of a site about 1000 km eastward, they changed this direction, now preferring northwesterly headings [175], just as they had had done when really displaced to that site [176]. That is, birds, too, compensated for the virtual displacement simulated by magnetic intensity and inclination (see also [165]).

A magnetic 'map' or the involvement of magnetic components in the 'map' are also proposed for other animals, among them amphibians [177]—the observations that animals as different as spiny lobsters, marine turtles and birds compensate for magnetically simulated displacements suggests that a magnetic 'map' may be widespread among animals.

Little is known about the sensory basis of magnetic 'maps'. While the perception of magnetic directions in birds is based on radical pair processes and is associated with the visual system (see above), the effect of the magnetic pulse (see above) indicates that sensing the magnetic 'map' involves magnetite [178], with the duration of the pulse effect—about 10 days [170]—suggesting superparamagnetic particles (see [179]). The respective information is transmitted to the brain by the trigeminal system (see [180,181] for details). Without intact trigeminal nerve, birds could not compensate for virtual displacements [182]. How magnetic 'map' information is obtained by other animals remains largely unknown.

Gravity: It was considered as a possible navigational factor when the disorientation of displaced homing pigeons in magnetic anomalies was observed [155], because magnetic anomalies often coincide with gravity anomalies. Yet releasing pigeons in a gravity anomaly in America spoke against this possibility [183]. Recently, however, an effect of raising pigeons in different gravities anomalies in Southeastern Europe was reported [184], and tracking the flight of pigeons across gravity anomalies showed increased scatter up to disorientation, together with greater losses, which was interpreted as indicating navigation by use of gravity [156]. A possible role of gravity in avian navigation is still open.

Infrasound: Natural infrasound (frequencies below 20 Hz) arises from wind over mountains, waves on the shore, etc.; they are transported over long distances in the atmosphere and in the ground with little attenuation. Pigeons were shown to be able to hear them [185], hence they were considered as a potential navigational cue [186,187].

Hagstrum [188] analyzed large data sets of the late W.T. Keeton and found a correlation between predictions concerning atmospheric infrasound and the initial orientation of pigeons toward home. Another analysis comparing the orientation of pigeons deprived of hearing with that of untreated controls produced mixed results [189]. Altogether, the validity of the *acoustic navigation model* proposed by Hagstum [188] is unclear, the more so since it is hardly compatible with the Map-and-Compass model (see [160] for discussion).

Odors: The role of odors in avian navigation has been most controversially discussed so far. In the beginning of the 1970s, Papi and colleagues in Italy reported that pigeons deprived of olfaction were reluctant to take off, departed randomly, and many got lost [190]. The authors concluded that odors are essential navigational cues and forwarded the *olfactory navigation hypothesis*. It assumes that birds associate airborne chemical substances with the respective wind direction, thus forming an olfactory 'map', which was believed to provide the most important, it not the only navigational information for birds. Numerous further experiments testing the role of olfaction in pigeon homing in various ways were conducted in the following years (for review, see [159,160,191].

Replicating the experiments with anosmic pigeons (i.e., pigeons deprived of smelling) in the USA and Germany produced different results; however (e.g., [192, 193]), further experiments indicated that the conditions of raising and training the birds were of crucial importance [194] for the pigeons' response to olfactory deprivation. Experiments with migrating birds also showed that birds deprived of olfaction were unable to compensate for displacements and fell back on their innate migratory direction [195,196].

An odd aspect of the olfactory findings was that olfactory deprivation had an effect only at sites that were unfamiliar to the birds. The protagonists of the olfactory hypothesis claimed that at familiar sites, birds followed sequences of familiar landmarks (e.g., [197], see [160]). In critical tests at a familiar site, however, anosmic pigeons deprived of object vision by frosted lenses departed homeward oriented [198], indicating that they used non-olfactory, non-visual cues to determine their home direction. Anosmic pigeons released at familiar sites also responded to shifting their internal clock with departing in the expected, deflected direction with respect to untreated controls (see above) [199], showing that they did not follow sequences of landmarks, but they determined their home direction as a compass course.

In 2009, Jorge and colleagues replaced natural odors by artificial odors and got similar results as in the olfactory studies [200,201]. The authors suggested that instead of providing navigational information, odors had an activation effect, a hypothesis which was supported by electrophysiological data [202].This, together with the findings at familiar sites, suggests that odors may play a activating role when pigeons have to integrate new local data into their 'map' at an unfamiliar site (see [203] for a discussion). The controversy on the role of odors in bird orientation is still not finally resolved.

Salmons, however, orient by odors solved in the water when returning to their natal creeks. They have been imprinted on the chemical situation of the stream in which they were born [147]. After spending a number of years in the ocean, they begin to return to their parental creek to spawn. When reaching the estuary of their natal river system, they swim upstream, following the imprinted odors until they reach their natal creek (see [204] for an overview). Here, however, odors are not used as part of a 'map', but as a direct cue which the fishes follow when heading upstream against the current.

4.3.3 Navigation near home: the 'Mosaic Map'

In the vicinity of home, there is an area where birds are no longer able to distinguish the local values of the navigational factors from the home values. Here, they turn to landmarks. A study where the routes of pigeons deprived of object vision by frosted lenses were recorded showed that these birds managed to approach the loft in Upstate New York about 0.5–5 km [205], while in Germany many birds with frosted lenses ended up closer to the loft, within 100 m, some of them even managing to reach the loft itself [206]. Landmarks thus appear to be important in the immediate vicinity and the final approach to the loft.

Yet even here near their loft, pigeons do not seem to follow sequences of landmarks, but still determine their home course as a compass course. This is indicated by clockshift experiments within 1.6 km from the loft, where the birds showed deviations from the untreated controls indicating sun compass use [207,208]. This led to the concept of the *Mosaic Map*, which assumes that birds memorize the directional relationship and distance of landmarks near their home, thus forming a 'map' analogue to the navigational 'map', but consisting of the representation of numerous individual marks instead of gradients (see [150,209]).

4.4 A flexible system based on innate and learned components

Young, inexperienced birds first rely on innate mechanisms like route reversal and path integration on the basis of compass orientation; inexperienced migrants are guided by innate migration programs. This gives them a chance to learn and memorize the spatial distribution of potential navigational factors, i.e., to establish a 'map' of their home region and their migration route. The 'map', in contrast to routebased information, allows birds to redetermine the course to the goal whenever they feel it necessary—this increases the certainty of reaching the goal.

We must assume that young birds include in their 'map' all suitable factors that can be used for navigation—the 'map' is multifactorial (see e.g., [209,210]) and probably includes more factors than just the ones mentioned above, e.g., the view of landscape feature as they change with distance [211] and others. The 'map' appears to be largely redundant: When released within a strong magnetic anomaly, pigeons deprived of magnetic 'map' information by local anesthesia of their upper beak left in an oriented way—not being able to sense the anomalous magnetic field they were not confused and obviously turned to non-magnetic cues for navigation right away [212].

Being based on experience, the 'map' is perfectly adapted to the situation within the home region and along the migration route and allows birds to directly head to familiar goals. However, the available navigational factors may differ in various regions, and so we cannot expect the 'map' to be identical everywhere.

There may be differences in the preferred cues, and findings obtained in one region thus cannot simply be generalized to another without testing.

The above considerations are based on navigational experiments with birds—to what extent they also apply to other animals covering greater distances remains to be determined.

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Global Data Enrichment and Geo Addressing Coverage Precisely

Precisely has announced the regional expansion of its unique location identifier, the PreciselyID, for its World Points of Interest (POI) data offering. Points of interest located in the US, Canada, Belgium, Luxembourg, the Netherlands, United Kingdom, Ireland, France, Sweden, and Singapore now benefit from accurate, standardized, and meaningful data – allowing businesses to streamline location-based decision-making across multiple regions of operation. Keeping POI data fresh is no small feat, even for companies such as Google, who recently revealed that it removed seven million fake business profiles and prevented 12 million from being created throughout 2021 alone. Standardizing POI data is just as difficult; differences in address standards, language, character variations, or a lack of accurate address data, make it challenging for companies to effectively operationalize data from multiple regions. *www.precisely.com*

VCTI launches broadband map integrity service

VCTI has announced its Broadband Map Integrity service. The new offering is designed to help states, municipalities, schools and other interested parties to quickly and efficiently submit challenges to the recently-released FCC maps, the Broadband Serviceable Location Fabric (Fabric), that will inform the allocation of $42.5 billion in BEAD (Broadband Equity Access and Deployment) grants. Current estimates place map inaccuracies at around one-to-two percent, which could translate to three million underserved households being excluded from the final maps.

One fundamental challenge is the variability in how addresses are captured in the myriad of government systems, such as tax records, and within the FCC Fabric. Leveraging their expertise and suite of geospatial tools, the VCTI Broadband Map Integrity solution normalizes the addresses to map to the Fabric, and identifies missing and misclassified locations. *www.vcti.io*

ISRO to develop SDI Geoportal for UT-Ladakh, India

Union Minister of State (Independent Charge) Science & Technology; Minister of State (Independent Charge) Earth Sciences; Dr Jitendra Singh recently informed that Government of UT – Ladakh has approached the Indian Institute of Remote Sensing (IIRS), a unit of Indian Space Research Organisation (ISRO) for developing "Spatial Data Infrastructure geoportal 'Geo-Ladakh' for UT-Ladakh".

The project encompasses spatial database generation (water resources, vegetation and energy potential) using remote sensing, geospatial techniques and the development of a Geo-portal for hosting this database.The project also aims towards training of UT-Ladakh officials on Geospatial techniques and applications. Portal provides geospatial data visualization and analytics for UT-Ladakh, consisting of Spatial viewer, Carbon Neutrality, Geospatial utlility mapping and Geo-Tourism. An MoU was also signed between IIRS (ISRO) and UT-Ladakh Administration on January 1, 2022 towards carrying out the above work.

UAE Space Agency and AWS sign agreement

The United Arab Emirates Space Agency and Amazon Web Services (AWS) have signed a Statement of Strategic Intent and Cooperation that is designed to support the creation of a vibrant, sustainable, competitive, and innovative space sector in the United Arab Emirates (UAE).

AWS will collaborate with the Space Agency and related UAE government space organizations on the following three initiatives, designed to support the Space Agency's long-term development goals:

1. The Emirati – AWS Space Industry Development Program (EASID). This initiative focuses both on the growth of existing commercial space organizations as well as the promotion of an environment conducive to new entrants like

space startups. This initiative is set to provide them access to AWS Activate and the AWS Founders program, both designed to provide startups with AWS credit, technical training, and business support.
2. The Emirati – AWS Talent for Space Program (EATS). This initiative includes outreach and training designed to support talent development for the space industry in the UAE, particularly with regards to cloud computing and big data.
3. The Emirati – AWS Open Data Sponsorship Program. This initiative will encourage collaboration among the UAE space and research community through the sharing of data sets on AWS related to space data-driven initiatives such as space surveillance and space situational awareness programs.

The UAE Space Agency is the first in the region to sign such an agreement with AWS. This agreement builds on AWS's ongoing support of regional space endeavors including the UAE Mohammed Bin Rashid Space Centre, whose Hope Probe is using AWS to analyze and share scientific data about the Martian atmosphere. *https://aws.amazon.com*

CoreLogic launches Climate Risk Analytics

CoreLogic has announced the launch of Climate Risk Analytics™, designed to help government agencies and enterprises measure, model and mitigate the physical risks of climate change to the real estate industry, initially through 2050. This solution is built on Google Cloud's secure and sustainable infrastructure.

Built on CoreLogic's Discovery Platform, a spatial data and analytics platform, CoreLogic Climate Risk Analytics is powered by CoreLogic's CLIP™ system, which leverages professional-grade, granular data to pinpoint a property's exact location and its attributes. The solution provides a comprehensive, blended risk score for every U.S. property with a granular breakdown of specific peril risks and each risk's financial impact. *www.corelogic.com*

Epic Games announces full release of RealityScan app

Epic Games and Capturing Reality announced this month that theRealityScan app is now available for free download on iOS products.The app is a step forward for easily creating 3D models of real-life objects to be used in a variety of different applications without the complex process of recreating the objects completely from scratch. With the app, users "scan" the real-life object they are trying to recreate, which is done by taking a series of photos capturing the entire object from all angles. *www.capturingreality.com*

Google to combine Maps and Waze teams

Google plans to merge its teams working on Maps products and the mapping service Waze with effect from December 9. The decision to consolidate processes comes as the search giant is facing pressure to streamline operations and cut costs. The restructuring is expected to reduce overlapping work across the Waze and Maps products. Waze's more than 500 employees will be merged with Google's Geo organization, which oversees Google Maps, Google Earth, and Street View products.

High-res spatial maps to assess climate-related shocks

ICRISAT scientists in collaboration with the Asian Development Bank (ADB) have developed high-resolution spatial maps that enable cropland mapping for insurance claims and agriculture policy decision-making on targeting regenerative agriculture (RA).

Physical ground surveys are a laborious process and often require an army of surveyors to validate the effects of floods and drought. ICRISAT scientists in collaboration with the ADB developed spatial maps for South Asia to assess croplands, crop type and crop intensity data. South Asia accounts for 1.9 billion people, constituting almost 25% of the world's population, 87% of which are smallholder farmers. Insurance companies and government agencies require high-quality satellite imagery to monitor and map floods/droughts and other climatic conditions to make the claims process more accurate and efficient.

To this end, ICRISAT scientists have produced three distinct spatial maps for South Asia with a spatial resolution of 30 m, which is much higher to get finer details of cropland for food and water security assessments. Currently, these factors are evaluated using mainly coarse-resolution (250–1000 m) remote sensing data.

The team developed three spatial maps for South Asia for the year 2014-15 to support food and water security assessments and management. These maps would assess irrigated versus rainfed croplands, crop types or crop dominance and cropping intensity i.e., the number of times a crop is grown on the same plot of land in a year. *www.tandfonline.com*

Stuttgart's urban digital twin project

Hexagon's Safety, Infrastructure & Geospatial division and Fujitsu Limited have partnered to deliver a digital twin platform for Stuttgart, Germany, to support the city's urban digital twin project. The Civil Engineering Office will use the SaaS solution to visualize and analyze data from IoT sensors across the city to promote sustainability and enhance quality of life for the 600,000 residents of Stuttgart.

The solution will provide a common operating picture for monitoring sensor values, such as water quality, flood levels and parking space occupancy, enabling the city to derive insights for optimizing operations and making informed decisions for the future. The digital twin platform is based on Hexagon's M.App Enterprise and Xalt | Integration, with Fujitsu providing the necessary cloud infrastructure service for the project. *hexagon.com*

Creating new synergy for satellite data

Synspective and Topcon Positioning Asia (TPA), have recently announced a partnership to deliver satellite data solution services. Synspective, a synthetic aperture radar (SAR) satellite data and solutions startup, and Topcon, a company for surveying and construction, will collaborate to yield new opportunities and innovate in the satellite data space in Japan and globally. *synspective.com*

GHGSat partnership with KSAT

GHGSat is partnering with Kongsberg Satellite Services (KSAT) to provide satellite operations and control of their constellation of greenhouse gas monitoring spacecraft. KSAT will operate the current 5 commercial satellites in orbit.

KSAT will provide services to GHGSat from the new Tromsø Satellite Operations Centre (TSOC, which is a highly advanced operations centre designed to meet the specific needs for resilient and secure solutions, while being adaptable to manage multiple missions featuring different platforms and Mission Control Systems. The service is fully integrated with the Ground Station Network, ensuring seamless scheduling, tasking and ground station operation. KSAT has worked with GHGSat since 2019 with their emissions data from their first satellite for the Earth Observation services. *www.ghgsat.com*

GalaxEye raises $3.5 million in seed funding

Satellite maker GalaxEye announced a seed-stage funding of $3.5 million led by deep-tech venture capital firm Speciale Invest. The Bengaluru-based company in India will focus on hiring new employees and expediting the launch of a new multi-sensor earth observation satellite.

GalaxEye was founded in 2020 by 5 alumni of IIT Madras who previously worked at Avishkar Hyperloop. It became the only Asian Finalist at the SpaceX Hyperloop Competition 2019.

Planet geospatial data available through Amazon SageMaker

Planet Labs PBC announced that it is making geospatial data available through Amazon SageMaker, a fully managed machine learning (ML) service from Amazon Web Services (AWS). Now, Planet data can be directly embedded into Amazon SageMaker, allowing data scientists and ML engineers to acquire and analyze global, daily satellite data. With this data, customers can train, test, and deploy ML models all within Amazon SageMaker.

Planet operates the largest constellation of earth observation satellites in the world, with the capacity to provide daily medium- and high-resolution imagery of Earth's landmass every day. *www.planet.com*

Golden Bauhinia satellite no. 1 05/06 successfully launched

Hong Kong Aerospace Technology Group Limited announced on 9 December 2022, two satellites under Golden Bauhinia No. 1 05/06 have been launched from the sea launch platform in the Yellow Sea area, China, using the Jielong — 3 (Y1) carrier rocket which marked its first sea hot launch.

Launching a carrier rocket from the sea is a groundbreaking solution, and has the advantages of efficiency, high flexibility, and excellent launch economy, with options for the launch point and drop zone.

When launching a low-inclination satellite from land, the launch vehicle routes need to cross a wide range of economically developed and densely populated areas, and there is an increasing number of safety issues. By using a sea launch platform, the growing demand for satellite launching can be met. Both of Golden Bauhinia No. 1 05 and 06 are optical remote sensing satellites equipped with an optical camera and satellite platforms that have achieved technological breakthroughs including miniaturization, high-speed data transmission, and zero-momentum control.

Philippines, UAE ink space cooperation

The Philippines and the United Arab Emirates (UAE) have signed early this month an agreement for space cooperation

According to the Philippine Space Agency (PhilSA), the collaboration is with the UAE Space Agency (UAESA) on space research and development; space data mobilization for disaster management, emergencies, food security, and agriculture, among others.*www.pna.gov.ph*

China launches new remote sensing satellite

China sent a new remote sensing satellite into space from the Taiyuan Satellite Launch Center in north China's Shanxi Province on December 9, 2022. The satellite, Gaofen-5 01A, was launched aboard a Long March-2D rocket and entered its planned orbit successfully. It is a hyperspectral satellite that will be used for remote sensing and applications in diverse fields, such as pollution reduction, environmental monitoring, natural resource surveys, and climate change studies. *www.ecns.cn*

ISRO successfully launches India-Bhutan developed PSLV-C54 rocket

The satellite jointly developed by India and Bhutan was launched along with eight other nanosatellites on an Indian rocket on November 26, 2022, paving the way for the Himalayan country to use high-resolution imagery for the management of its natural resources.

India's Earth Observation Satellite-06 (EOS-06), a third-generation satellite in the Oceansat series, was among the satellites launched. This was the 56th flight of PSLV, which marks the final mission for the year for PSLV-C54 rocket.

India has assisted in building up the capacity of Bhutanese engineers through hands-on training at the UR Rao Satellite Centre in Bengaluru, the external affairs ministry said. These engineers were trained in satellite building and testing, as well as the processing and analysing satellite data. This culminated in the joint development of the customised satellite for Bhutan, the ministry said.The India-Bhutan SAT will provide high-resolution images to Bhutan for the management of the country's natural resources. *www.hindustantimes.com*

ISRO successfully launch India's maiden private Vikram-suborbital rocket

Indian Space Research Organisation (ISRO) made history by launching successfully India's maiden private Vikram-suborbital (VKS) rocket.

Vikram-S is a single stage fuel rocket meant to test most systems and processes in Skyroot Aerospace's project ahead of the launch of Vikram-1 next year. The rocket goes to the max altitude of 81.5 kilometres and splashes into the sea and the overall duration of launch is about 300 seconds only.

Skyroot was the first StartUp to sign a MoU with ISRO for launching its rockets. Apart from being the nation's first private launch, it is also the maiden mission of Skyroot Aerospace, named "Prarambh". *https://pib.gov.in*

Protecting Leicestershire Highways from Falling Trees

A unique tree mapping tool is being used by Leicestershire County Council as part of its programme to help keep its highways safe throughout the county. The Council has turned to Bluesky International, for insight and data into the county's trees that sit alongside these key routes. The National Tree Map (NTM) is a unique dataset that includes height, location, and canopy cover data for trees 3 metres and taller in England, Scotland, Wales, and the Republic of Ireland. *www.bluesky-world.com*

Developing AI delivery drones

Drone Express has partnered with Microsoft to launch a new version of their DE-2020 drone using Artificial Intelligence (AI) for in-flight navigation systems. This creative collaboration will equip delivery drones with Microsoft Azure to host the AI solutions and use Azure Machine Learning to train machine learning models. *droneexpress.com*

Providing foresters with digital forest management information

Quantum-Systems GmbH and SKYLAB have announced a partnership to help forestry customers maximize productivity and reduce costs.

With deep learning and advanced aerial data analytics, SKYLAB provides fully-digitalized forest management, from seedling survival and weed monitoring to full timber and carbon stock inventories, as well as monitoring forest health and harvesting operations for 100% of the areas. Combining the state-of-the-art hardware from Quantum-Systems and the sophisticated forestry and plantation management software from SKYLAB, customers have access to a complete solution that maximizes the usage of aerial data generated by the Trinity F90+ UAV. *www.quantum-systems.com*

New eBee VISION intelligence

AgEagle has announced its introduction of the new eBee™ VISION, a small, fixed-wing unmanned aerial system ("UAS") designed to provide real-time, enhanced situational awareness for critical Intelligence, Surveillance and Reconnaissance ("ISR") missions.

Scheduled for global commercial release in 2023, the eBee VISION delivers high resolution, medium-range video imagery made possible by its 32x zoom and powerful thermal observation capabilities. Its sensor payloads are capable of detecting, tracking and geo-locating objects in both day and night conditions. *www.ageagle.com*

SmartSurveyor 3-in-1 mapping tool

Position Partners has unveiled SmartSurveyor, which facilitates accurate, survey-grade aerial mapping and photogrammetry without the need for a connection between a camera shutter and a GNSS receiver.

The fully compact, handheld, aerial mapping survey rover is compatible with DJI Mavix 2 and 3 series and Phantom 4 Pro drones. The design is dissimilar to other drone mapping systems in that it works from a drone or smartphone and with two or more ground control points (GCPs) while using an ultra-matching technique. Once data is captured by SmartSurveyor, all the photos and the GNSS file are uploaded to a PC and analyzed through the Agisoft UltraMatch workflow to confirm their accuracy before they are exported. Data can be managed in the cloud or on a local PC using software designed by MapSender. *www.positionpartners.com.au*

Dubai Municipality launches GeoHub

Dubai Municipality has launched the geospatial business and innovation incubator, 'GeoHub' within the framework of joint cooperation by its GIS Centre with the Mohammed Bin Rashid Establishment for Small and Medium Enterprises Development (Dubai SME) and the Hamdan Innovation Incubator.

The incubator is one of the first in the region based on two ecosystems, first being creativity, which includes the entrepreneurship ecosystem and the second being innovation that includes academic development ecosystem. The incubator aims to develop the latest working models, which establishes directives to solidify the Municipality's leading position in nurturing best creative practices, supporting startups, offering leading companies with investment opportunities in municipal work and attracting new geospatial innovation, research, and development in Dubai. *https://wam.ae/en/details/1395303110869*

Tech Mahindra to deploy captive private network in partnership with Airtel

Bharti Airtel and Tech Mahindra have announced a strategic partnership under which they have deployed '5G for Enterprise' solution at Mahindra's Chakan manufacturing facility, making it India's first 5G enabled Auto manufacturing unit.

The '5G for Business' solution has significantly enhanced Chakan's network connectivity that has resulted in improved speeds for software flashing, a critical operation for all vehicular dispatches. Blazing hi-speeds and ultra-low latency now allow managers to undertake multiple software flashing sessions in parallel, which has resulted in reduced turn-around time for an operation. Further, the computerized vision based inspection is now fully automated resulting in improved paint quality. *www.techmahindra.com*

First permanent installation of autonomous mobility service

WHILL,Inc. has announced the first permanent installation in North America of its autonomous mobility service at Winnipeg Richardson International Airport.

An estimated one in three travelers will require some form of assistance by the year 2038. This makes it difficult for airports to meet the additional demands that come with accommodating their needs.

The WHILL autonomous mobility service relieves airlines of fulfilling wheelchair push demands and allows airline passengers to travel more freely by autonomously transporting them to their gates.

After the user selects their destination on a touch screen, the WHILL autonomous power chair proceeds to transport the passenger safely and reliably to the desired gate. The service covers the entire route from check-in counter to security checkpoint, and then to the departure gate to provide a seamless travel experience. *https://whill.inc*

Purdue partnership with Digital Envoy

Digital Envoy is partnering with the Purdue University School of Management for its data for good program, Data for Impact, on research examining how retail crime impacts consumer demand and how accessibility to public transportation can be improved.

Digital Envoy introduced the concept of privacy-sensitive IP-based geolocation and IP intelligence in 1999. The technology allows businesses, from ad networks to publishers, websites, retailers and more, to harness the power of location and new intelligence about connected users for many mission-critical applications. The Data for Impact program aims to educate consumers about the realities and benefits of IP and geolocation data, reform the location data industry from the inside out, and provide the advantages of location data to causes and organizations that otherwise might not have access to it. *www.digitalenvoy.com*

Robots to advance last-mile delivery

Hyundai Motor Group has started two pilot delivery service programs using autonomous robots based on its Plug & Drive (PnD) modular platform at a hotel and a residential-commercial complex located on the outskirts of Seoul.

The Group's PnD modular platform is an all-in-one single-wheel unit that combines intelligent steering, braking, in-wheel electric drive and suspension hardware, including a steering actuator for 360-degree, holonomic rotation. It moves autonomously with the aid of LiDAR and camera sensors. An integrated storage unit allows the robot to transport products to customers.

By adding autonomous driving capability, the robot can find the optimal route within the area to deliver packages to recipients. It can recognize and avoid fixed and moving objects and drive smoothly, providing a fast delivery time. *www.hyundaimotorgroup.com*

Nexar releases CityStream Live

Nexar has released CityStream Live, a real-time mapping platform. It enables the mobility industry, including connected vehicles, maps, mobility services, digital twins or smart city applications, to access a continuous stream of fresh, crowd sourced road data. It provides real-time mapping technologies at the edge of the network, enabling detection of work zones, road sign changes, potholes and free parking spaces. The platform is designed to provide fresh data on nearly every road across the United States at a dramatically reduced cost. *https://mapping.getnexar.com*

AVL and Rohde & Schwarz collaboration

Electric vehicles contain many electronic components that emit radio-frequency interference, which may have a negative impact on the vehicle performance and driving experience. To ease and speed up the development process, AVL and Rohde & Schwarz present an innovative solution for automated electromagnetic compatibility (EMC) data analysis of an electric drivetrain under real driving conditions.

AVL and Rohde & Schwarz have developed a solution that supports automated testing with simulation of real driving conditions while covering typical automotive standards. The AVL PUMA 2™ automation controls the test cycle and stores the measured data, in synchronization with the R&S ELEKTRA EMC test software to exchange information between the testbed and the EMC measurement equipment. The ELEKTRA software has been modified to enable automatic and seamless communication with AVL CONCERTO™ software, replacing a previously manual process. CONCERTO™ is post-processing the measured data automatically and gives a full test report according to the pre-defined pass and fail criteria. *www.avl.com*

IDS GeoRadar extends IQMaps software to more GPR solutions

IDS GeoRadar, part of Hexagon announced that it is extending the IQMaps software application to a wider range of GPR systems. IQMaps is IDS GeoRadar's post-processing software application for advanced ground penetrating radar (GPR) data analysis, enabling fast interfacing between the user and GPR data. *https://idsgeoradar.com*

Intermap announces its second contract to enable urban air mobility

Intermap Technologies announced a new contract with a leading Unmanned Traffic Management (UTM) provider to integrate Intermap's certified aviation terrain data to continue the development of an urban air mobility platform. Integrating NEXTView into UTM systems empowers operators to plan and execute eVTOL aircraft flights based on predetermined flight paths for efficient urban air taxi services. *www.intermap.com*

Surface-mount embedded GNSS antenna by

Linx Technologies has expanded on its Splatch antenna series with the release of the ANT-GNL1-nSP, a surface-mount embedded GNSS antenna supporting GPS, Galileo, GLONASS, Beidou and QZSS in the L1/E1/B1 bands. The antenna exhibits notable performance in a compact size (10 mm x 8 mm x 1 mm) and features linear polarization and an omnidirectional radiation pattern. *https://linxtechnologies.com*

Swift Navigation adds BeiDou support

Swift Navigation has expanded the capabilities of its Skylark precise positioning service to several product tiers. With new services providing real-time kinematic (RTK) and differential GNSS (DGNSS) options, Swift meets the broadening needs of its growing customer base. In addition, new BeiDou signal support and regional coverage has been added. Skylark is Swift's cloud-based GNSS corrections service designed to deliver affordability, high accuracy and fast convergence, eliminating the complexity of deploying and maintaining GNSS networks. *http://swiftnav.com*

CHC Navigation launches Landstar8 data-collection app

CHC Navigation has released LandStar8, a field surveying and mapping application for Android devices. It is versatile, modular and customizable for topographic tasks such as surveying, stake out, cadastral, mapping and GIS. Building on the legacy of LandStar7, the new LandStar8 provides features such as a refined user interface, streamlined workflows, faster operation, and integrated cloud services.Cloud connectivity is built in, for backup, data storage or remote technical support. *https://chcnav.com*

Realistic testing to emerging LEO satellite applications

Spirent Communications plc has announced availability of SimORBIT, the first high-accuracy orbital modelling software solution specifically developed for Low Earth Orbit (LEO) satellite simulation. Created in partnership with spaceborne receiver developer SpacePNT, Spirent SimORBIT enables developers to calculate LEO orbits and their distinctive characteristics more precisely and realistically for GNSS/PNT testing.

This capability complements the ability of Spirent's simulation systems to generate non-ICD signals via I/Q injection, or by the unique Spirent "Flex" feature, enabling new space based PNT signals to be developed in the lab as realistically as possible. *www.spirent.com*

Orolia's Ultima-S emergency locator transmitter

Orolia was recently acquired by Safran Electronics and Defense, recently certifications for the Ultima-S survival emergency locator transmitter (ELT). The Ultima-S is a new generation ELT installed in either the cabins or life rafts and relays accurate aircraft location information to search and rescue teams.

The Ultima-S provides free and global coverage service through the dedicated Cospas-Sarsat infrastructure while meeting the highest aviation safety standards. It offers non-rechargeable lithium batteries that are compliant with the latest FAA and EASA special conditions standards, also known under TSO-C142b/DO227A. The Ultima-S also meets the most recent ELT performance and environmental standards through TSO-C126c. Once activated, a 406MHz distress signal is transmitted and includes the ELT location thanks to the Ultima-S internal GNSS receiver. *www.orolia.com*

Hexagon, OSASI partnership

Hexagon's Safety, Infrastructure & Geospatial division and OSASI Technos Inc. announced a partnership to deliver next-generation disaster management and monitoring solutions. The wide area remote monitoring systems with 3D visualization capabilities will allow governments to detect, predict and simulate impending disasters, enabling them to better plan for and respond to emergency events. The partnership brings together OSASI's advanced on-site sensors and monitoring solutions with the real-time situational awareness and location intelligence capabilities of Hexagon's Luciad Portfolio. *hexagon.com*

GMV's positioning solution is now on the road

GMV has recently reached the milestone of incorporating its safe, high precision and reliable positioning technology onboard vehicles of the German premium car manufacturer BMW Group. Its positioning solution comprises two components: an onboard Positioning Engine software (PE) and a GNSS Correction Service (CS). The CS provides BMW Group vehicles with corrections to the Broadcast Ephemeris for different GNSS constellations,

MARK YOUR CALENDAR

February 2023

GeoWeek 2023
13-15, February
Denver, CO, USA
www.geo-week.com

March 2023

Munich Satellite Navigation Summit 2023
13-15 March
Munich, Germany
www.munich-satellite-navigation-summit.org

GEO CONNECT ASIA
15-16 March, 2023
Singapore
www.geoconnectasia.com

Digital Twins 2023 (Virtual)
23 March 2023
www.digitaltwins2023.com

DGI 2023
27 Feb-01 March
London, UK
https://dgi.wbresearch.com

April 2023

GISTAM 2023
25-27 April
Prague, Czech Republic
https://gistam.scitevents.org/Home.aspx

May 2023

International Conference on Geomatics Education
10-12 May 2023
Hong Kong
www.polyu.edu.hk/lsgi/icge22/en

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

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

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

June 2023

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

July 2023

IGARSS 2023
16-21 July
Pasadena, CA, USA
https://2023.ieeeigarss.org/index.php

September 2023

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

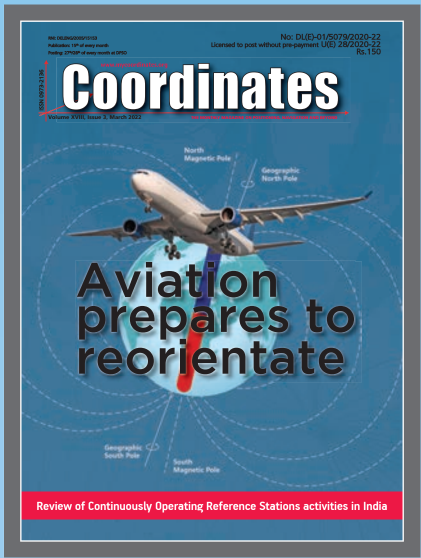
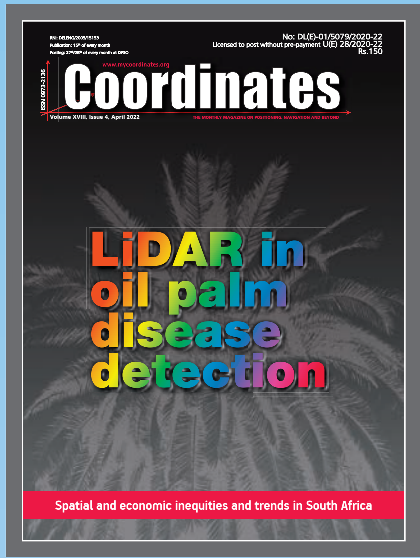
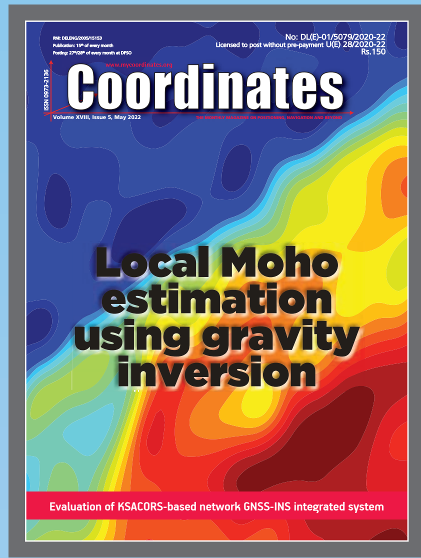
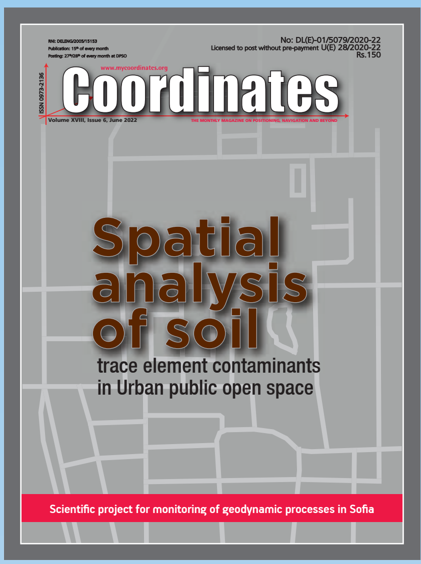
augmentation data to remove local atmospheric effects and safety-related information for computing a reliable user position. The PE integrated in the vehicles' on-board unit also uses the corrections, together with GNSS signals and information from other sensors, to compute a trustable vehicle position, speed, and heading.

GMV in Australia and New Zealand

GMV has signed an agreement with Lockheed Martin Corporation to develop the processing and control centers for the Southern Positioning Augmentation Network system, known as SouthPAN. This project is a joint initiative of the Australian and New Zealand governments with the purpose of providing a satellite-based augmentation system (SBAS) for navigation and precise point positioning (PPP) services. GMV will also be responsible for monitoring both of these services in the region and for ensuring compliance with the committed performance levels.

SouthPAN is also the first system with these characteristics available in the Southern Hemisphere. With this new program, Australia and New Zealand will be contributing to improved global coverage and interoperability for services of this type, by joining the list of countries and regions that already have their own SBAS system, such as the USA (WAAS), Europe (EGNOS), India (GAGAN), and Japan (MSAS).

In Australia, the development, entry into service, and operation of the SouthPAN system are being supervised by the Australian government's geoscience agency, Geoscience Australia, in collaboration with New Zealand's equivalent agency, known as Toitū Te Whenua Land Information New Zealand. In 2020, the two agencies signed the Australia New Zealand Science, Research and Innovation Cooperation Agreement (ANZSRICA). Over the next 20 years, the Australian government will be contributing 1.4 billion Australian dollars to the SouthPAN project. *www.gmv.com*


Coordinates
Aviation prepares to reorientate
Review of Continuously Operating Reference Stations activities in India

Coordinates
LiDAR in oil palm disease detection
Spatial and economic inequities and trends in South Africa

Coordinates
Local Moho estimation using gravity inversion
Evaluation of KSACORS-based network GNSS-INS integrated system

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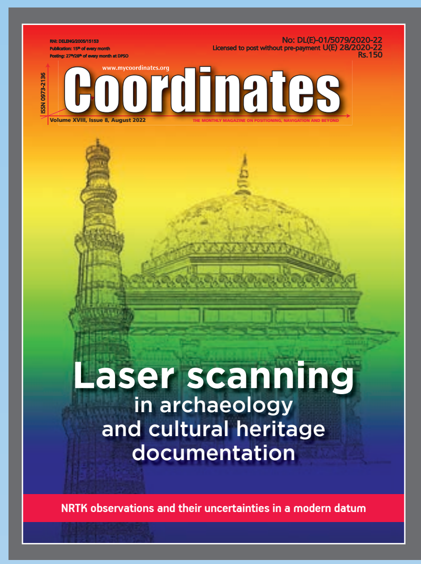
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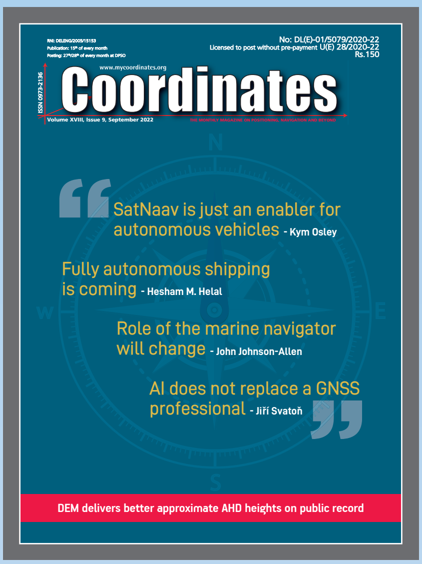
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