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EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

Addendum to NAVISP Element 1 Work Plan for 2018

Subject

This document presents the Addendum to NAVISP Element 1 Work Plan 2018 activities.

Required action

The Participating States in the Element 1 of NAVISP are invited to approve the attached addendum to the Work Plan for 2018.

Voting rights and required majority

Simple majority of the Participating States in the Element 1 of the NAVISP Programme (AT, BE, CZ, DK, FI, FR, NL, NO, RO, CH, UK) representing at least half of the contributions to this Element.

Legal Basis

Act in Council on the Introduction of Weighted Vote in the Agency's Optional Programmes (ESA/C/CCXXIX/Act 1 (Final) attached to ESA/C(2012)102).
Article 3 (d) of the Implementing Rules of the NAVISP Programme.

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1. INTRODUCTION

Activities under Element 1 of the Navigation Innovation and Support Programme (NAVISP) are defined and implemented according to an annual work plan to be prepared and proposed by the Agency, and to be approved by participating States in Element 1.

The Executive announced at the 105th PB-NAV meeting in February that it was also assessing ideas for potential inclusion in an addendum to the Work Plan for 2018, which would be possibly submitted to the PB-NAV meeting in May after ad-hoc internal preparation and coordination with EC and GSA.

This document presents the Addendum to NAVISP Element 1 Work Plan for 2018.

2. RATIONALE FOR THE PREPARATION OF THE ADDENDUM TO NAVISP ELEMENT 1 WORK PLAN FOR 2018

In order to collect the most promising ideas and proposals and be able to prepare both Element 1 Work Plans for 2017 and 2018 , the Executive had implemented the ‘funnel scheme’, which has proven to be a successful process for their approval.

The funnel scheme is based on:

- an ESA-wide consultation, to populate the work plans according to well-established guidelines;
- external input, not only based on recommendations from recognised experts in the PNT sector, but also from consultative workshops organised by Participating States.

In particular, at the 105th PB-NAV meeting in February, the Executive announced its plan to increase outreach in order to enrich the preparation of the next work plan(s) with external input, in particular through:

- the GNSS Science Advisory Committee (GSAC) for science-driven ideas and relevant applications in the PNT sector;
- senior-level sectorial advice;
- shaping, maintaining and linking to sectorial roadmaps (beyond rail and maritime);
- sustained interaction with Participating States.

During the process of enhancing external interactions, a number of ideas and proposals have been brought forward, in particular a couple supported by GSAC, that the Executive deemed worthwhile and sufficiently mature to be advanced as an addendum to the Work Plan for 2018.

3. STATUS OF COORDINATION

As per the previous work plans, the Addendum to Element 1 Work Plan for 2018 has been shared with the EC and GSA strictly in line with the process outlined in "Coordination between the EC-GSA and ESA on NAVISP Programme Activities" (ESA/PB-NAV(2016)34). Comments received from the EC and GSA have been taken into account, and text describing the proposed activities has been updated for the sake of clarity.

EC and GSA experts will support the implementation of the activities as requested during coordination. Furthermore, as recommended by the EC and GSA, there will be a careful coordination with them on the projects addressing application domains calling for the involvement of institutional stakeholders at EU level.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

The activities proposed and approved in the Work Plan for 2018 had been grouped according to the following broad themes:

- Theme 1: Emerging New Space-Based PNT Concepts;
- Theme 2: Innovative Use of Space-Based Solutions in the PNT Context;
- Theme 3: Proof of concept of promising PNT Techniques and Technologies.

For the Addendum to Element 1 Work Plan for 2018, all four additional activities proposed below fall under Theme 3.

It is recalled that Theme 3 should form the basis for future innovative PNT techniques and technologies by attracting the wider interest of the space and non-space industry in developing and testing new solutions.

For the Addendum to Element 1 Work Plan for 2018 too, Theme 3 activity proposals range across diverse domains, addressing techniques and technologies for applications in space and on ground, including system engineering studies and development of testing platforms which could be made available to industry for follow-on developments in NAVISP or in other programmatic frameworks at ESA or outside.

In particular, two proposals attract strong interest from the scientific community and have been formulated through interaction with the GSAC.

4.1. NAVISP-El1-023: Earth-Moon Navigation / System Study and Development of a Highly-Sensitive Spaceborne Receiver Prototype

GPS has been used in space for more than 20 years and currently it is consistently used in LEO orbit satellites in order to provide position, velocity and time information. Extension of its use to higher altitude missions has been the subject of multiple studies, GEO and GTO orbits currently exploit GNSS signals and the NASA Magnetospheric Multiscale (MMS) mission has recently demonstrated that tracking of GPS signals is possible up to 70,000 km from Earth's surface. The interest of the various GNSS Service Providers has been reflected in the production of a multi-constellation SSV (Space Service Volume) booklet in the framework of the UN ICG (International Committee on GNSS), which has confirmed the interest of using GNSS signals for space missions even beyond near-Earth.

The possibility of extending GNSS for missions to the Moon has preliminarily been assessed by ESA via GSP (General Studies Programme). These preliminary studies conclude that navigation to the Moon using GNSS complemented by other instruments could be feasible, provided specific high-sensitivity techniques are implemented in receivers.

The interest of having in the near-future an available PNT service for the Earth-Moon system is currently supported by both institutional and commercial initiatives. On the commercial side, multiple companies are developing business solutions targeting the Moon (e.g. proposing tourism applications or moon mining) and several major European companies are proposing to team up to build a communications network on the Moon compatible with terrestrial standards. In parallel, NASA has recently announced its plans for a "Return to the Moon" in the next decade and the NASA-ESA Orion space vehicle should be operational in early 2020, with crewed missions covering the Earth-Moon system. ESA is also participating in multiple future reflections about potential missions to the Moon, such as the potential international Gateway station on Moon orbit or the launch of a Cubesat to the Moon (LUCE mission).

It is therefore of high interest to assess in detail the feasibility and associated achievable performance of a complete PNT system, exploiting current multi-constellation GNSS signals for Earth-Moon missions. As mentioned above, the scientific interest for the proposed activity has been conveyed through the GSAC.

The main objectives of the proposed activity are twofold:

- to perform a dedicated system study on the use of multi-constellation GNSS for Earth-Moon missions complementing previous studies, confirming feasibility, assessing achievable performance and identifying a preliminary architecture with possible enhancements to existing GNSS constellations;

- to develop a GNSS spaceborne receiver prototype as a technology risk mitigation for future application in demonstrations missions (e.g. the Cubesat

LUCE mission proposal) and in order to gather data and support further system activities.

The tasks to be performed will include:

- consolidation of the Earth-Moon PNT user requirements for Moon Transfer Orbit, Low Lunar Orbit, Descent/Landing and Surface Operations;
- derivation of the associated system requirements;
- assessment of multi-GNSS achievable performance for the Earth-Moon system, assuming current baseline constellations. This should include the identification and detailed sensitivity assessment of the critical assumptions in terms of GNSS system performance (e.g. antenna lobe gains) and necessary high-sensitive GNSS receivers/antenna;
- identification of possible Earth-Moon GNSS system enhancements (e.g. provision of dedicated additional GNSS-ranging sources at strategic orbital positions; availability of enhanced high-sensitive GNSS receivers; application of advanced signal processing techniques on-board; integration with additional sensors), and performing a system trade-off in order to assess complexity, feasibility and achievable enhanced performance;
- specification and design of a representative low-cost GNSS high-sensitive spaceborne receiver (including associated antenna) for a potential future flight demonstrator;
- development and testing of a highly-sensitive GNSS spaceborne receiver prototype, and setting-up of a complete realistic simulation environment to confirm the achievable performance.

System study and GNSS receiver prototyping tasks will be performed in parallel, with periodic interactions.

The results of the activity will provide:

- A detailed assessment of the feasibility and achievable performance of a complete PNT system for Earth-Moon missions, exploiting available multi-constellation GNSS signals;
- The development of a highly-sensitive GNSS spaceborne receiver prototype for future application in relevant demonstration missions.

Funding required: €800k	*Duration:* 18 months	*ITT issue:* Q4 2018

4.2. NAVISP-El1-024: Precise Relative Positioning in MEO to support Science Missions

Precise relative positioning in MEO (Medium Earth Orbit, at altitudes ranging between 2,000 and 36,000 km) exploiting GNSS is a subject that has been little explored while having high potential for enabling an interesting set of applications based on space-to-space interferometry.

Establishing accurate inter-satellite baselines based on GNSS measurements would open the door to new missions at affordable complexity and cost in the areas of Science, Lunar Exploration and Earth Observation. Examples are the imaging of the event horizon of the supermassive black hole in the centre of our galaxy, the positioning of spacecraft in Lunar orbits or aperture synthesis for Earth atmospheric sounding.

Reaching a baseline accuracy of 0.1 mm as required for some of those applications is not easy when using GNSS signals. The advantage of MEO is that atmospheric drag is negligible and orbital mechanics might be simpler than in LEO, even if the number of GNSS satellites in common visibility of a pair of MEO receivers is in general low, and the angle of arrival of signals upon each receiver is quite different, so that common errors do not cancel as well as they do for small baselines on ground.

The main objective of the proposed activity is to address the relative positioning between a pair of satellites at slightly different altitudes for a few selected study cases in different MEO orbits.

The tasks to be performed will include:

- Modelling of the orbital perturbations;
- Modelling of the spacecraft and AOCS systems;
- Modelling of the antennas phase centres;
- Development of relative positioning filters.

The results of the activity will aim at providing a demonstration by simulation of an expected on-the-fly relative position accuracy between a pair of MEO satellites of better than 5 cm and 0.5 mm in post-processing. If this technical performance is confirmed thanks to GNSS, this will enable a large number of potential application/scientific missions at reduced complexity and cost.

Funding required: €350k	*Duration:* 15 months	*ITT issue:* Q3 2018

4.3. NAVISP-El1-025: Multi-Sensor, Multi-System for Space PNT Applications

Position uncertainty during autonomous manoeuvres such as orbit-raising/de-orbiting requires that the local knowledge during low thrust (i.e. with electric propulsion) is accurately determined.

Current orbit-raising assumes semi-autonomous control assisted by GNSS, with a long time integral to measure increasing altitude and trajectory of the satellite.

For autonomous control and/or close manoeuvre of two spacecraft in relation to each other (e.g. rendezvous & docking), the relative position and movement need to be understood and controlled in a timelier fashion with a tightly-closed loop between measurements and estimates of thruster actuation. While in LEO, GNSS can help, above MEO, more reliance will fall on IMUs and other sensors. As such, the current approaches require significant ground monitoring and control.

The use of a hybrid GNSS unit that incorporates a low power INS (Inertial Navigation System) and potentially other sensor capabilities (e.g. millimetre wave radar/lidar, stereo cameras) provides a mechanism through which control can be fully or highly autonomous for close manoeuvre in combination with methodologies for modulating electric thrusters.

The understanding of spacecraft position, orientation and velocity gradient with a capable hybrid GNSS unit may provide further mission management opportunities to maximise propellant utilisation.

The main objective of the proposed activity is to:

- develop a multi-sensor, multi-system PNT system that will help automate the orbit-raising and/or docking of space vehicles while employing electric propulsion when approaching non-responsive bodies;
- contribute significantly to the area of Space Servicing where close-proximity approaches are required allowing inspection, in particular visual inspections of a failed or failing satellite (to assess the tumbling) or docking to a failed satellite in order to push it to a graveyard orbit.

The tasks to be performed will include:

- assessing and defining a limited set of scenarios/use cases;
- reviewing and apportioning the activities between on-board autonomy and ground support considering different mission phases;
- ascertaining the AOCS requirements during autonomous, cooperative/un-cooperative manoeuvre operations;
- given the occurrence of “loss of thrust owing to beam outs”, performing a preliminary assessment on the possible contingencies and possible mitigations;
- identifying the hybrid GNSS capability and the level of coupling required within the GNC function;
- trading-off different IMUs, sensors and GNSS low gain antennas (single or multiple);

- trading-off between large spacecraft and small satellite constraints;
- reviewing and identifying the other sensors and systems that can be used extrapolating from automotive, marine and aircraft applications and developments (technology transfer);
- identifying and assessing the benefit of utilising multi-band GNSS capability.

The results of the activity will provide:

- the identification of types of sensors and INS needed for the different satellite phases with their different constraints;
- an assessment of different types and levels of ground support activities;
- the elaboration of a phased roadmap with increasing levels of autonomy towards achieving a fully-autonomous system;
- the outline of a follow-on activity to demonstrate and improve a product to a higher TRL.

Funding required: €480k	*Duration:* 12 months	*ITT issue:* Q4 2018

4.4. NAVISP-El1-026: Enabling Ultra-High Accuracy Positioning in Challenging Environment

The need for high accuracy PNT in challenging environments has become obvious and, henceforth, mandatory for many applications. Currently, an accuracy target of 1 m in an urban environment seems a realistic achievement with multi-GNSS PPP or RTK capabilities. A significant R&D effort is ongoing to reach this target in operational products, using carrier phase positioning (PPP and RTK) and European institutions are actively taking their part in this effort.

In most hybrid PNT systems, GNSS is rightly considered the primary source of high-accuracy positioning, including in urban environments. Hence, current techniques and R&D efforts rely on GNSS as the primary source of high accuracy for both absolute and relative positioning.

High accuracy is both ‘addictive’ and an enabler for new applications (e.g. autonomous vehicles like cars, UAV, etc.). There is little doubt that achieving accuracy better than 30 cm will stimulate new applications and reduce implementation costs of autonomous vehicles. Whereas the 1 m target seems in range of floating carrier positioning (standalone or hybridized with IMU depending on the environment), any further improvement would require carrier ambiguity fixing or resolution (IAR: Integer Ambiguity Resolution for RTK and PPP).

In challenging environments (urban, dense canopy, etc.), this seems apparently out of reach of current technologies and R&D efforts, because ambiguity fixing requires at least four high-quality measurements at each epoch, a situation rarely encountered in an urban environment (typical fix rate is around 10%).

In this context, ambiguity fixing in the challenging urban environment calls for a change of paradigm in the way hybrid PNT measurements are built and used in high-accuracy user equipment, in particular, the GNSS carrier phase measurements. This activity aims at bringing the carrier positioning technologies in urban environments one step further, by investigating new approaches to achieve carrier ambiguity fixing. It will further leverage multi-constellation GNSS, in particular Galileo features such as wide band signals, three frequencies (E5ab, E6 and E1) and their valuable distribution in L-band.

Progress made on PNT sensors allows to achieve very high relative accuracy over the short term: using miniaturized clocks (OCXO, CSAC) and high-end position and motion sensors (e.g. IMUs, camera, vehicle to vehicle ranging), a 4D relative trajectory with an accuracy of 30 cm-1ns can be maintained up to 100 s (30 s with mid-grade IMU). In the coming years, sensor fusion and further technological evolutions are expected to make such performance affordable for many professional applications.

The combination of those sensors could become the primary source of affordable very high-accuracy relative positioning (~30 cm).

The main objective of the proposed activity is to:

- study, develop and demonstrate innovative GNSS processing techniques at user level, hybridized with external sensors to achieve carrier ambiguity resolution in challenging environment. Hybridization would include motion sensors (IMU, optical, etc.) and high-quality Time / Frequency references (e.g. miniaturized clocks such OCXO or CSAC).

The tasks to be performed will include:

- consolidation of the state-of-the-art on high-accuracy positioning user technologies in an urban environment (PPP, RTK, additional sensors) and gathering the lessons-learned for the design of the enabling building blocks. This will also include survey of patents, a valuable source of innovative ideas;
- consolidation of requirements for the targeted use cases, e.g. autonomous vehicles, in terms of accuracy, non-GNSS sensors, urban environment, source and availability of corrections data including ionosphere and troposphere. Information already available from relevant GSA activities could also be leveraged;
- identification of promising concepts at user level: architecture and algorithms for the enabling building blocks, study their feasibility and performances (theory and simulation);
- consolidation of the design, with combination of multiple concepts, potentially;

- implementation on a representative platform, as well as validation in controlled conditions, with lab-testing and field-testing using high-end sensors;
- field-testing in real environments to demonstrate positioning performance in real conditions and assess sensitivity to effective external sensor quality and assumptions on correction quality. These tests may also rely on tools available at the ESA Navigation Laboratory.

The results of the activity will provide:

- a complete assessment of achievable capabilities of ambiguity fixing and related hybrid positioning performance with accuracy possibly better than 30cm in urban environments, to be compared with the 1-2 m currently achievable with floating carrier phase positioning (current PPP and RTK technologies);
- a breadboard, not requiring real-time capabilities, with associated test results;
- an outline of follow-on actions, such as a test bed to complete demonstration of technologies and capabilities or industrialisation of some results to be considered, e.g. in NAVISP Element 2.

The activity is a follow-on activity to an ongoing TRP project, and will build upon its results and lessons-learned on floating carrier positioning.

Funding required: €400k	*Duration:* 12 months	*ITT issue:* Q3 2018

5. SUMMARY

Activity Title	Funding required (€k)	Duration (months)
NAVISP-El1-023: Earth-Moon Navigation / System Study and Development of a Highly-Sensitive Spaceborne Receiver Prototype	800	18
NAVISP-El1-024: Precise Relative Positioning in MEO to support Science Missions	350	15
NAVISP-El1-025: Multi-Sensor, Multi-System for Space PNT Applications	480	12
NAVISP-El1-026: Enabling Ultra-High Accuracy Positioning in Challenging Environment	400	12
Total	2030	

El1 ID	Activity Title	Planning											
		2018				2019				2020			
023	Earth-Moon Navigation / System Study and Development of a Highly-Sensitive Spaceborne Receiver Prototype				ITT								
024	Precise Relative Positioning in MEO to support Science Missions			ITT									
025	Multi-Sensor, Multi-System for Space PNT Applications				ITT								
026	Enabling Ultra-High Accuracy Positioning in Challenging Environment			ITT									