NAVISP-EL1-004

MSMSPNT
MULTI-SYSTEM MULTI-SENSOR MARITIME PNT TEST PLATFORM

Final Presentation

06/02/2023

INNOVATING SOLUTIONS

Meeting Agenda

- Introduction
- WP overview
- Summary of the deliverables
- Maritime PNT requirements and standards review
- Algorithms design and implementation
- MSMSPNT testing and validation
- Conclusions and suggestions
- Questions

Introduction

NAVISP-EL1-004, "Multi-System Multi-Sensor Maritime PNT Test Equipment

- The key objectives of **MSMSPNT** are to
  - Study methods and techniques for the combined use of multiple systems and sensors in maritime PNT receivers to characterise achievable classes of performance;
  - Implement an experimental platform for a multi-system multi-sensor maritime PNT receiver testing the combination of methods and techniques studied.
- Inline with the International Maritime Organisation's (IMO) guidelines that define a high-level framework for the processing and combination of data of multiple systems and sensors
- The contract was awarded to Nottingham Scientific Ltd (NSL) at the beginning of 2018
- Kongsberg Seatex AS are a project partner, subcontracted to NSL

5 years on, what has happened?

There have been a number of significant events ....

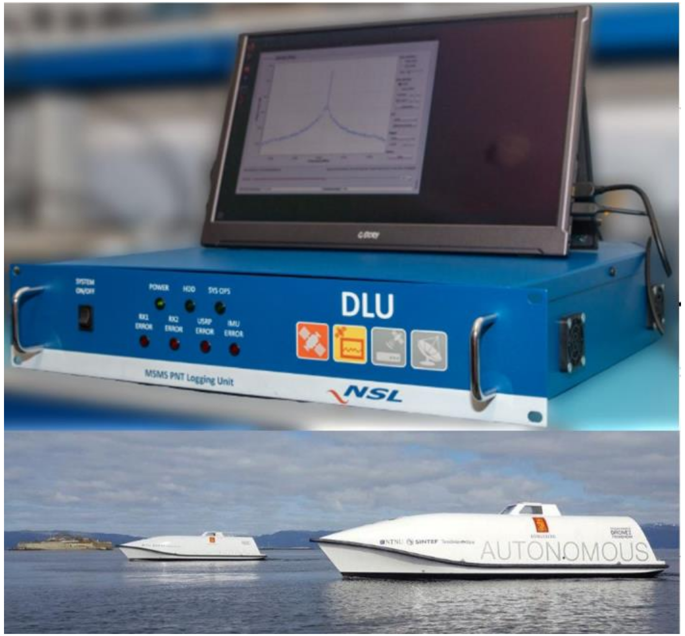
- Change in GMV (NSL) Technical Lead
  - Jiachen Yin, assisted by Tom Stacey
- Change in the ESA Technical Officer
  - Jose Vicente Perello Gisbert
- Covid and lockdown
  - Particularly affected work that required work/lab environment
- GMV acquired NSL and merged GMV with their existing UK company
- GMV office move

- The project has taken a long time and GMV would like to thank ESA for their continued support of the work

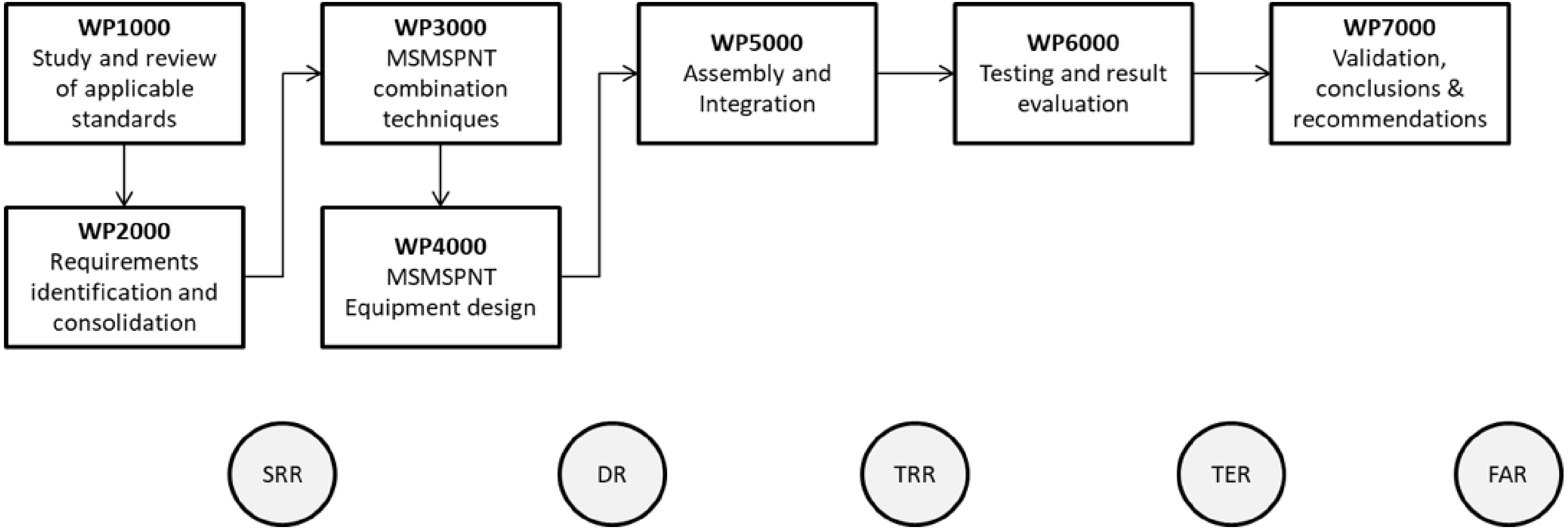
Key achievements of Project

MSMSPNT has created:

- A fully configurable software integrated hardware test platform for maritime PNT applications along with a comprehensive set of maritime field data for testing and future research.
  - A fully configurable software based GNSS receiver,
  - A positioning engine supporting augmentation and additional sensor data fusion,
  - An extendable data logging unit for the field collection of GNSS RF alongside additional navigation sensor.
  - GNSS and sensor data collected in a maritime environment which has been used to test the system.



Work Package Overview



Summary Delivery Status

WP summary and deliverables

WP 1000

- Study and review the applicable standard and evaluate the combination methods and techniques.
  - *D1 Standard Review (GMV, KONGSBERG)*

WP 2000

- Requirement Revision.
  - *D2 MSMSPNT Requirements (GMV, KONGSBERG)*

WP 3000

- Study and trade off multisensor combination techniques used in maritime PNT.
  - *D3 MSMSPNT techniques (GMV)*

WP 4000

- MSMSPNT test equipment design and justify the architecture of the functions.
  - *D4 Equipment design document (GMV)*
  - *D5 Assembly and Integration plan (GMV)*
  - *D6 Statement of Compliance against requirements(GMV)*

Summary Delivery Status

WP summary and deliverables

WP 5000

- Manufacture the MSMSPNT test equipment.
  - *D7 User Manual (GMV)*
  - *D8Test Procedure and Report on Dry run(GMV)*

WP 6000

- Verify the test equipment and combination technique in laboratory environment and design validation plan.
  - *D9 Test Report (GMV)*
  - *D10Validation Plan (GMV, KONGSBERG)*

WP 7000

- Updated the design document and perform validation test and derive conclusion and recommendation according to the validation test campaign.
  - *D4Updated Design Document (GMV)*
  - *D11Conclusion and Recommendation (GMV)*
  - *D12Validation Report (GMV)*

MARITIME requirements and standards review

IMO Standards

IMO Resolution A.915

- The IMO Resolution A.915(22) describes the “Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)” and was adopted on 29 November 2001

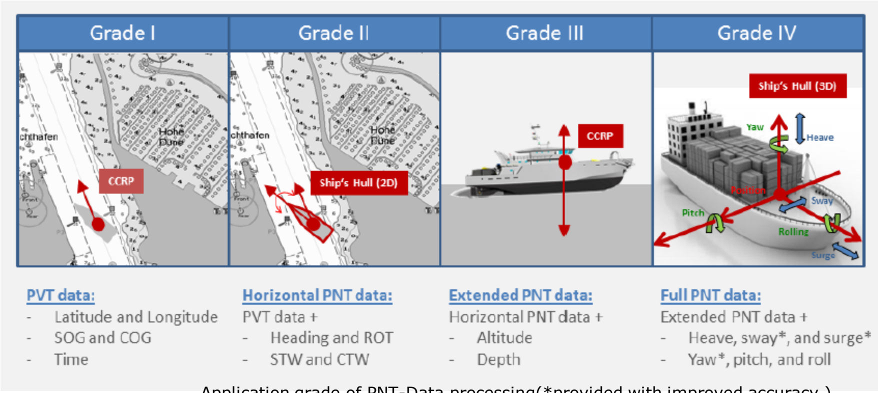
	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval (s)
	Horizontal (metres)	Alert limit (metres)	Time to alarm[2] (s)	Integrity risk (per 3 hour)				
Ocean	10 (100)[1]	25	10	10^{-5}	99.8	N/A	Global	1
Coastal	10	25	10	10^{-5}	99.8 (99.5)	N/A (99.85)	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8 (99.8)	99.97 (99.97)	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

[1] Figures in brackets refer to operational requirements according to Res. A.953

IMO Standards

IMO resolution MSC.401(95)

- **The guidelines define four application grades that are used to specify the different requirements for PNT**



Application grade of PNT-Data processing(*provided with improved accuracy)

1. Grade I supports the description of position and movement of a single onboard point
2. Grade II ensures that horizontal attitude and movement of ship's hull are unambiguously described
3. Grade III provides additional information for vertical position of signal onbord point and depth
4. Grave IV is prepared for the extened need on PNT data

MSMSPNT Algorithms and Implementation

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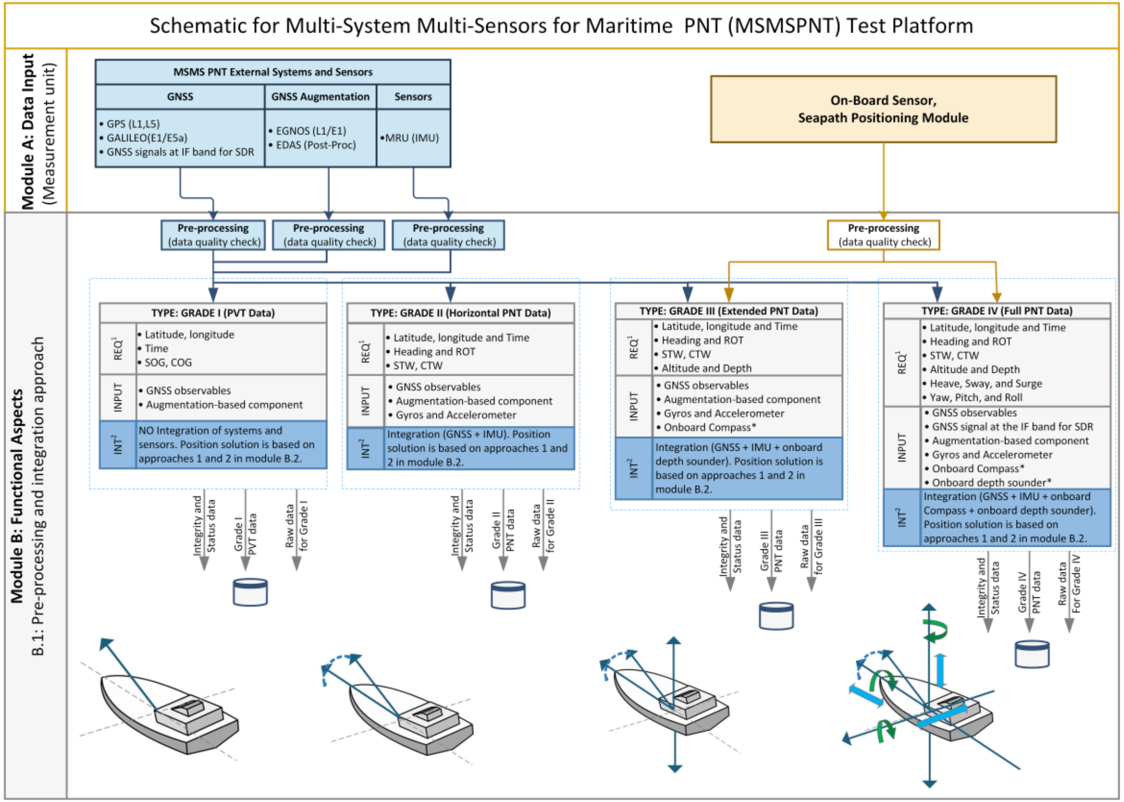
Schematic Design

High level of MSMSPNT design

- **External System and sensor**
  - GNSS (Multi constellation and multi frequency)
  - *COTS and RF signal for SDR*
  - GNSS augmentation
  - Inertial sensor (MRU)
- **On board sensor**
  - Seapath (Reference)
  - PPP solution via Inertial Explorer Novatel
- **Integration/combination scheme**
  - Loosely coupling (Extended Kalman filter)
- **Validation**
  - Laboratory
  - Field Trial



* These onboard sensors were not available during the field trials but the testbed is adaptable to incorporate them for future testing.

GNSS Receivers

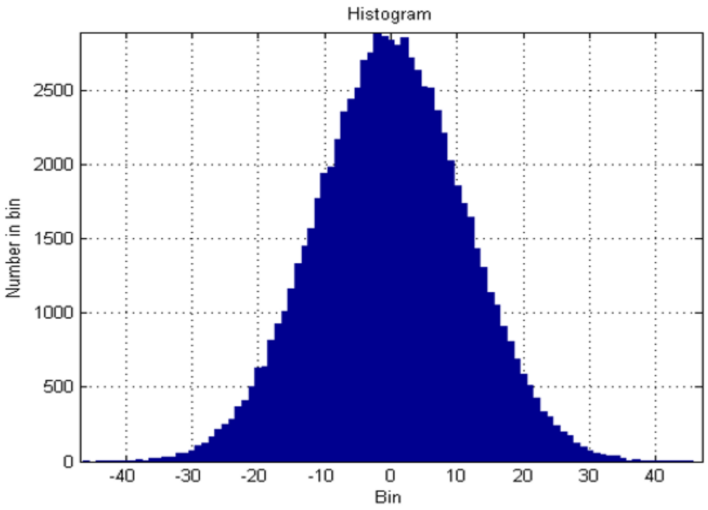
GNSS COTS and Software receiver

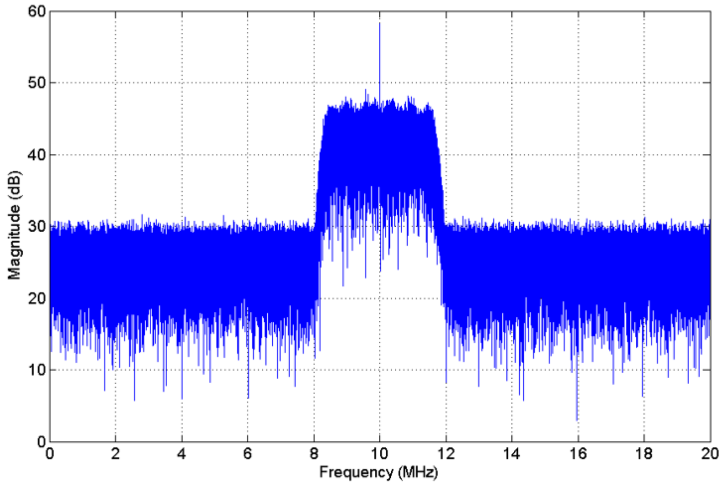
- **GNSS COTS receiver**
  Provide state of the art COTS GNSS for comparison/benchmarking
  Provide GNSS heading system
    - ➢ Septentrio PolaRx 5s GNSS receiver
    - ➢ Septentrio AsteRx 4 OEM GNSS receiver
- **GNSS software receiver (SoftRx)**
  Bespoke MSMSPNT solution for fully configurable receiver
    - ➢ MATLAB-based GNSS receiver
      - ❑GNSS signal processing acquisition, tracking and navigation message decoding
        - ❖ Dual frequency and Dual constellation (L1/E1b,L5/E5a)
        - ❖ RINEX file
      - ❑PVT estimation engine
        - ❖ Least mean square snapshot GNSS positioning
        - ❖ IMU sensor fusion (Extended Kalman filter for multisensor fusion)

GNSS Software Receiver (SoftRx)

GNSS Software receiver signal processing

- Maritime testing platform
  - MATLAB based post processing
  - GNSS raw data collected from RF front end , ADC, down conversion
  - Baseband or IF signal





GNSS Software Receiver (SoftRx)

GNSS Software receiver signal processing

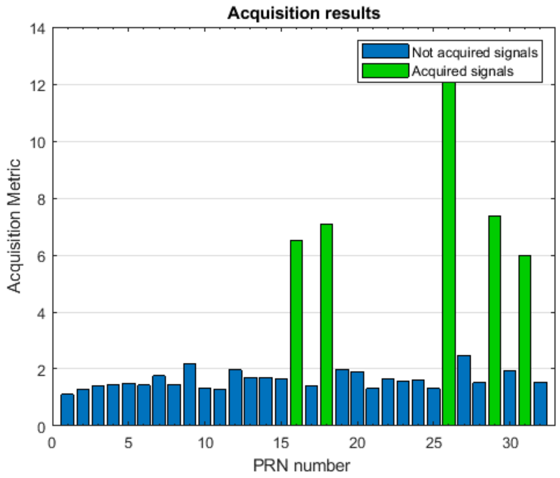
- Maritime testing platform
  - Developed in MATLAB and compiled into executable program
  - GPS L1/L5, Galileo E1b/E5a, EGNOS L1

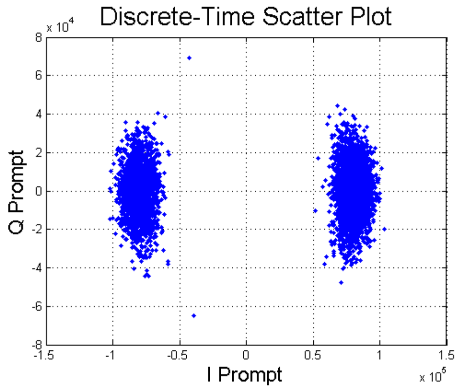
```
C:\Users\JIYI>cd Desktop

C:\Users\JIYI\Desktop>cd MSMSPNT_SDR_FINAL

C:\Users\JIYI\Desktop\MSMSPNT_SDR_FINAL>MSMSPNT_SDR.exe MSMSPNT_SDR_Configureation.cfg 1

GPS L1 Acquision and Tracking

 GMVNSL

[01 * * * * * * 08 * * * * * 14 * * * 18 * * * 22 * * * * * * * * * 32 ]
Run Tracking PRN8 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
Run Tracking PRN22 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
Run Tracking PRN18 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
Run Tracking PRN1 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
Run Tracking PRN32 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
Run Tracking PRN14 01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20
```

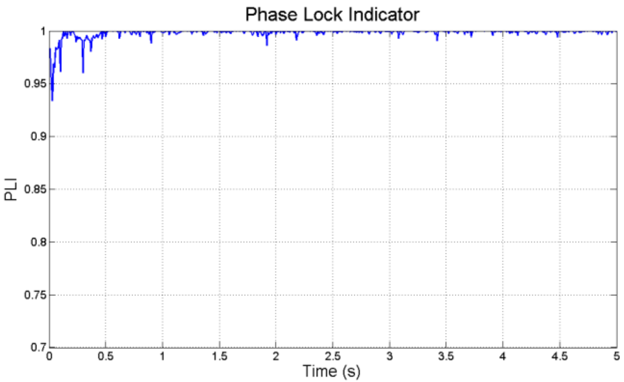
GNSS Software Receiver (SoftRx)

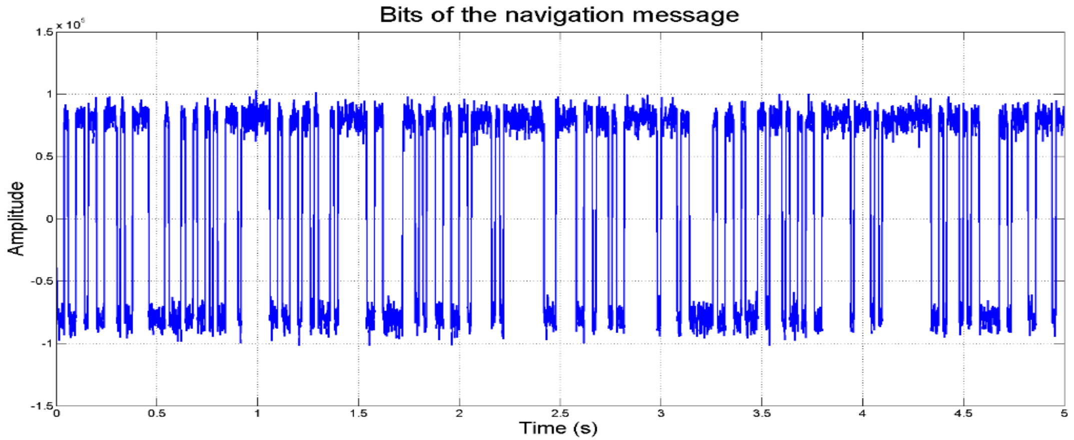
GNSS Software receiver signal processing

- Maritime testing platform
  - Post processing of captured RF
  - GNSS signal acquisition and tracking
  - Output RINEX Files





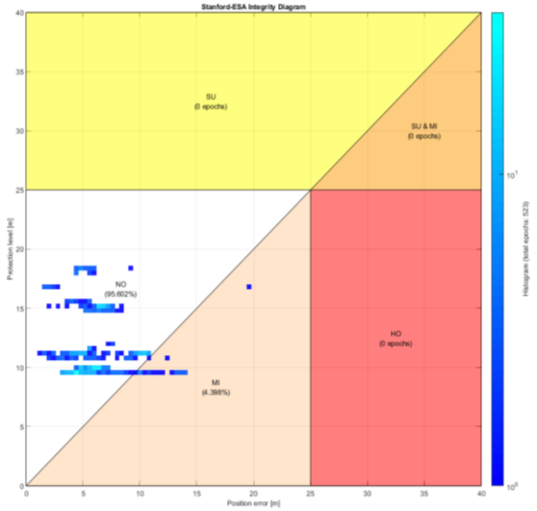


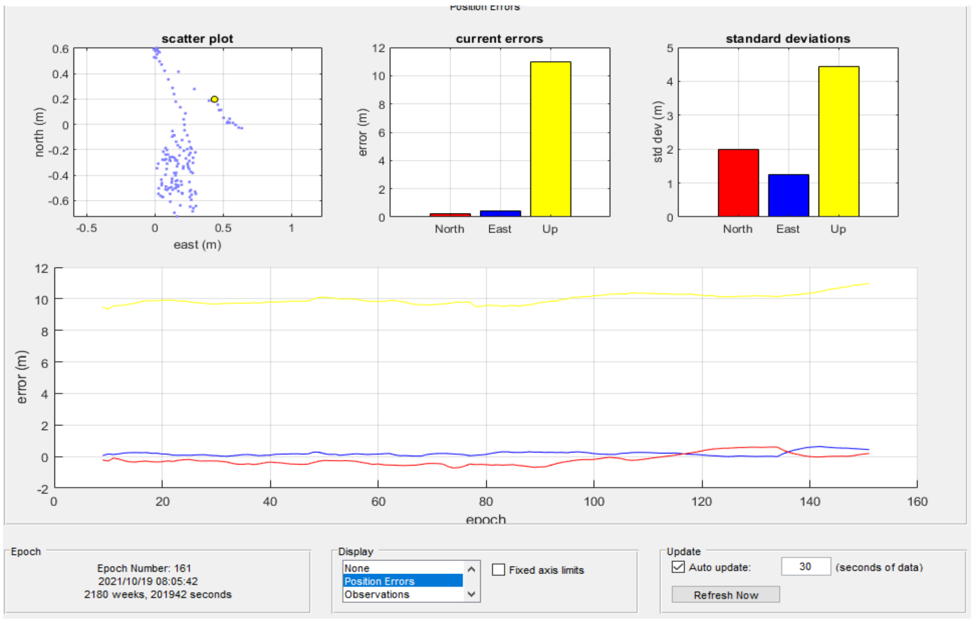


GNSS Software Receiver

GNSS Software receiver PVT estimation

- Least mean square based snapshot receiver
  - RINEX observation and navigation files from SoftRx or COTs as input
  - IMU measurement if multisensor fusion scheme enabled
  - Reference file available to process real time positioning error





Configurable Parameters

SoftRx

- Constellation and frequency band
- Sample frequency
- Bit depth
- Integration period
- Phase discrimination types
- Upsampling rate
- Navigation message updating rate

PVT Engine

- Constellation and frequency band
- IMU fusion enable/disable
- EGNOS enable/disable
- Precise obits information enable/disable (SP3 file)
- Smoothing
- Elevation angle mask

MSMSPNT Test Platform Design

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DLU (Data Logging Unit)

Technical Specification of MSMSPNT

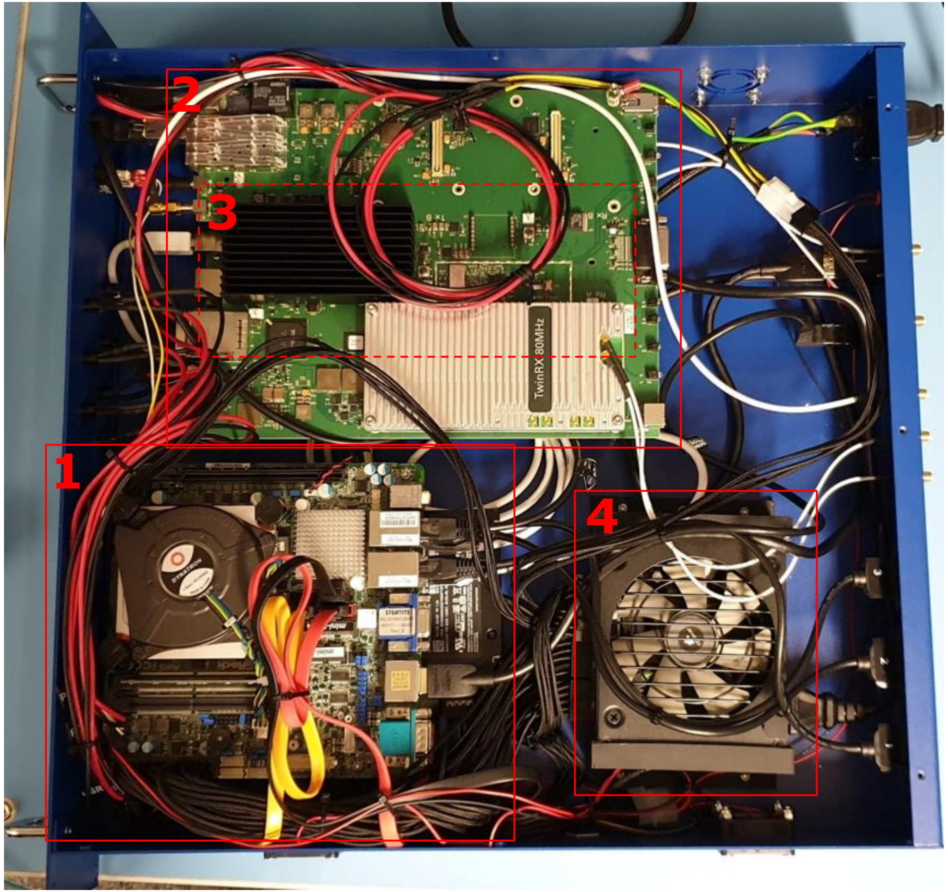
Specification of DLU:

- Front on/off switch and system indicators
- **Rear Panel:**
  - 3 USB 3.0 ports connected to the PC
    Future sensor connectivity
  - 5 SMA connectors:
    2 for the RF frontend RF channels
    1 for the RF frontend external clock sync
    2 for the AsteRx 4 RF channels
  - 1 Ethernet port for external communication to the PC
    Future sensor connectivity
  - 1 HDMI port for connectivity of an external monitor
  - 1 reset button in case the system crashes and needs rebooting
  - 1 fused power socket suitable for both UK and EU kettle leads

DLU

Technical Specification of DLU

1. IMB-194-L motherboard
2. USRP X310 with TwinRx daughterboards
3. Septentrio AsteRx 4 GNSS Receiver (installed beneath the USRP)
4. Corsair 600W Power Supply Unit

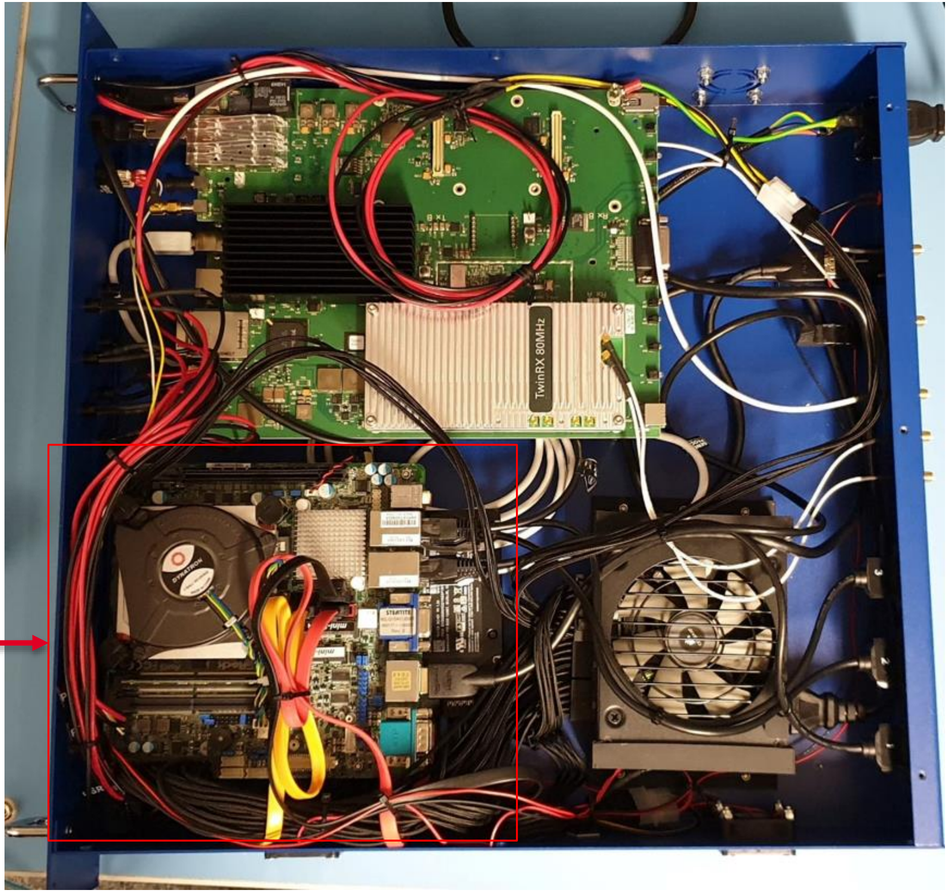


DLU

Technical Specification of MSMSPNT

Computer

- Intel Core i5 processor
- 8GB of RAM
- 4 USB 3.0 ports
- 2 Ethernet for speeds of 10/100/1000 Mbps
  - 1 connected to the RF frontend
  - 1 connected to the rear panel of the DLU for external interfacing
- 4 SATA3 ports supporting speeds of 6.0 Gb/s
  - 32GB SDD for operating system and low memory program
  - 1TB SDD for temporary data storage (SDD selected to avoid loss data packet from USRP
  - 4TB HDD for main data storage, and considered as field backup storage
- Linux Ubuntu 18.4 operating system

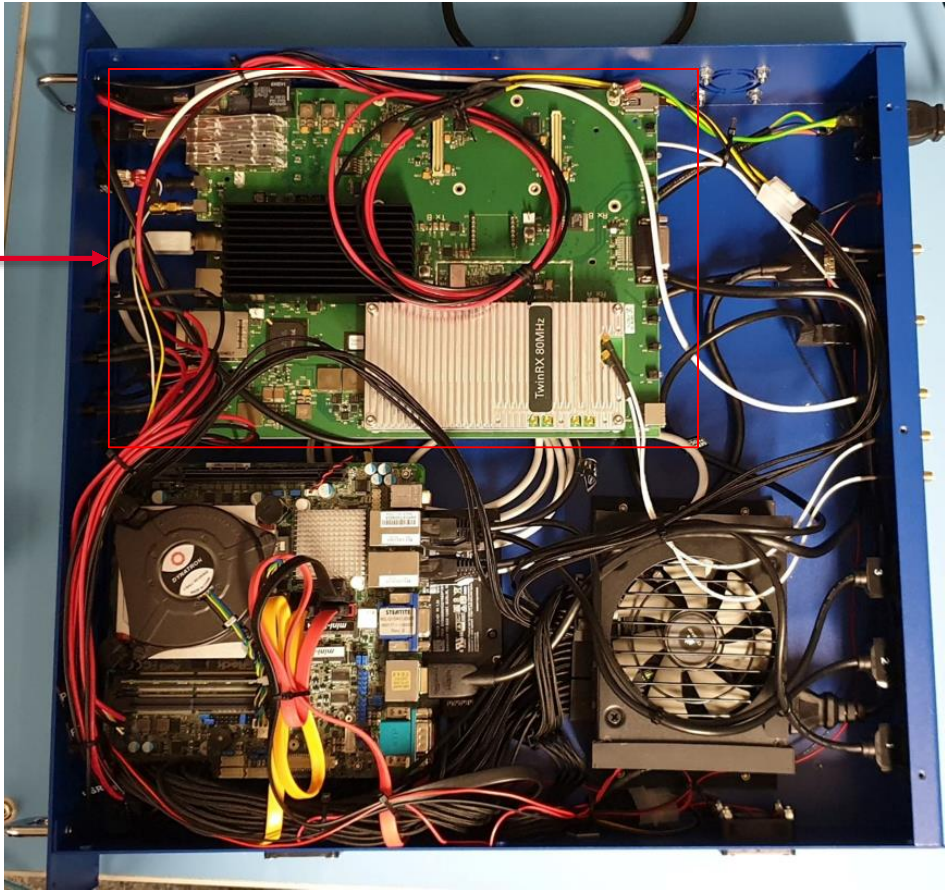


DLU

Technical Specification of DLU

GNSS RF Frontend

- USRP X310 with mounted twin receiver as daughterboard
  - TwinRx (two stage super-heterodyne with dual channel)
  - Central frequency range 10MHz to 6GHz;
  - GNSS frequency target L1/E1 and L5/E5;
  - Bandwidth up to 80MHz;
- Multiple high-speed interface option (PCIe, 10GigE, 1GigE)
- 10GigE applied (data rate 10 Gb/second)
- Larger user-programmable Xilinx Kintex-7410T FPG
- Clock-synchronization: external clock at 10MHz sine wave
- OPTIONAL FEATURE: The external GPIO connector for users to control external devices such as amplifiers, switches, event triggers and observe debug signals.



Additional Sensors

Septentrio PolaRx5S

Used for comparison and benchmarking of the SoftRx via standalone PVT and fusion with the MRU 5.

This device also provides a 10 MHz synchronisation signal to the RF frontend

MRU 5

Used for fusion with the SoftRx and COTS receiver

- Roll and pitch accuracy: 0.02°
- Data rate output: 200Hz
- Accelerometer scale factor: 0.02% RMS
- Gyro angular rate noise: 0.025% RMS
- Gyro scale factor: 0.08% RMS

MSMSPNT test and validation

Laboratory test

Field trial

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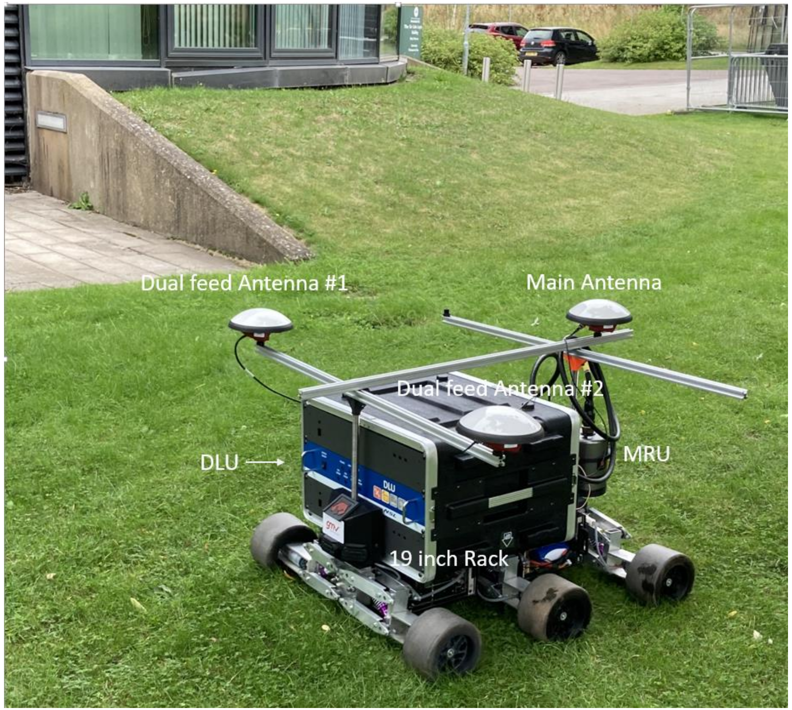
Laboratory test

Mobility platform test

- **Mobility platform test**

This test was used for initial performance analysis and benchmarking before deploying the equipment in the field

- **Testing features:**
  - GNSS/IMU fusion enable
  - Battery powered DLU and receiver
  - Post processing



Laboratory test

- **MSMSPNT maritime test platform functional test**
- **MSMSPNT maritime test platform performance test**
  - Comparing the software receiver against COTS receiver

Receiver types Items	Septentrio AsteRx 4 Receiver	Software Receiver (SoftRx)	Performance Ratios
Number of satellites 95%	16	13	0.8
Horizontal Error without aiding 95% (m)	5.6	11.7	2.1
Horizontal Error with SBAS correction 95% (m)	4.4	11.3	2.5
Horizontal positioning error with IMU fusion 95% (m)	4.5	11.1	2.4
Normal operational availability	99.6%	95.6%	0.96

These results showed confidence that the MSMSPNT testbed would perform suitably in the field trials and was ready to be deployed.

Field Trials

Testing location and schedule

- Trondheim fjord test range in Northern Norway has been designated as an official test bed for autonomous shipping by the Norwegian Coastal Authority (NCA), during a special event in Trondheim, Norway on Friday 30th September 2016.
- Trondheim fjord is the first coastal area in the world officially dedicated to the development of technology for autonomous ships

Data collection companion schedule

Tuesday 19th October 2021:

- Morning scenario - **open water** test.
- Afternoon scenario - **island loop** test.

Wednesday 20th October 2021:

- Morning scenario - **inland water morning** test.
- Afternoon scenario - **coast east afternoon** test.

Thursday 21st October 2021:

- Morning scenario - **coast west** test.
- Afternoon scenario - **inland water afternoon** test.

Friday 22nd October 2021:

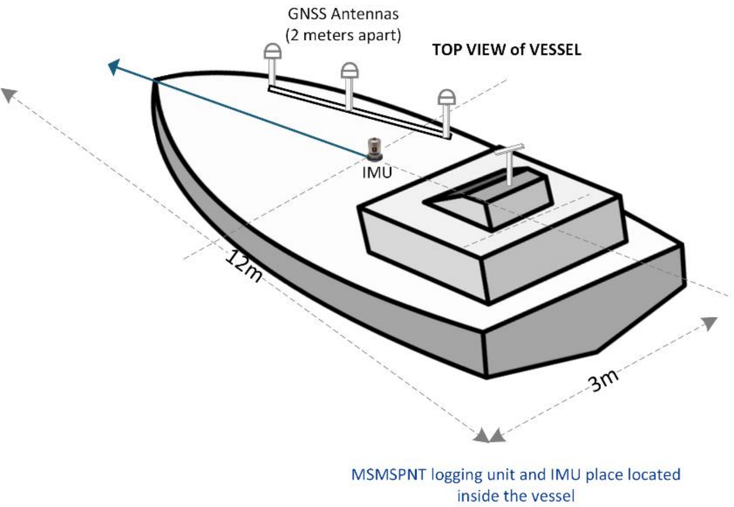
- Morning scenario - **coast east morning** test.

Field Trials

Equipment Setup

The image below shows Kongsberg’s vessel that was used in the field trials.

The antennas were installed on a fixed pole along the starboard side of the vessel.



Field Trials

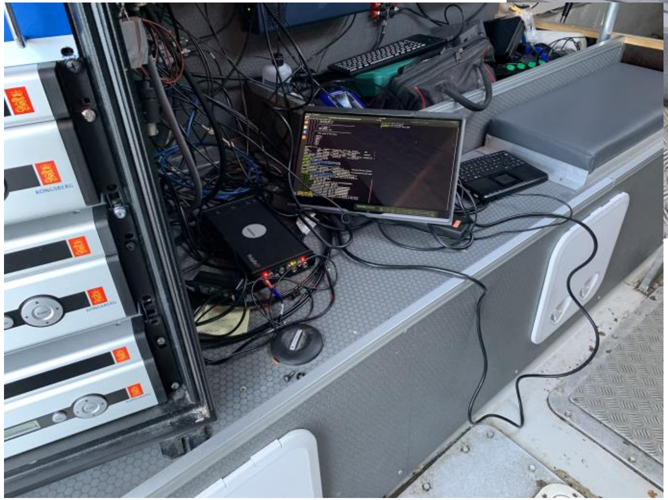
Equipment Setup

The images show the MSMSPNT test bed setup within the Kongsberg’s vessel in Trondheim, Norway.

The DLU was installed in a 19” rack and powered from the internal generator.

The MRU was installed in Kongsberg’s fixed bracket that has been measured for the lever arm from the antenna used.

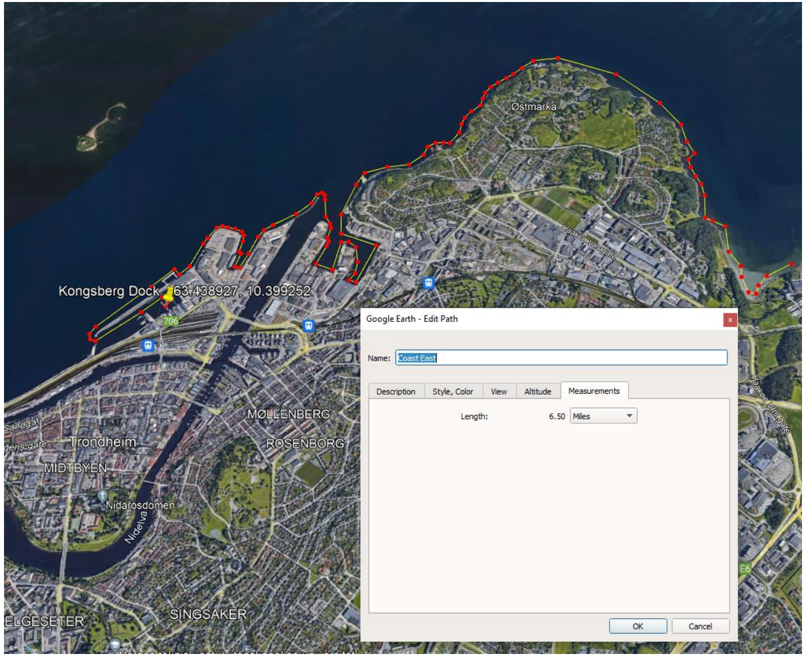
The Septentrio PolaRx5S was placed next to the 19” rack and the data logging was observed through the screen next to it.



Field Trials

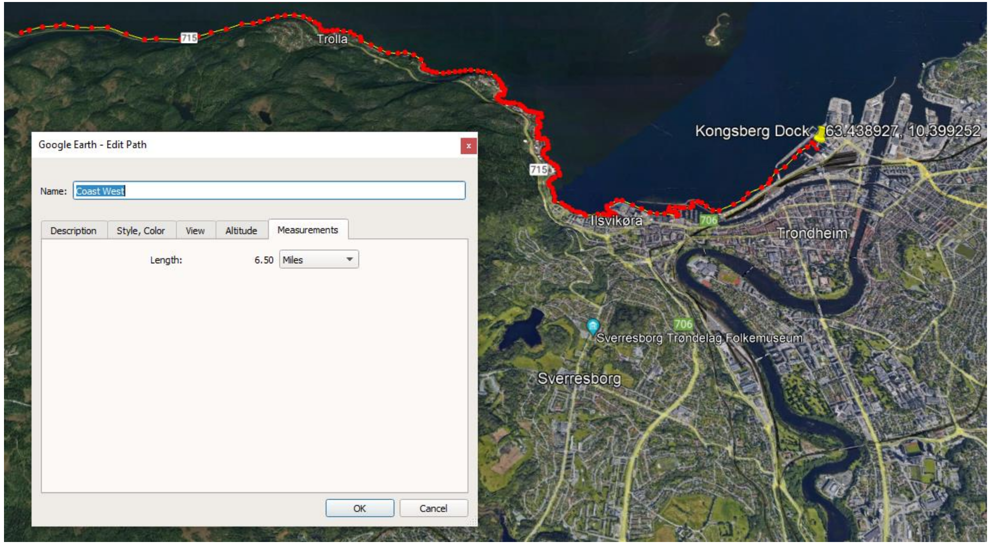
Coast East

6.5 miles journey along the east coast and returning to result in a total trip of 13 miles.



Coast West

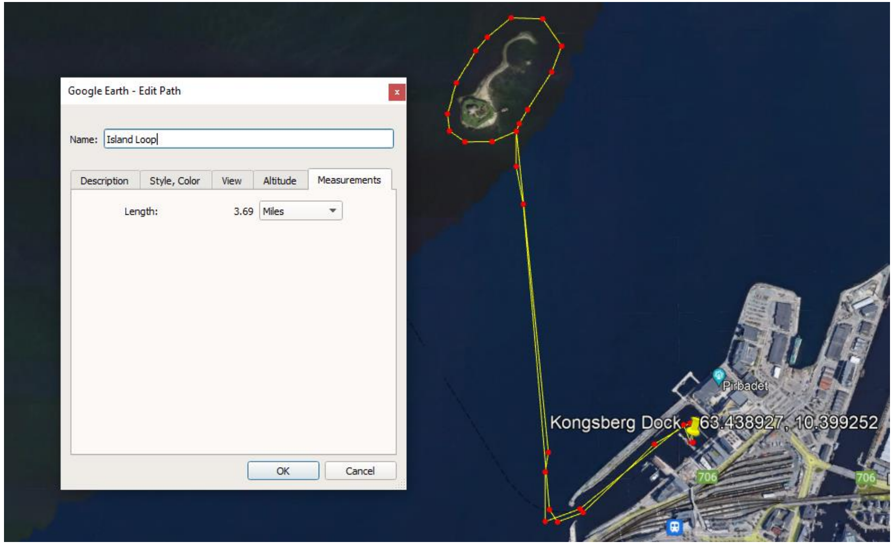
6.5 miles journey along the east coast and returning to result in a total trip of 13 miles.



Field Trials

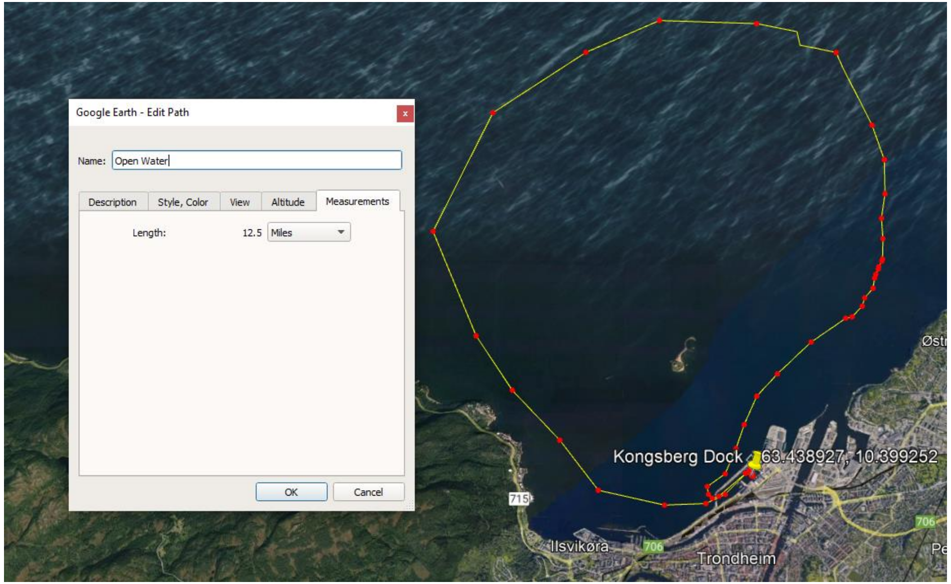
Island Loop

Three 1.2 miles loops around a nearby island resulting in a total trip of 6.09 miles.



Open Water

12.5 miles loop around the open water of the fjord.

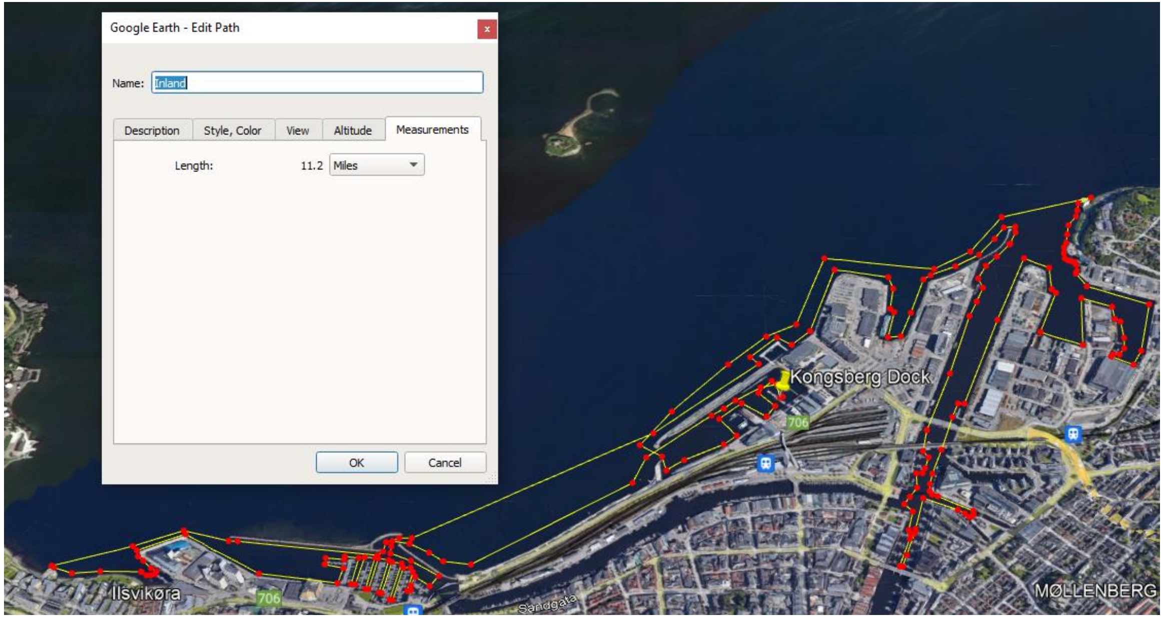


Field Trials

Inland

Loop around the docks of Trondheim resulting in an 11.2 miles journey.

This was the most challenging environment for data collection due to the close boats and buildings



DLU recorded Data description

7 scenarios

Test 1 (T1 Open water)

The duration of the data used in these tests is 2343 seconds

Test 2 (T2 Island loop)

The duration of the data used in these tests is 2701 seconds

Test 3 (T3 Inland water)

The duration of the data used in these tests is 2816 seconds

Test 4 (T4 Coast east)

The duration of the data used in these tests is 1135 seconds

Test 5 (T5 Coast west)

The duration of the data used in these tests is 1524 seconds

Test 6 (T6 Inland water)

The duration of the data used in these tests is 1046 seconds

Test 7 (T7 Coast east)

The duration of the data used in these tests is 2112 seconds

	USRP (8 bit)		PolaRx 5S	AsteRx 4	MRU 5
	L1/E1 (GB)	L5/E5a (GB)	SBF (MB)	SBF (MB)	TSA (MB)
Scenario 1	179.230	179.230	99.032	175.805	42.374
Scenario 2	108.792	108.792	60.048	101.935	13.965
Scenario 3	143.383	143.383	74.177	132.584	18.451
Scenario 4	144.442	144.442	77.349	140.906	34.245
Scenario 5	161.140	161.140	42.341	77.139	19.999
Scenario 6	148.320	148.320	45.161	78.890	18.881
Scenario 7	110.087	110.087	59.197	112.588	26.355
Total	995.394	995.394	457.305	819.847	174.270

The total collected file size is 1992.2239422 GB

Field Trial Results summary

	SoftRx			COTS Receiver			Positioning Ratio Between SoftRx and COTS
	Positioning 95% Accuracy (m)	Integrity Risk	System Availability (%)	Positioning 95% Accuracy (m)	Integrity Risk	System Availability (%)	
Scenario 1 Open water							
Without aiding	6.638	0	100	1.592	0	100	4.17
With SBAS	6.280	0	99.5	1.352	0	99.7	4.65
With IMU	4.579	0	99.5	1.401	0	99.8	3.27
Scenario 2 Island loop							
Without aiding	6.408	0	99	0.569	0	100	11.26
With SBAS	6.154	0	100	0.550	0	100	11.19
With IMU	5.131	0	100	0.561	0	100	9.15
Scenario 3 Inland water Morning							
Without aiding	5.956	0	100	0.908	0	100	6.56
With SBAS	5.639	0	99.4	0.748	0	100	7.54
With IMU	5.120	0	99.4	0.716	0	100	7.15
Scenario 4 Coast East Afternoon							
Without aiding	3.748	0	100	1.275	0	100	2.94
With SBAS	3.306	0	100	1.147	0	100	2.88
With IMU	3.005	0	100	1.058	0	100	2.84
Scenario 5 Coast West							
Without aiding	4.883	0	100	2.030	0	99.8	2.41
With SBAS	4.444	0	99.1	1.935	0	99.2	2.30
With IMU	3.690	0	99.1	1.567	0	99.4	2.36
Scenario 6 Inland water Afternoon							
Without aiding	3.738	0	100	1.433	0	100	2.61
With SBAS	3.497	0	100	1.263	0	100	2.77
With IMU	2.785	0	100	1.313	0	100	2.12
Scenario 7 Coast East Morning							
Without aiding	5.559	0	100	0.836	0	100	6.65
With SBAS	5.271	0	100	0.573	0	100	9.20
With IMU	4.635	0	100	0.552	0	100	8.40

Field Trial Results Conclusion

- The performance of the MSMSPNT maritime test platform meet the IMO requirement from open water to restricted water.

	IMO Requirement	COTS receiver	Compliance (Y/N)	SoftRx	Compliance (Y/N)
Ocean					
Horizontal Error 95% (m)	100	1.4	Y	5.8	Y
Integrity Risk	10^{-5}	0	Y	0	Y
Availability	99.8	99.9	Y	99.8	Y
Coastal					
Horizontal Error95% (m)	10	1.2	Y	4.2	Y
Integrity Risk	10^{-5}	0	Y	0	Y
Availability	99.8	99.9	Y	99.8	Y
Inland water					
Horizontal Error95% (m)	10	1.06	Y	4.45	Y
Integrity Risk	10^{-5}	0	Y	0	Y
Availability	99.8	99.9	Y	99.8	Y

Conclusions and future work

Conclusions

- Fully study the maritime requirements and standard.
- Comprehensive evaluate the methods and techniques for the combined use of multiple systems and sensors in maritime PNT receivers
- Implement an experimental platform for a multi-system multi-sensor maritime PNT receiver testing the combination of methods and techniques studied.
  - The hardware of the designed MSMSPNT test platform is compatible to the multi frequency and multi constellation GNSS signal
  - The MSMSPNT maritime test platform is capable to estimate the PVT information from the RF raw data.
  - External aid source such as SBAS and IMU are compatible to improve the PVT accuracy
  - The overall performance of the software receiver of the MSMSPNT test platform is comparable to the COTS receiver.

- Comprehensive set of Maritime field data collection for future research

Future work

- Comprehensive set of maritime field data has been collected for the testing of these new techniques
- MSMSPNT has developed hardware and software positioning capability that is fully adaptable for research and development of alternative and future techniques for signal acquisition and PVT. This includes:
    - Software based GNSS receiver allow us to further develop the enhance approach for better acquisition and tracking results
    - Estimation algorithm for PVT
    - Enhanced Integration schemes
    - Additional maritime sensor, depth sensor

Thank you

MSMSPNT Team

Jiachen Yin
Jiachen.Yin@gmv.com

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