



HAL
open science

North Star: Data-Driven Sailing for an Efficient and Safe Passage in the Arctic Ocean

Paola Breda, Arthur Kho Caayon, Avin Vadas, Adam Abdin

► **To cite this version:**

Paola Breda, Arthur Kho Caayon, Avin Vadas, Adam Abdin. North Star: Data-Driven Sailing for an Efficient and Safe Passage in the Arctic Ocean. 73rd International Astronautical Congress (IAC), Paris, France, International Astronautical Congress, Sep 2022, Paris, France. hal-03965080

HAL Id: hal-03965080

<https://hal.science/hal-03965080>

Submitted on 31 Jan 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

IAC-22-B1.IPB.15.x70390

North Star: Data-Driven Sailing for an Efficient and Safe Passage in the Arctic Ocean

Paola Breda^{a*}, Arthur Kho Caayon^b, Avin Vadas^c, Adam F. Abdin^d

^a HyImpulse Technologies GmbH, Neuenstadt am Kocher, Germany, breda@hyimpulse.de

^b Movial, Helsinki, Finland, arthur.kho@movial.com

^c Freelancer Product Designer, Lisbon, Portugal, vadas.avin@gmail.com

^d Université Paris-Saclay, CentraleSupélec, Laboratoire Génie Industriel, 91190, Gif-sur-Yvette, France, adam.abdin@centralesupelec.fr

* Corresponding Author

Abstract

Maritime navigation in the Arctic Ocean is fraught with danger such as strong atmospheric electromagnetic interference, adverse weather conditions, unreliable satellite signal and coverage. A vessel not knowing its position while navigating in the Arctic may find itself in a critical situation. In the framework of the 2nd CASSINI Hackathon aimed to promote ideas based on safe passage in the Arctic, the authors developed a product called North Star. The aim of North Star is using Earth Observation data provided by Galileo and Copernicus services to improve navigation in the Arctic. It consists of an on-board neural engine, the AI Pilot, which searches for and identifies a safe route for the user. The neural engine can be trained on the Copernicus data from the Sentinel constellation, which includes information such as ice thickness, iceberg distribution, wind speed direction, and wave height for a specific passage. In the event of a satellite signal loss, the AI Pilot reuses the information received from Galileo up to that point and integrates them with the vessel's own maritime sensors to maintain the viability of the projected route. The idea behind the AI Pilot is that when a vessel is within communication range with other North Star vessels, they form an ad-hoc mesh network of data collectors with edge computing capabilities. The creation of a mesh network can provide augmented data to the entire GNSS ecosystem. While shipping transportation of oil and gas across the Arctic passages undergoes more strict regulations, private tourism and charter yacht operators in the Arctic are an emerging market due to the relatively unsafe travel conditions. North Star can have a beneficial impact on the tourist sector in the first place, extending afterwards to support Search and Rescue operations, as well as contributing to the protection of the environment and the Arctic fauna. This research presents the concept of operations of North Star, as well as its high-level description from the technical perspective. The potential of this business case is further investigated, to include a roadmap of services offered until the return of investment, potential customers, and current competitors.

Keywords: Arctic Ocean, Maritime Navigation, Artificial Intelligence, Sensor Fusion, Copernicus Services, Tourism

Acronyms

AI	Artificial Intelligence
AIS	Automatic Identification System
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
CASSINI	Competitive Space Start-ups for Innovation Initiative
CMEMS	Copernicus Marine Environment Monitoring Service
CNN	Convolutional Neural Network
CORS	Continuously Operating Reference Stations
COTS	Commercial off-the-shelf
DIAS	Data and Information Access Services
EGNOS	European Geostationary Navigation Overlay Service
EO	Earth Observation

GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
MARPOL	International Convention for the Prevention of Pollution from Ships
ML	Machine Learning
NLS	Noxious Liquid Substances
SAR	Search and Rescue
SAT-AIS	SATellite-based AIS
SBAS	Space-Based Augmentation Systems
SOLAS	International Convention for Safety Of Life At Sea

1. Introduction

Due to climate change, the strong rise in temperature at the high latitudes causes a rapid decline in sea ice, making sea routes more accessible to maritime traffic.

One example is the Arctic Sea route connecting the Pacific and Atlantic north of the continents [1]. Although this route was historically used by adventurers, researchers, and the local population, nowadays it is also accessible to commercial ships. In fact, the main activities occurring in the Arctic include the offshore extraction of resources and minerals, the study of environmental and ecological changes, maritime trading paths between Atlantic and Pacific oceans, as well as private tourism [2].

Nonetheless, navigation in the Arctic is particularly challenging due to several factors. Challenging weather conditions and untimely weather information [3] increase the navigational risk in open waters. Ionospheric and tropospheric disturbances produce random delays and rapid signal power fluctuations (scintillations) of Global Navigation Satellite System (GNSS) signals, an effect increasing when the GNSS satellite is low on the horizon. Wireless communication causes telecommunication issues [3]. The ice surface reduces the mobility of the ship offshore and increases the navigational risks. The lack of infrastructure for telecommunication and cellular coverage is sometimes experienced close to the shore as well.

One of the biggest challenges is the poor navigational service caused by uneven coverage of positioning [3], because the signal often suffers from line-of-sight blockage (through icebergs or vessels) and is redirected in a multipath. Among the existing GNSS constellations (GLONASS, Galileo, BeiDou and GPS), the Russian GLONASS has the highest orbital inclination of $64^{\circ}8'$, while the remaining three are located at inclination orbits of 55° (GPS, BeiDou) and 56° (Galileo). Because the Arctic region is defined for latitudes above $66^{\circ}33'48''$ (the Arctic circle), it becomes clear how GNSS connectivity is scarce in this region. An interesting overview of challenges encountered during navigation in the Arctic was collected in [3] by means of a user survey based on real-life experiences. Overall, GNSS performance in the Arctic is rated as not optimal. Fig. 1 shows the current GNSS coverage in the northern hemisphere.

Conventional technologies to improve positioning performance exist [4] but not all of them solve the challenge of navigating in the Arctic, especially for the category of the small vessels used for fisheries or tourism.

Differential positioning, scintillation mitigation techniques, and space-based augmentation systems (SBAS) are typical systems used to improve accuracy. The regional SBAS for Europe is the European Geostationary Navigation Overlay Service (EGNOS) which uses GNSS measurements taken by accurately located reference stations deployed mainly across Europe and North Africa. However, SBAS relies on geostationary satellites not visible above 72° latitude, so

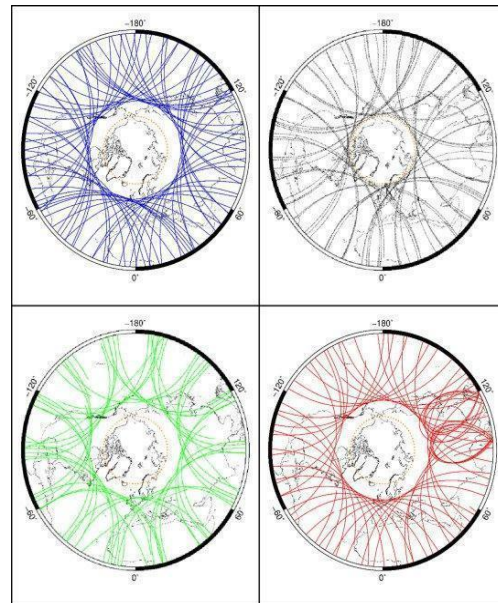


Fig.1. Coverage of GPS (blue), GLONASS (black), Galileo (green) and BeiDou (red) in the northern hemisphere.

that its application for navigating the Arctic is not optimal.

Maritime communications exploit satellite-based automated identification data exchange systems (SAT-AIS). An Automatic Identification System (AIS) is required by the International Maritime Organization (IMO) for vessels heavier than 300 tons in international waters and passenger ships regardless of the size. The AIS is available only near the coastal areas or in ship-to-ship line-of-sight. However, in a scenario of total GNSS denial the AIS seems to be unable to calculate the range to nearby vessels [5]. A cost-effective solution to provide SAT-AIS services would be having a constellation of microsattellites, like the ESAIL microsattellite developed within an ESA Partnership Project [6]. Nonetheless, SAT-AIS does not seem to be applicable to private vessels or tourist charter for navigating the Arctic.

The use of multi-GNSS positioning increases the complexity of the system. A study conducted explicitly for the Arctic region [4] for Galileo, GPS and GLONASS showed that Galileo provides the worst satellite geometry, while GPS provides the best one. The comparison of satellite visibility over 48h shows that the constellations have sufficient visibility for an elevation angle less than 20° , while the high noise level of satellite signals leads to a reduction in position accuracy. When considering accuracy, thus how close the device's calculated position is from the true position, sufficient accuracy is reached by GPS, GLONASS and Galileo (1-3 m in open sea) as required for autonomous systems [4]. Multi-GNSS positioning can be useful to private vessels or tourist charter for navigating the Arctic.

A promising technique used to support navigation is using remote sensing for positioning. Earth Observation (EO) satellites can detect non-AIS-enabled vessels, thus in the weight class of less than 300 tons or without AIS requirement on board, like private vessels or tourist charters. EO can be also used to map the region, for example for monitoring iceberg formation. The Copernicus program is an excellent example of how EO data are made available to the public as it offers services for monitoring atmosphere, marine environment, land, climate change, and can be integrated into security and emergency services [7].

However, the most promising technique to improve satellite-terrestrial connectivity is using sensor fusion [4]. It is not a navigational aid developed specifically for the Arctic challenge, but it is used in autonomous systems, and it is connected to Artificial Intelligence (AI) systems. The connectivity development towards high communication bandwidth like ITS-5G, WiFi and LTE would also enable small vessels to communicate via mobile network infrastructure. It is important to understand that sensor fusion for navigation systems is not a single sensor technology. Satisfactory performance is usually provided by collecting the information from different positioning data sources, such as GNSS, Internal Motion Units (IMU), sonar, Light Detection and Ranging (LiDAR), and radar on board the vessel. A robust sensor fusion algorithm on board would help to support navigation under critical conditions as occurring in the Arctic.

Based on the challenges of navigating into the Arctic and the existing navigational aids mentioned before, this paper proposes an innovative product to enable safe navigation in Arctic waters. The AI and sensor fusion unit on board exploits the EO database available through the Copernicus services for training. The product is given the name of North Star and it aims to ensure an accurate positioning in the Arctic Ocean so that a vessel can navigate safely, on-time and cost effectively.

The paper is structured as follows. Section 2 provides an overview of the market analysis leading to North Star. The high-level technical description of North Star as well as the use case is provided in Section 3, while Section 4 presents the first draft for the business development. Section 5 covers important aspects of how North Star can bring value to the environmental cause. Section 6 drafts the conclusions and paves the way to future action.

2. Market analysis

This section identifies the market opportunities for North Star to cover shipping activities in the Arctic, provides an initial description of the product, the value proposition for the customer and the competitive landscape.

2.1 Market opportunity

According to the previous discussion, a significant need exists for improving the safe navigation of shipping activities in the Arctic. Studies estimate that overall shipping activity in the Arctic will increase by more than 50% over the next few decades [8]. Many of these vessels are currently constrained by their risk aversion to navigate in uncharted marine pathways in the Arctic, with fear of GNSS signal loss and inability to ensure a safe pathway towards their destinations. This is particularly true for smaller vessels such as fisheries and tourism cruises, whose numbers are expected to significantly increase in the coming years.

Fishery and tourism represent a significant portion of the Arctic economic activities. Arctic shipping currently represents around 9.3% of the world's shipping traffic in movements [9]. Within Arctic shipping, fishing vessels represent the highest share with 12.4%, while passenger vessels have a 5.5% share. Over the period 2005-2017 these activities have increased by over 7 times for fishing vessel voyages and over 3 times for pleasure and adventurer vessels [9]. The current projections indicate that cruise tourism will at least double by 2027 to reach around 412,000 passengers, which is double the current market size (primarily using large cruises) [10]. Moreover, Arctic fisheries are also expected to increase of 20%-30% by 2050 [11].

While projections for the number of small tourism vessels are not readily available, the general projections of tourism in the Arctic provide a good indicator of the expected market size for smaller adventure and leisure vessels that could benefit from navigational tools to safely navigate the Arctic.

Based on this preliminary market research, there is a clear opportunity for marine navigation systems that are capable of: assisting vessels in adapting to the dynamic sea conditions; maintaining safe navigation in hard-to-reach locations such as the Arctic. The total marine navigation and information system market is around 1.8 billion USD and expected to reach 2.9 billion USD by 2027 [12-13]. This represents a growth in the market of 10.1% from its current size. While it is difficult to obtain estimates on the proportion of this market size particularly related to the Arctic, it is reasonable to consider the current share of the total Arctic maritime activities (9.3%) as a pessimistic estimate of the navigation market share. By assuming no growth in the share of Arctic navigation compared to worldwide navigation, the projection is still significant, as the market size of 167 million USD is projected to increase to 270 million USD by 2027.

2.2 Product description

North Star is an intelligent marine navigation and sailing system that uses GNSS, computer vision and advanced Machine Learning (ML) algorithms to perform

inferences to obtain the safest routes for marine navigation in case of GNSS signal loss. The system is particularly aimed to be used by small marine vessels that are not equipped to navigate in difficult zones of the Arctic, with limited access to GNSS and satellite telecommunication. The system consists of a combination of a central hardware unit, optical sensors, ground communication relay as well as an operating software with state-of-the-art ML algorithms capable of performing near real-time data-fusion and analysis to obtain the safest navigation paths. The data are obtained from the on-board sensors, the GNSS constellations and weather buoys if available. This allows the system to ensure a continuous safe navigation in difficult environments, thus in places where GNSS coverage is not optimal or temporarily lost. Moreover, North Star uses a mesh-like concept that allows the mapping of safe routes by communicating with other North Star units available in vessels nearby. The mesh cloud enables the sharing of information during assisted navigation and mapping remote areas during nominal navigation. The technology implemented in North Star and the details of its operation will be presented in Section 3.

2.3 Value proposition

The selected user profile of recreational charters would benefit from North Star because the AI unit is user friendly and requires minimal effort in its use. In this view, North Star could allow the user to extend the time of travel in the Arctic regions beyond the conventional sailing season (May to October), as long as the ice coverage is still acceptable. Note that the sailing experience of the user would determine the threshold for the ice coverage above which the designed route would be considered unsafe to navigate prior to departure.

Another interesting feature of North Star is its capability of integrating with the Galileo Open Service and Search and Rescue (SAR) [14] to minimise the response in rescue time during emergencies on sea. This is possible due to the mesh connectivity presented in Section 3.1. The SAR/Galileo service represents the contribution of Europe to the international COSPAS-SARSAT effort for search and rescue activities. SAR/Galileo improves localization of distress signals, covering regions up to 85° North latitude [14] with an accuracy reduced to less than 5 km.

Moreover, North Star can provide added value to the environmental cause, as reported in Section 5; not only by monitoring and balancing growing traffic through the maritime region, but also by identifying sensitive areas subjected to migratory routes or breeding sites.

2.4 Competitive landscape

The need for safer and optimal solutions for improving navigation in the Arctic led to efforts in developing alternative solutions and novel technologies.

Potential competitors of North Star provide solutions particularly focused on assisting maritime navigation in icy waters.

Table 1. Potential competitors for North Star.

Competitor	Technology	Application
Olex AS [15]	GPS and sonar	Seabed mapping; navigational aid
Stanford Engineering: Arctic Navigation and ION GNSS [16]	Dual frequency multiple constellation SBAS and ARAIM	Autonomous ice navigation; aircraft precision approach
U.S. Office of Naval Research/ U.S. Army [17]	Cosmic ray muons	Navigation at high latitudes with little or no GPS service
Drift and Noise Polar Services: IcySea [18]	Satellite image processing	Identification of sea ice and ice drifts for navigational aid

The identified competitors and their solutions are summarised in Table 1 and include:

- Olex AS [15]: Olex is a mapping system that uses GPS and sonar to collect depth data for subsea mapping. It is installed on ships and maps the seafloor for uncharted waters to register these data for future navigation. Olex also uses a meshing concept in which data can be shared among navigating ships.
- Stanford GPS Lab – Arctic Navigation and ION GNSS [16]: the research group at Stanford University proposes a solution for autonomous ice navigation in the Arctic based on dual frequency multiple constellation SBAS and Advanced Receiver Autonomous Integrity Monitoring (ARAIM). For this purpose, they propose the Quasi-Zenith Satellite System (QZSS) to fill the gap left in Geostationary Earth Orbits (GEO) with a constellation of three Highly Elliptical Orbits (HEO).
- U.S. Office of Naval Research (ONR) [17]: The ONR is researching a novel technology to assist navigation in areas where GPS does not work. The technology relies on cosmic ray muons as a natural source of radiation for geolocalization and can be used at high latitudes north of the Arctic Circle. The project is still in the research phase and, thus, limited information is available.
- Drift and Noise Polar services (IcySea) [18]: IcySea is a map-based application designed to

display and deliver ice relevant information for navigation purposes in the polar regions. The backend merges satellite imagery near real-time to model ice drift information. It also provides forecasts for future location of ice patches using ML techniques.

Compared to the competitors, North Star aims at providing a more comprehensive and easier to use system, capable of assisting small vessels to navigate safely and effectively in challenging regions in the Arctic, with less-than-optimal GNSS and communication coverage. The technical description of North Star is given in the next section.

3. North Star

North Star is conceived as an intelligent route navigation and sailing system consisting of a software/hardware combination with of a neural engine and on-board sensors and actuators. Fig. 2 summarises the system concept. The database contains real-time information about the sensors on board the vessel. The neural engine performs inference based on a training database containing historical data and imagery from the Copernicus Services [7]. It is currently planned to use a Convolutional Neural Network (CNN) for feature recognition like iceberg formation. The training of the CNN is done upon deciding with the customer which Arctic route is to be covered, at which time of the year and which imagery from Copernicus are suitable for the user case.

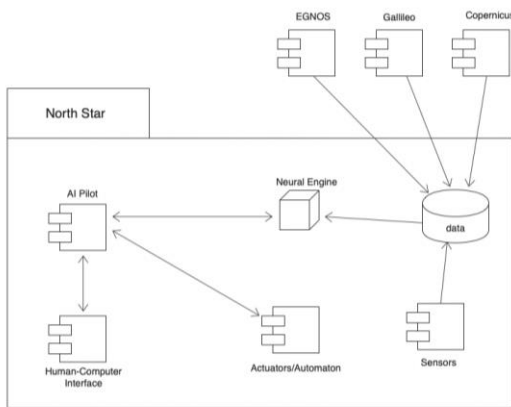


Fig. 2. North Star unit concept.

The AI Pilot is the central unit which would take over and predict the route within an allocated time during loss of GNSS signal. It is from this aggregated data that the maritime AI Pilot uses to solve the specific problem its vessel is having. A maritime pilot is conventionally described as a mariner who manoeuvres ships through dangerous or congested waters.

The AI Pilot relies on the neural engine and the on-board sensors to make a route prediction. A list of possible on-board sensors is provided in Fig. 3.

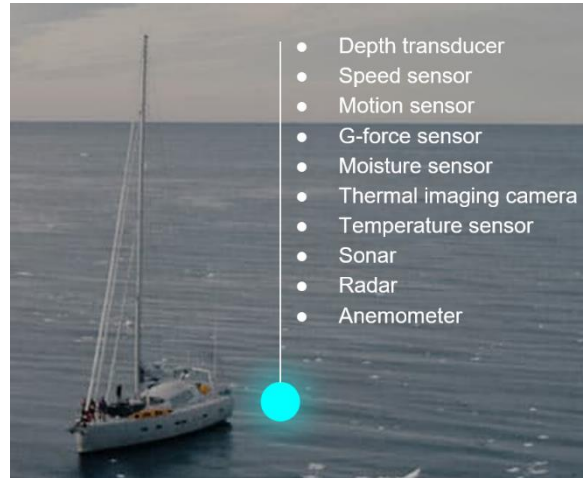


Fig. 3. Recommended on-board sensors.

Note that the AI Pilot is capable of receiving manual inputs from a human operator, based on observations on board and navigational experience of the crew, to correct the predicted route. The system concept is therefore seen as an automated system which might require inputs from an operator for optimization of the route prediction. In addition to the sensor fusion on board, North Star is transforming the vessel into a rover, as explained in the next paragraph.

3.1 The mesh cloud

A rover is a GNSS receiver capable of collecting and transmitting data. Any vehicle, vessel, or person that carries this receiver switched on, is by extension, a rover. Among many of its important applications it includes measuring terrestrial surfaces both on land and on water. Its margin of error is known to be around 3 cm horizontal and 3 cm vertical [19].

The concept of North Star is simple. Each vessel entering within the communication range of other North Star vessels becomes a participant in the mesh network. The communication range can be extended or expanded by dynamically appointing other rovers to play the role of a repeater (bucket brigade); or automatically switching different communication types when deemed appropriate. For example, when the vessel is near the coast, it uses ITS-5G network to communicate with Continuously Operating Reference Stations (CORS) or other land-based base stations, while at the same time it uses Long Range (LoRa) technology to communicate with other vessels far out in the ocean (out of range of ITS-5G network). Simultaneously, it throttles the amount of data it transmits or receives from other nodes commensurate with their bandwidth capacity.

Fig. 4 gives an idea about the distribution of rovers on sea (red dots) and their communication mesh (white lines). Within the network mesh, vessels receiving the

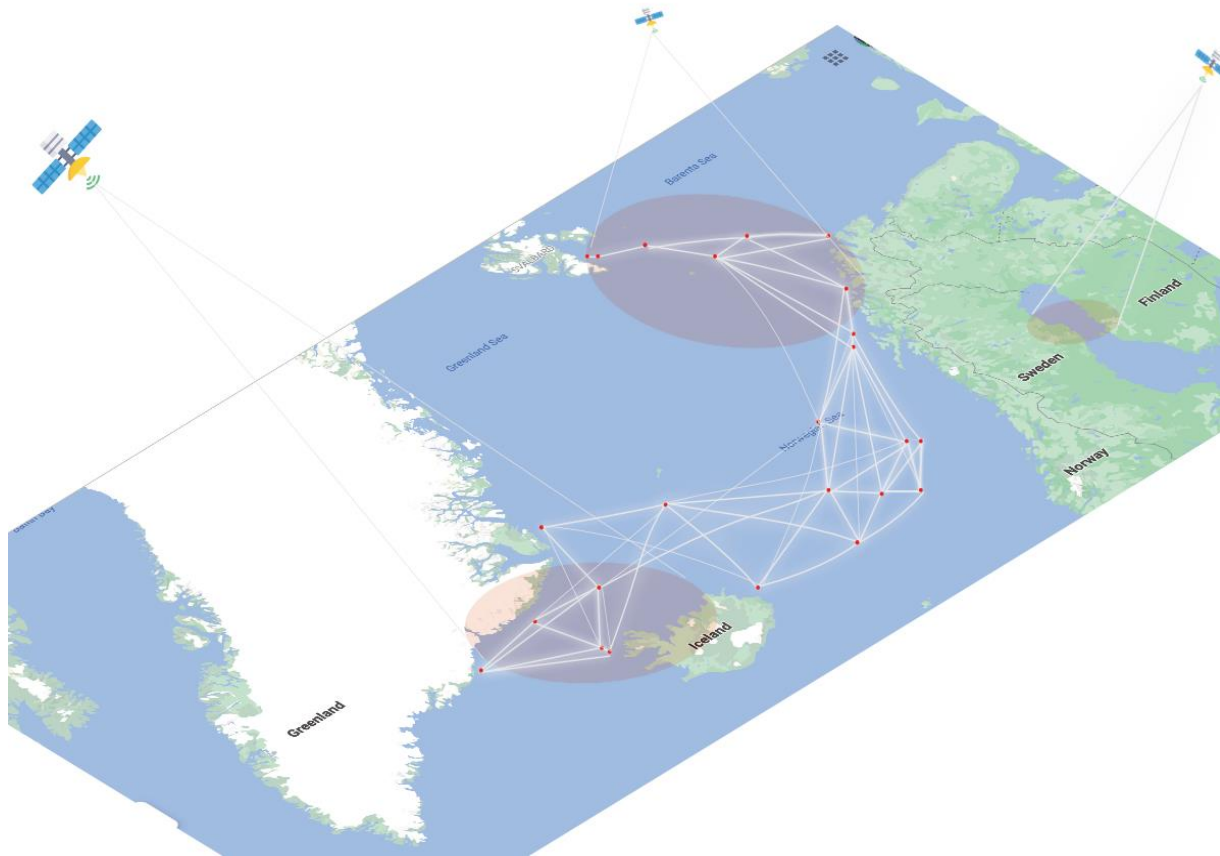


Fig.4. Mesh connectivity of North Star. Red dots: vessels carrying North Star. White lines: communication links.

GNSS signal from satellites can transmit to neighbouring vessels that lost GNSS connectivity.

The ultimate vision of North Star foresees hundreds of rovers strewn around in the Arctic Sea, receiving data from satellites, CORS, weather buoys, and other North Star vessels; in turn transmitting their own collected data. North Star leverages the network effect to improve all aspects of its utility. As more and more North Star vessels participate in the mesh, their collective data become more robust and more accurate.

3.2 The training database

Taking inspiration from the 2nd CASSINI Hackathon promoted by the European Commission, the authors found it convenient to use the Copernicus Services [7] for North Star, where most of the data is made available and accessible to any citizen and any organisation worldwide on a free basis and using cloud services. The use of a cloud-based service is necessary because the satellite constellation of Copernicus can collect about 16 terabytes of EO data per day [7].

Copernicus data are accessed via Data and Information Access Services (DIAS), cloud-based platforms funded by the European Commission. The DIAS selected for North Star is WEKEO which contains

environmental data, virtual processing environments and user support [20]. Note that WEKEO is only one possibility of five DIAS to access Copernicus data. All DIAS provide access to Copernicus Sentinel data as well as to the six operational services of Copernicus covering the areas of air quality, ice monitoring, farming, climate change, floods and surveillance. HDI APIs were used by the authors to access specific Copernicus data in Python. WEKEO allows users to select and download specific areas of the Arctic, based on the user request.

The following data can be potentially used for North Star:

- Historical data from Sentinel-1 since 2014 based on synthetic aperture radar imaging: weather, day/night applications
- Historical data from Sentinel-3 since 2017 for ocean monitoring
- Copernicus Marine Service (CMEMS): Arctic Ocean physics, sea ice, ocean waves and tides, ice charts.

Sentinel-1 is frequently used for sea ice mapping, iceberg detection, and vessel detection. Adding images from different years to the training database would allow North Star to learn the possible changes in sea ice coverage. The

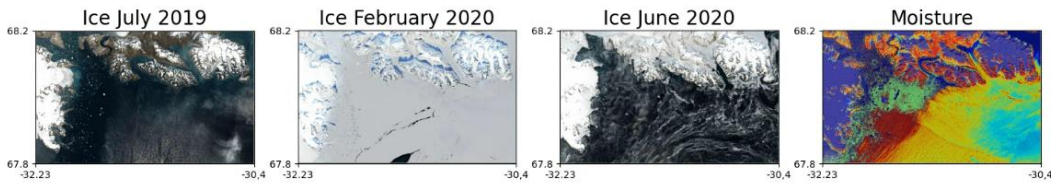


Fig.5. Example of extracted historical images from the WEkEO database for ice coverage and moisture and useful to train the CNN.

within-year time series can be used for tracking sea ice drift, icebergs and vessels in the region instead. CMEMS provides near-real-time in-situ data for ice in the Arctic, such as ice thickness, ice type (pack ice or iceberg), ice coverage, ice drift. An example of historical images extracted from the WEkEO database and useful for training the CNN is shown in Fig. 5.

Note that the training database of North Star can be extended to cover weather prediction and environment monitoring. Data from the Copernicus Atmosphere Monitoring Service can be useful to predict recurring weather events in specific areas. The Copernicus Climate Change Service would help to monitor the environment instead.

3.3 The technology

Although North Star is in a concept phase, several high-level requirements on the technology involved can be already identified.

North Star shall have multi-band frequency receivers. GLONASS can be used for initial calibration as it

extends to higher latitudes and the system can switch to an assisted mode to increase accuracy, thus including GPS or Galileo as additional aids [4].

The use of sensor fusion on board (see Fig. 3) requires a robust sensor fusion algorithm. Situational awareness sensors would help to identify collision avoidance manoeuvres. OpenCV (Open Source Computer Vision Library) can be used for video and images analysis on board, thus it is aimed at real-time computer vision. Potential inputs on board could be proximity detection sensors as well as submerged large objects detectors. A 360° camera on the vessel mast would ensure complete visibility of the vessel's geofence if the weather conditions allow it. A front camera combined with a LiDAR would help navigation also during adverse weather conditions (e.g., fog) and at night. OpenCV could be potentially used to detect emergencies like man overboard, if trained for facial and gesture recognition.

The use of Internet of Things (IoT) devices on board allows to combine GNSS and EO information. IoT also supports the creation of the mesh cloud among vessels. Wireless mesh networks work with different wireless technologies including 802.11, 802.15 and 802.16

cellular technologies and do not need to be restricted to a single protocol.

Finally, no AIS tracking system would be required on board.

3.4 The scenario

Zero visibility and atmospheric disturbance interferes with the ability of receiving satellite signals. This is the main scenario where the AI Pilot would take over. It synthesises all the data it received so far from the satellites, with the data collected from the on-board sensors, to project a safe route for the next 2NM with a high degree of safety. Fig. 6 shows the simplified algorithm for this scenario.

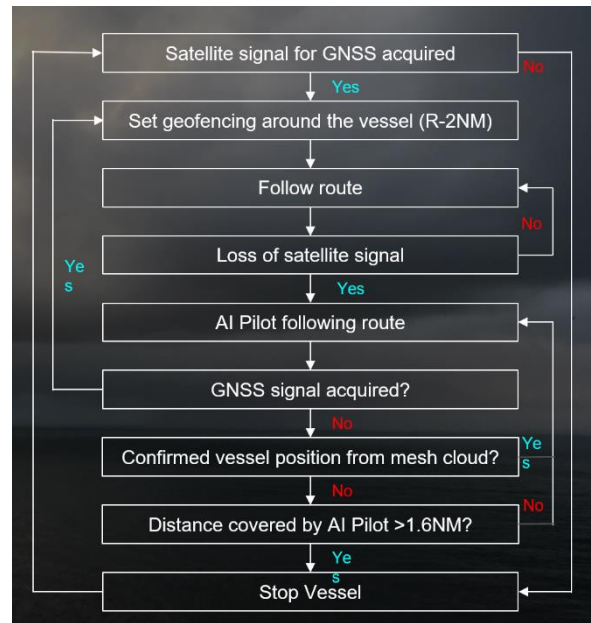


Fig. 6. GNSS loss – AI Pilot simplified algorithm.

Note that the geofencing radius around the vessel is set to 2NM, but the total distance covered by the AI Pilot during signal loss is stopped after 1.6NM. This is a safety factor given by the authors and will be reassessed in the next phases of the project to be more accurate. A vessel speed of 6-7 knots is assumed, which is typical for a catamaran or a monohull (instead of 20 knots for commercial ships). For the selected geofencing the AI

Pilot will be active for a time window of maximum 13-15 minutes by keeping this speed. If GNSS signal is re-established within this time frame, the AI Pilot stops the predictions and reverts to GNSS navigation.

When the mesh cloud will be extended to include more users, it is likely that the geofence radius will be increased, thus increasing the time that the AI Pilot can cover without GNSS signal. This will be possible because more rovers will be available in the mesh.

Fig. 7 provides a qualitative idea of where this scenario would likely occur in the European Arctic region, especially at the beginning when the mesh cloud of North Star is not dense. The regions marked as black are in open sea and not necessarily covering common shipping routes. This could be the satellite coverage map available to the recreation vessel before departure. The aim of the AI Pilot during loss of satellite coverage would be mapping the predicted route within the black regions, as indicatively shown by the blue corridors. The denser the mesh cloud will become, the easier it will be for the vessel to map the black areas.



Fig. 7. Arctic region north of Scandinavia. Black zones: areas with low GNSS coverage and not yet mapped by the AI Pilot.

4. Business model

This section provides a high-level assessment of the potential business model for North Star. As the project is still in a conceptual phase, the general overview for the business development will be subject to further updates as the project develops.

4.1 Target market

The services provided by North Star for intelligent navigation and improving positional accuracy can be used across several sectors in maritime navigation. However, it is particularly useful for navigating in challenging environments such as that of the Arctic, and specifically for small and medium sized vessels that do not have access to expensive enterprise-grade alternatives.

To this end, the primary target market for North Star is providing Arctic navigation services to cruise tourism vessels or adventure sailing. Secondary markets that can be served by North Star include fisheries as well as exploration and research vessels. Rough estimations of the market size have been provided in Section 2.1 with an estimated market growing from 167 to 270 million USD by the end of the decade for this specific portion (Arctic navigation).

4.2 Differentiating factors

North Star relies on existing and proven technologies as well as EO data that are publicly and freely available via the Copernicus and Galileo constellations. The communication and imaging technologies deployed as well as the hardware components are off-the-shelf technologies (COTS) that are ubiquitous, relatively easy to install and use. Moreover, North Star offering extends beyond that of the existing solutions in the range of services it can provide.

North Star greatest advantages over existing solutions are:

- **Offering:** North Star services range from intelligent navigation; mapping of uncharted waters; capability of integrating with the Galileo Open Service and Search and Rescue Service; and identification of sensitive environmental regions subject to environmental protection.
- **Affordability:** as North Star relies on mature technologies, COTS hardware, and open-source data, pricing of the services can be adapted to accommodate different customer profiles and needs. This guarantees that every customer can select a solution that fits their technical requirements and budgetary constraints.
- **Simplicity:** the reliance on common, market-ready technologies both in hardware and software, and a focus on user experience offers users a guaranteed level of reliability and ease-of-use.

4.3 Pilot funding and revenue model

Pilot funding will allow the development of the first prototype and pilot testing of North Star, to validate its capabilities and perform any calibrations needed in the real operations. This first funding is projected to be obtained via European grants and start-up support like the Copernicus Marine service (CMEMS) User Uptake program and ESA Business Incubation grants.

Obtaining pilot funding via these grants would allow providing the solution free of charge for the test customers and kick-starting the meshing network needed for the project to provide its full operational services. Subsequent to the testing and validation phase, North Star generates revenue through the leasing of the hardware component (e.g., ITS-5G module, multi-

frequency GNSS receiver) and a combination of a freemium and subscription model for key software functionalities and technical support.

Basic software and technical services (e.g., OpenCV libraries, personalised user interfaces, personalised CNN training based on route, device installation and on-board validation) will be provided free of charge with the possibility for the user to opt for paid services to unlock advanced features (e.g., extended coverage maps, connectivity to Galileo Search and Rescue Service, environment monitoring, real-time customer service with possibility of resetting the system remotely).

The leasing and subscription model is expected to be most suitable for North Star customers since their needs may be seasonal, therefore, allowing the flexibility and encouraging them to try and test the service without a high barrier to entry. In addition, since North Star's business model consists of a network component, ensuring early adoption of the solution via flexible offering provides value for other users and incentive to adopt the service.

4.4 Key milestones

A preliminary road map leading to the technical development of North Star is proposed based on the following key milestones:

- Prototype tested on ground by 2023
- Beta-release of software and testing on research vessels by 2024
- First device sold by 2025
- Minimum mesh coverage reached by mid-2026

This is just an indicative timeline and further assessment has to be performed when moving from the current phase (concept) to the next phase (system design), where the choice of the technologies providers is made. The development will follow an agile approach to reach a Minimum Viable Product in the short term (end of 2023) and within 80% of the allocated budget.

5. The environmental cause

The customer value of North Star aims to support the environmental cause as well. The increasing traffic expected in the Arctic routes could have detrimental effects in the Polar region. Traffic on the Northern routes for commercial shipping will increase due to decreasing ice coverage. Since the Arctic contains rich natural resources, the exploitation of tourism and the Arctic passage could cause environmental catastrophes.

The vessel category targeted by North Star is usually not covered by existing maritime regulations for commercial activities. The Polar Code [21] for example is a regulation for navigation in the Polar waters which is mandatory for certain ships under the SOLAS and MARPOL conventions. The SOLAS Chapter V (Safety of navigation) applies to all ships on all voyages with some specific exceptions, while the other chapters do not

apply to some categories of ships, including cargo ships of less than 500 gross tonnage; pleasure yachts not engaged in trade; and fishing vessels (sometimes termed as "non-SOLAS ships"). This means that recreational vessels targeted by North Star are not bound to these regulations. The Polar Code also does not apply to the region between Scandinavia and Iceland, the main access point from vessels from Europe. The integration of the AI Pilot on tourist vessels and the creation of the mesh would allow to support the authorities for the detection of

- illegal oil discharge
- oil spillage accidents
- discharge of waste, plastics, animal carcasses
- noxious Liquid Substances (NLS) or mixtures containing NLS.

In addition, North Star aims to support the achievement of several United Nations Sustainable Development Goals (SDG), such as by actively participating in the climate action, or by monitoring waters and life underneath.

Finally, North Star can support existing projects in the EU, such as project EU FP7 ICE-ARC [22] investigating the rapid retreat and collapse of Arctic sea-ice cover, or project Automated Sea Ice Products (ASIP) [23] which merges Copernicus Sentinel-1 imagery with other satellite sensor data for timely ice-mapping formation.

6. Conclusions

This work proposes a solution for enabling safe navigation in Arctic waters which is targeted to small vessels for tourist activities and operators experienced in navigating in open waters.

The market of marine navigation aid and information system in the Arctic Ocean has an estimated size of 167 USD which is predicted to grow to 270 million USD by the end of the decade, incentivised by the continued reduction in ice coverage, increased overall shipping activities in the Arctic, and the need for intelligent and reliable navigation tools. Although commercial shipping has the major share of activities in the Arctic, smaller vessels are frequently used by private tourism, fisheries and research activities. Nonetheless, the navigation in Arctic waters is challenging due to, for example, strong electromagnetic interference, adverse weather conditions and poor satellite coverage. While commercial ships can rely on additional navigation aids, the choice is more limited for recreational charters.

The product presented in this work, North Star, consists of an AI unit which integrates information in real-time from on-board sensors, GNSS signals and EO imagery from selected Copernicus Services (e.g., the WEKEO DIAS). The AI unit navigates the vessel in case of loss of GNSS signal, it is user friendly and allows manual inputs from the operator to optimise the route prediction. The vessels act as rovers and can

communicate within a mesh cloud made of nearby vessels provided with North Star units. The North Star mesh is compatible with the Galileo Search and Rescue Service to support emergency operations. Overall, North Star offers advantages compared to the identified competitors.

The initial business model for North Star is based on offering, affordability and simplicity of the product. Pilot funding would allow the development of the first prototype and testing of the product, and to provide a solution free of charge for the test customers and early adopters. Consolidated technologies shall be included for the communication devices, the training of the neural network and the sensor fusion analysis when developing the product. Leasing and subscription are selected as a suitable option to generate revenue at a later stage.

North Star also supports the environmental cause in helping the authorities to monitor and detect discharge of waste or liquids in Arctic waters, which can lead to detrimental effects over time. The information collected can be also accessed for environmental monitoring, for example for bird or fish migration.

Acknowledgements

North Star as a product and its business case was initiated by A.K.C., A.V. and P.B. during the 2nd CASSINI Hackathon in November 2021 and further advised by A.A. in 2022. The authors would like to acknowledge the initiative of the European Commission's Competitive Space Start-ups for Innovation Initiative (CASSINI), and the organizers of the 2nd CASSINI Hackathon for providing context for the conception of North Star.

References

- [1] Shipping in the Arctic, German Arctic Office, August 2019.
- [2] Tourism in Polar Regions, German Arctic Office, April 2021.
- [3] L. Leppala, S. Honkala, G. Ferrara, M. Kirkko-Jaakkola, H. Kuusniemi, H. Miettinen-Bellevergue, Challenges in Arctic Navigation: the User Perspective, European Navigation Conference (ENC), 2019.
- [4] A. Yastrebova, M. Höyhty, S. Boumard, E. S. Lohan A. Ometov, Positioning in the Arctic Region: State-of-the-Art and Future Perspectives, IEEE Access 9 (2021) 53964-53978.
- [5] A. Grant, P. Williams, G. Shaw, M. De Voy, N. Ward, Understanding GNSS availability and how it impacts maritime safety, Proc. Int. Tech. Meeting Inst. Navigat. (2011), 687695.
- [6] Satellite Automatic Identification System (SAT-AIS) Available: <https://artes.esa.int/sat-ais/overview> (accessed 31.08.22).
- [7] Copernicus Service, <https://www.copernicus.eu/en> (accessed 31.08.22).

- [8] Arctic: Transport & Environment, <https://www.transportenvironment.org/challenges/ships/arctic/> (accessed 31.08.22).
- [9] J. Babin, F. Lasserre, P. Pic, Arctic shipping and polar seaways. Encyclopedia of water: science, technology, and society, 2020.
- [10] News CI. Expedition Market Report: Cruise Lines International Association. 2018, http://www.cruising.org/press/overview%202006/ind_overview.cfm (accessed 31.08.22).
- [11] Opportunities for fisheries as the Arctic ice melts. EUROFISH Magazine 6/2020, <https://eurofishmagazine.com/sections/fisheries/item/674-opportunities-for-fisheries-as-the-arctic-ice-melts> (accessed 31.08.22).
- [12] Global Marine Navigation System Market Research Report - Sample. Market Research Future®, <https://www.marketresearchfuture.com/reports/marine-navigation-systems-market-4890> (accessed 31.08.22).
- [13] Maritime Information Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027. IMARC, <https://www.imarcgroup.com/maritime-information-market> (accessed 31.08.22).
- [14] Galileo Search and Rescue Service, https://gssc.esa.int/navipedia/index.php/Galileo_Search_and_Rescue_Service (accessed 31.08.22).
- [15] Olex, https://olex.no/index/fishing_en.html (accessed 31.08.22).
- [16] T. Reid, T. Walter, J. Blanch, P. Enge, GNSS Integrity in the Arctic, Journal of the Institute of Navigation, 63(4), 469-492, 2016.
- [17] F. Reisch, How Science is finding ways to navigate in GPS-denied Environments. Office of Naval Research Global <https://www.nre.navy.mil/organization/onr-global/news-releases/How%20Science%20is%20Finding%20Ways%20to%20Navigate%20in%20GPS-Denied%20Environments> (accessed 31.08.2022).
- [18] IcySea, <https://driftnoise.com/icysea.html> (accessed 31.08.2022).
- [19] Rovers, <https://www.forconstructionpros.com/equipment-management/article/21049278/how-gps-rovers-improve-construction-project-management> (accessed 31.08.22).
- [20] WEkEO, <https://www.wekeo.eu/> (accessed 31.08.22).
- [21] The Polar Code <https://www.imo.org/en/OurWork/Safety/Pages/polar-code.aspx#:~:text=The%20International%20code%20of%20safely,waters%20surrounding%20the%20two%20poles> (accessed 31.08.22).
- [22] Ice, Climate, Economics – Arctic Research on Change, <https://www.ice-arc.eu/> (accessed 31.08.22).
- [23] Automated Sea Ice Products Project, https://www.esa.int/Applications/Observing_the_Earth/Using_artificial_intelligence_to_automate_sea-ice_charting (accessed 31.08.22).