CENTRE DE RECHERCHE EN DONNÉES ET INTELLIGENCE GÉOSPATIALES

UNIVERSITÉ LAVAL
Faculté de foresterie, de géographie et de géomatique

NSERC CRSNG

AmphibiAR Project

Marine Mobile LiDAR/SONAR System Adjustment

Mohsen Hassanzadeh Shahraji
Jordan McManus
Christian Larouche

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COLLOQUE 2023 SYMPOSIUM
CIDCO 20 ans years

INTRODUCTION

HIGH QUALITY SENSORS

MARINE PLATFORM

MARINE MOBILE LiDAR/SONAR SYSTEM

3D POINT CLOUD DATA

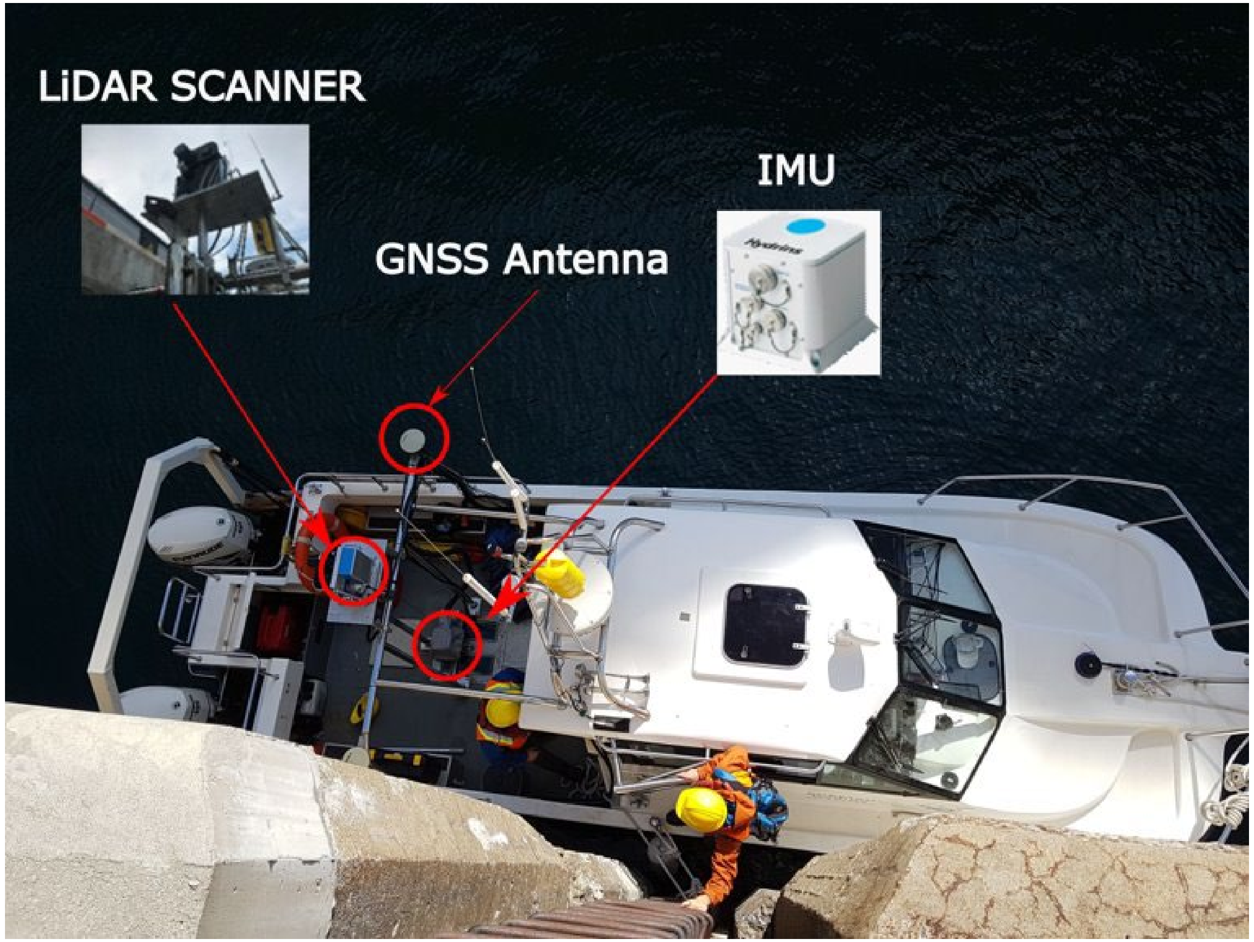
MARITIME INFRASTRUCTURE INSPECTION APPLICATION

INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

SENSOR

Positioning and Orientation System (POS)	OR	Inertial Navigation System (INS)
Global Navigation Satellite System (GNSS)		Inertial Measurement Unit (IMU)



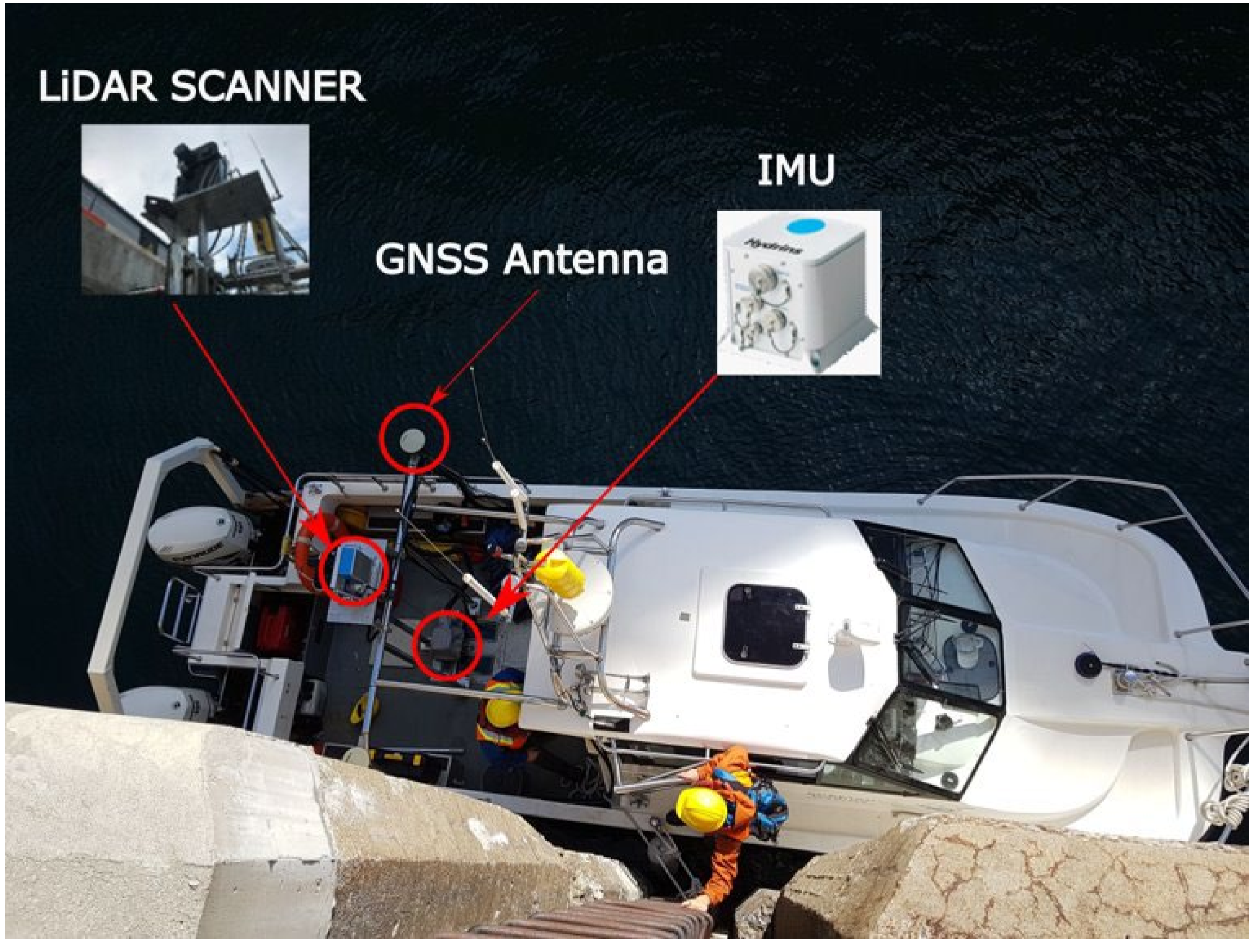
INTRODUCTION → OBJECTIVES → PHASE I → PHASE II → PHASE III → SUMMARY FUTURE WORKS

INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

SENSOR

Light Detection And Ranging (LiDAR) SCANNER	Sound Navigation And Ranging (SONAR)
Active Sensor Near-infrared Spectrum Precise and dense point cloud	Active Sensor Pulse of sound (ping) Bathymetry Application



INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

SENSORS

POS	Hydrins iXblue
Type	Navigation grade INS
Heading Accuracy	0.01 °
Roll & Pitch Accuracy	0.01 °
Horizontal Accuracy (X, Y)	0.006 + 0.5 ppm
Vertical Accuracy (Z)	0.01 + 1 ppm

LiDAR SCANNER	ZF Profiler 9012
Technology	Continuous Wave (Phase Interferometry)
Range Error	0.0087 m
Angular Resolution	0.0088 °
Beam Divergence	< 0.5 mrad
Angular Uncertainty	0.02 °

SONAR	R2SONIC 2022
Technology	Active Sonar System
Beamwidth across track	0.6 °
Beamwidth along track	0.6 °
Frequency	700 kHz
Number of soundings	Up to 1024 soundings per ping

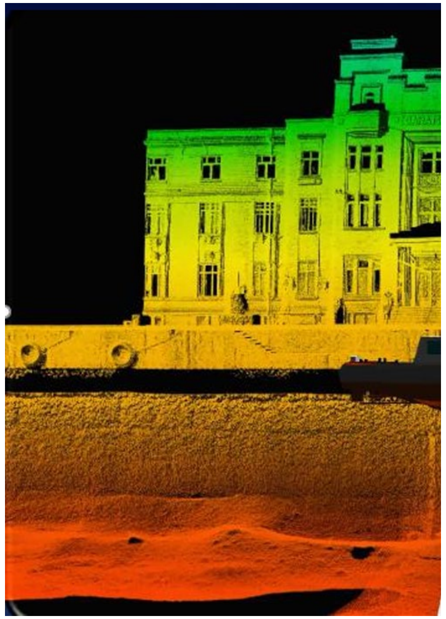
DATA

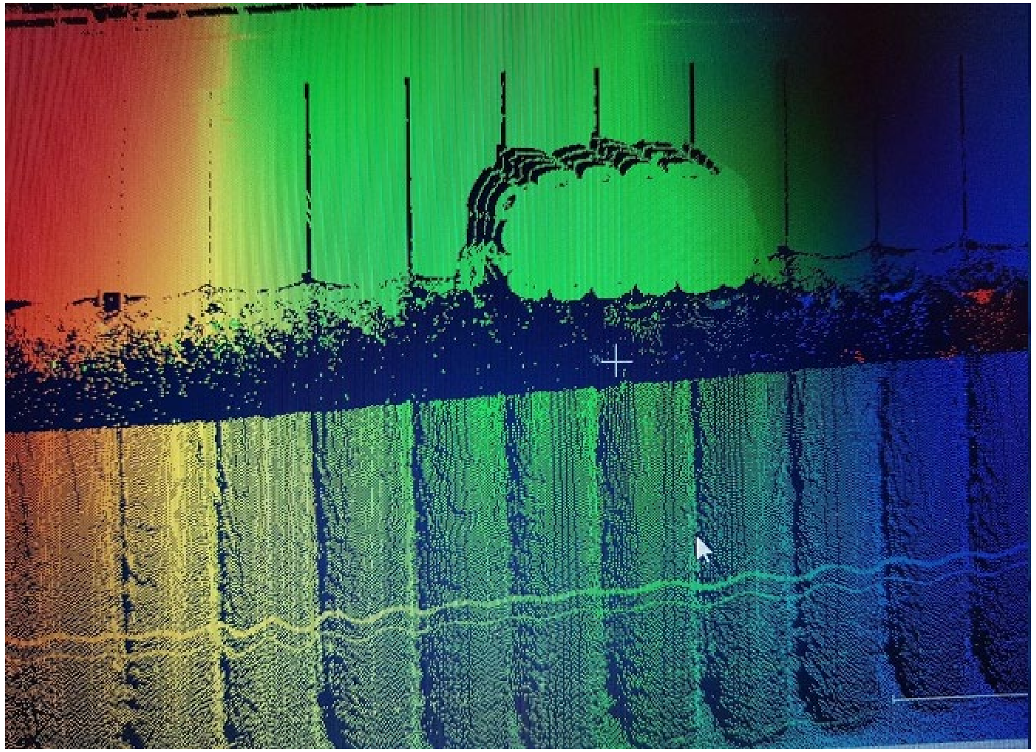
INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

DATA

- Discrete set of data points in 3D space
- Cartesian coordinate system
- Various density
- Various accuracy





INTRODUCTION | OBJECTIVES | PHASE I | PHASE II | PHASE III | SUMMARY FUTURE WORKS

INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

PLATFORM

HYDROGRAPHIC VESSEL

Length	8.2 m
Width	2.7 m
Speed in Operation	6 knots

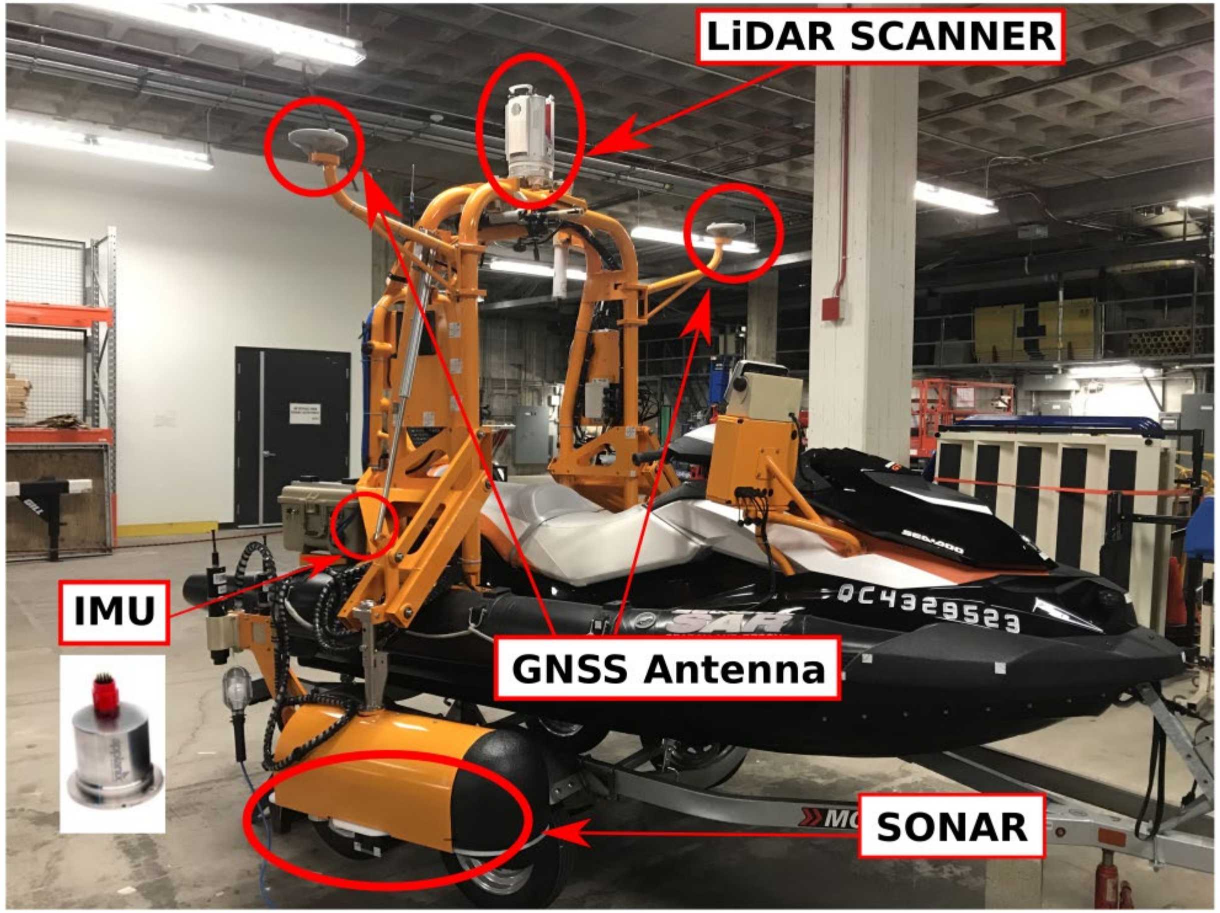
INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

PLATFORM

MOTOMARINE

Length	3.4 m
Width	1.2 m
Speed in Operation	4 knots



INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

PLATFORM

AUTONOMOUS SURFACE VEHICLE

Length	~ 1.7 m
Width	~ 0.8 m
Speed in Operation	3 knots

TELEDYNE Z-BOAT

SEAFLOOR HYDRONE

SEAFLOOR EchoBoat

INTRODUCTION

MARINE MOBILE LiDAR/SONAR SYSTEM

APPLICATION

MARITIME INFRASTRUCTURE MONITORING

===

3D LiDAR ACCURACY OF
LESS THAN 5 CM AT 95% CONFIDENCE INTERVAL

DENSITY OF MORE THAN 200 PTS/m^2

(Olson et al. 2013; Guan et al. 2016)

MARITIME INFRASTRUCTURE MONITORING

COASTAL AREA MANAGEMENT

OBJECTIVES

OBJECTIVE #1

Errors Stability Analysis of mobile LiDAR/SONAR system

OBJECTIVE #2

Trajectory Adjustment in GNSS-deprived environments

PROJECT AIM

Mobile LiDAR/SONAR system Adjustment

OBJECTIVES

HYDROGRAPHIC VESSEL	**PHASE I**	Errors Stability Analysis of Mobile LiDAR/SONAR System
	PHASE II	Trajectory Adjustment in GNSS-Deprived Environments
Autonomous Surface Vehicle	**PHASE III**	Adaptation of the developed methodology for an autonomous surface vehicle (ASV)

Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

PHASE I

Errors Analysis

- **Sensor: LiDAR or SONAR**
- **Calibration**
- **GNSS-Deprived environment**

3D POINT GEOREFERENCING MATHEMATICAL MODEL

w: WORLD FRAME
b: BODY FRAME
s: SENSOR FRAME

3D Georeferenced Point (WORLD FRAME)

Boresight Angles

Lever arm (BODY FRAME)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^w = \begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}^w + C_b^w(roll, pitch, heading)\left(C_s^b(\alpha, \beta, \gamma)\begin{bmatrix} x \\ y \\ z \end{bmatrix}^s + \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}^b\right)$$

Position (from GNSS) (WORLD FRAME)

Orientation (from INS)

Sensor Measurement (SENSOR FRAME)

OBSERVATION

CALIBRATION

Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

PHASE I

Errors Analysis

- **Boresight Error is important to be addressed.**

MLS SOURCES OF ERROR AND THEIR IMPACTS
(Point Positioning Error @ 10 m distance)

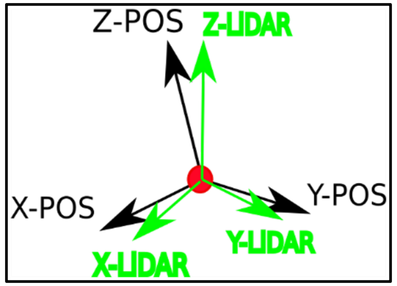
OBSERVATION	**POS**	**GNSS Related Errors (PPK – RTK)**	1.3 cm
		IMU Related Errors (Angular Accuracy)	1.5 cm
	LiDAR Scanner (Z+F Profiler)	**Ranging Accuracy**	0.2 cm
		Footprint Size	0.5 cm
	SONAR (R2Sonic)	**Vertical Accuracy (RMS)**	5 cm
		Planimetric Accuracy (RMS)	10 cm
		Resolution	Down to 0.3 cm
CALIBRATION For LiDAR	**Lever arm error**		0.5 cm
	Boresight error (For 1.2 ° angular error)		21 cm

Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

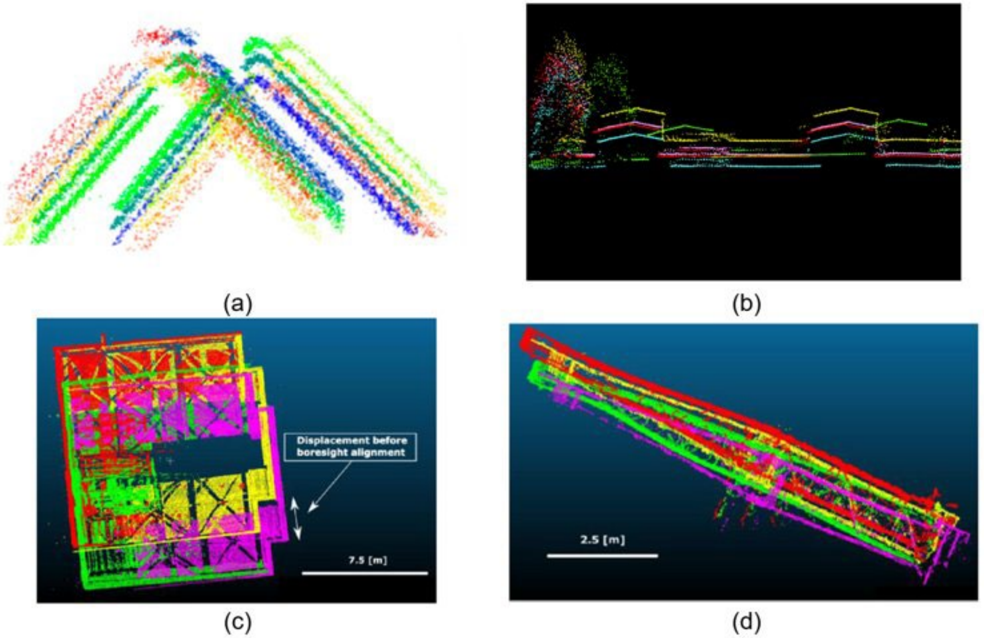
PHASE I

Errors Analysis



Distance [m]	Angular Error	Positioning Error
5	1.2 °	10 cm
10	1.2 °	21 cm
40	1.2 °	84 cm

MLS SOURCES OF ERROR AND THEIR IMPACTS



Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

PHASE I

Errors Analysis

PROS	CONS
• **Precision** • **Accuracy**	• **Exterior Meas. Unit** • **Repeat Frequently**

LEVER ARM (STATIC) MEASUREMENT

Installation of tragets on specific points on the sensors

↓

Network design

↓

Adjustment of the network

Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

PHASE I

Errors Analysis

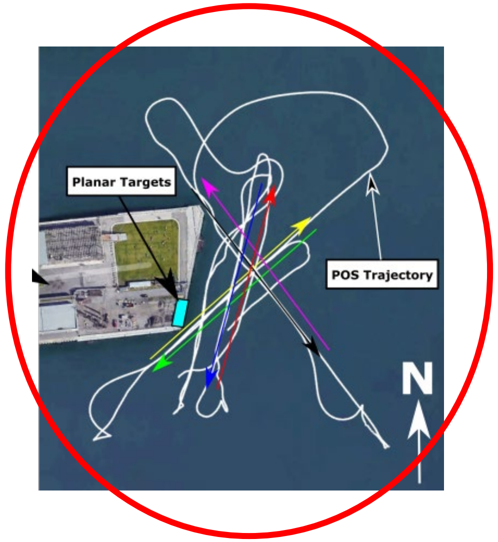
PROS	**CONS**
• **Precision and accurate estimation of this parameter.**	• **Exterior Meas. Unit** • **Site Limitation** • **Repeat Before Each Survey**

BORESIGHT ANGLES (DYNAMIC) ESTIMATION

Inclined Planar Target

Vertical Planar Target

PASSAGES



Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

PHASE I

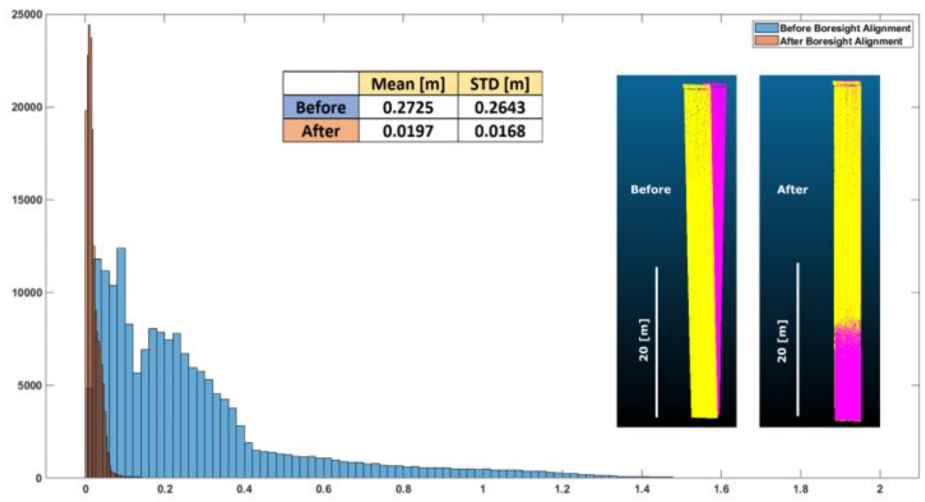
Errors Analysis

Improvement of the quality of the data after boresight adjustment

BORESIGHT ANGLES (DYNAMIC) ESTIMATION

VALIDATION PLANE (V2)

Count



Cloud-To-Cloud Distance (m)

INTRODUCTION | **OBJECTIVES** | **PHASE I** | **PHASE II** | **PHASE III** | **SUMMARY FUTURE WORKS**

Errors Stability Analysis of Mobile LiDAR/SONAR System (PHASE I)

HYDROGRAPHIC VESSEL

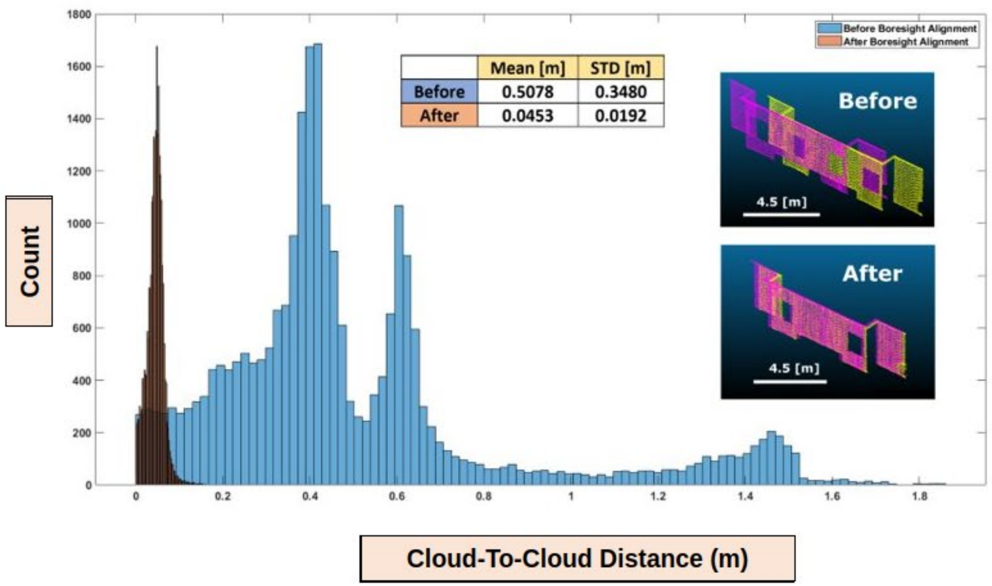
PHASE I

Errors Analysis

Improvement of the quality of the data after boresight adjustment

BORESIGHT ANGLES (DYNAMIC) ESTIMATION

VALIDATION PLANE (V3)



Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II

LiDAR Odometry for Trajectory Adjustment

LiDAR Odometry with IMU-based Motion Model

LiDAR Data Acquisition (3D Point Cloud) → **Feature Extraction** → **Successive LiDAR Scans Matching** → **Trajectory Reconstruction**

IMU DATA (Acceleration and Angular Velocity) → **Motion Model Estimation** → **Motion Prediction** → **Successive LiDAR Scans Matching**

CORRECTED TRAJECTORY WILL ALSO IMPROVE THE ACCURACY OF THE SONAR DATA

Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

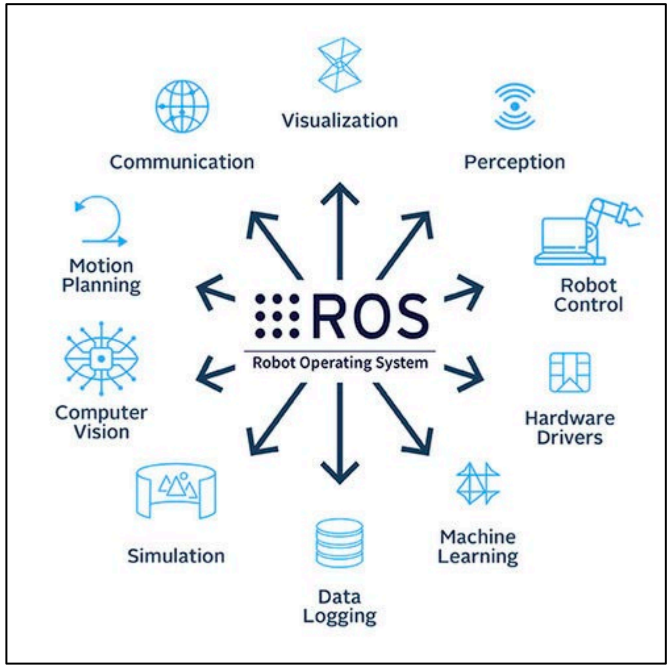
HYDROGRAPHIC VESSEL

PHASE II

LiDAR Odometry for Trajectory Adjustment

- **Sensors Communication**
- **Raw Data Logging**
- **Visualization**

LiDAR ODOMETRY with IMU-based Motion Model



NORLab

- Nothern Robotics Laboratory
- Specialized in mobile and autonomous systems
- Localization algorithms designed for laser sensors (lidar)

Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

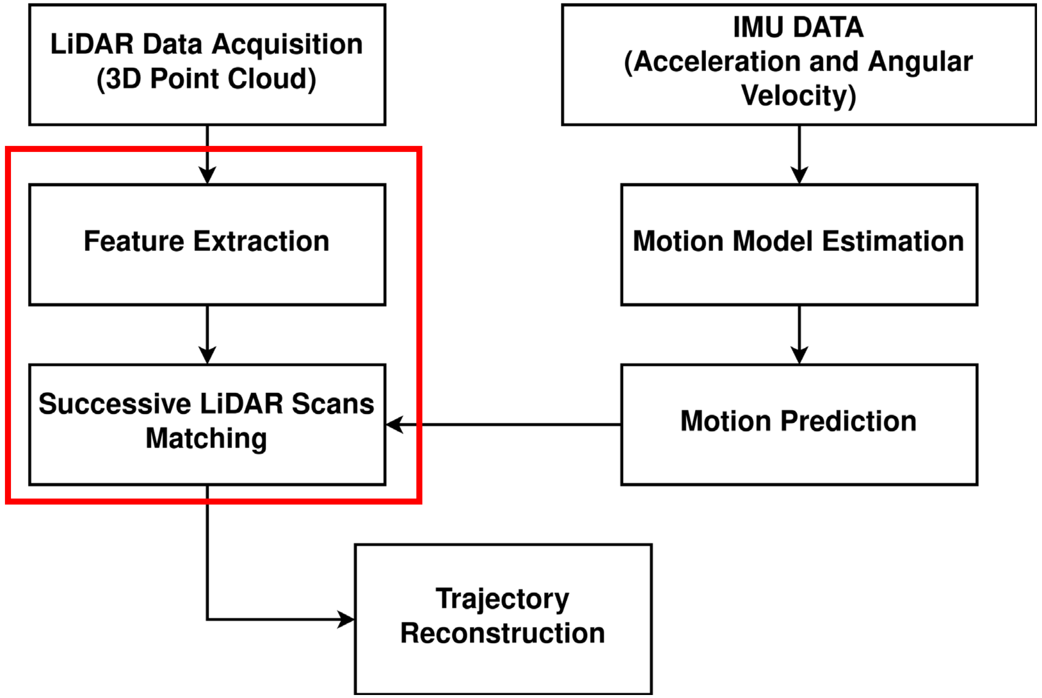
PHASE II

LiDAR Odometry for Trajectory Adjustment

Master Project

Planar Feature Extraction and Matching in Port and Harbor (Challenging) Environment

LiDAR Odometry with IMU-based Motion Model



Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II

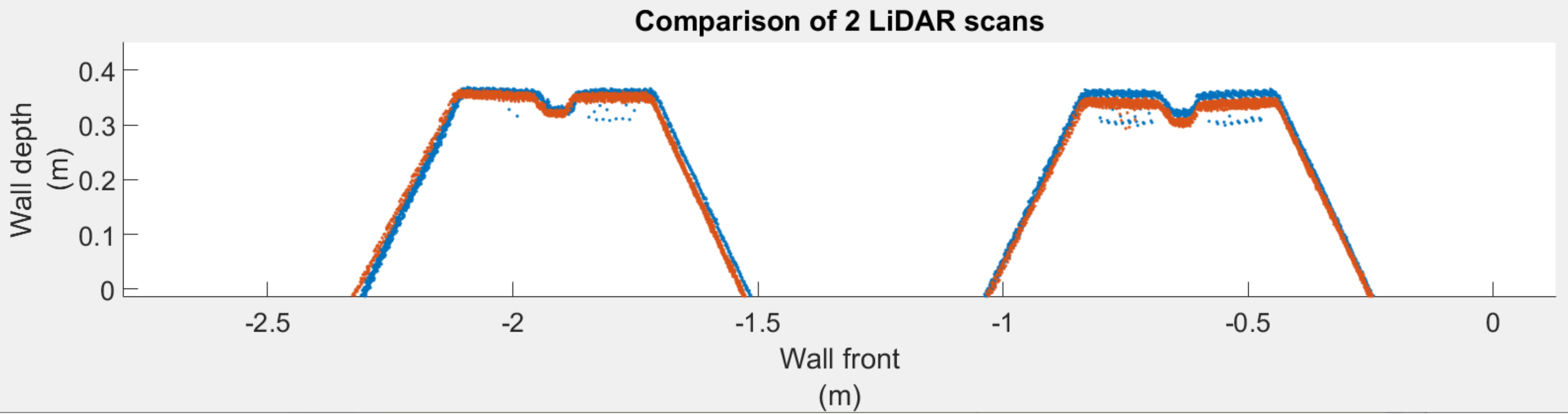
LiDAR Odometry for Trajectory Adjustment

Feature Extraction

Errors are not constant along the scans.

MLS SOURCES OF ERROR

Sources of Error			Point Positioning Error at 50 m distance
OBSERVATION	POS	GNSS related errors (PPK - TRK)	1.3 cm
		IMU related errors (angular accuracy)	1.5 cm
	LiDAR Scanner	Ranging accuracy	0.9 cm
		Footprint size	2.5 cm
CALIBRATION	Lever arm error		2 cm
	Boresight error		~ 1 cm



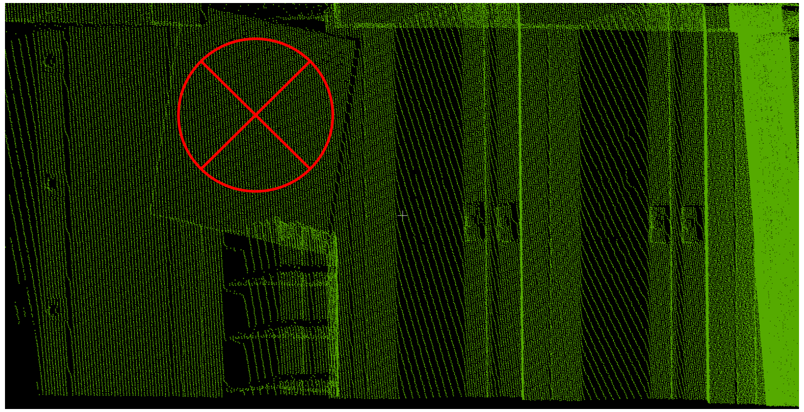
Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

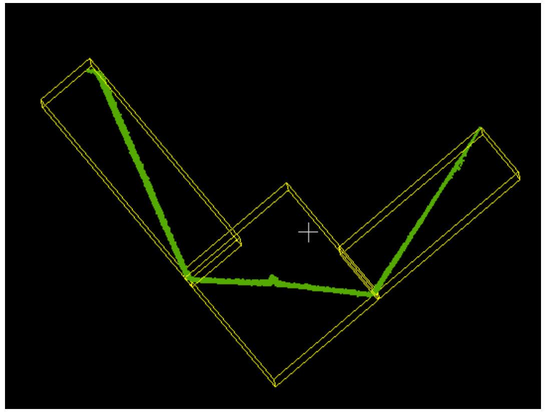
HYDROGRAPHIC VESSEL

PHASE II

LiDAR Odometry for Trajectory Adjustment

Feature Extraction

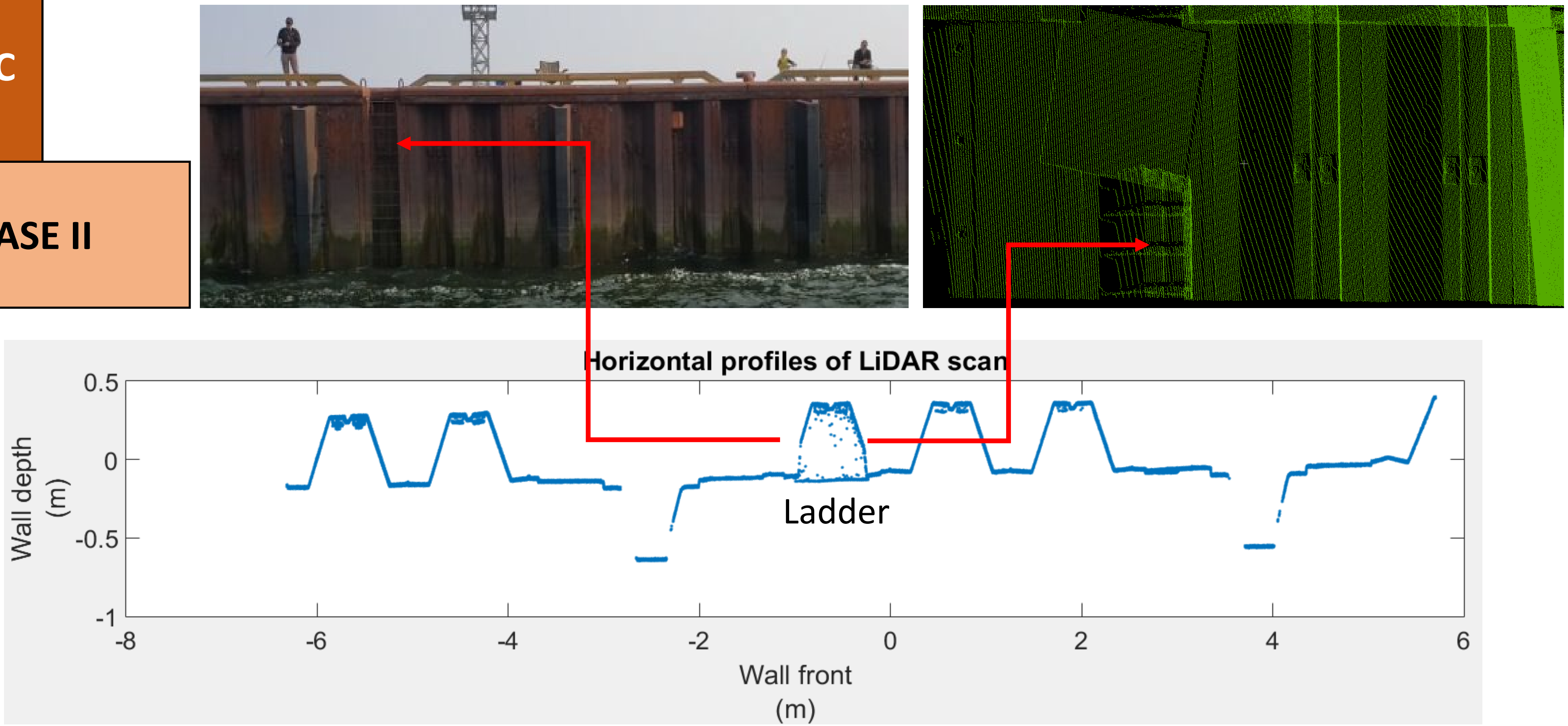




Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

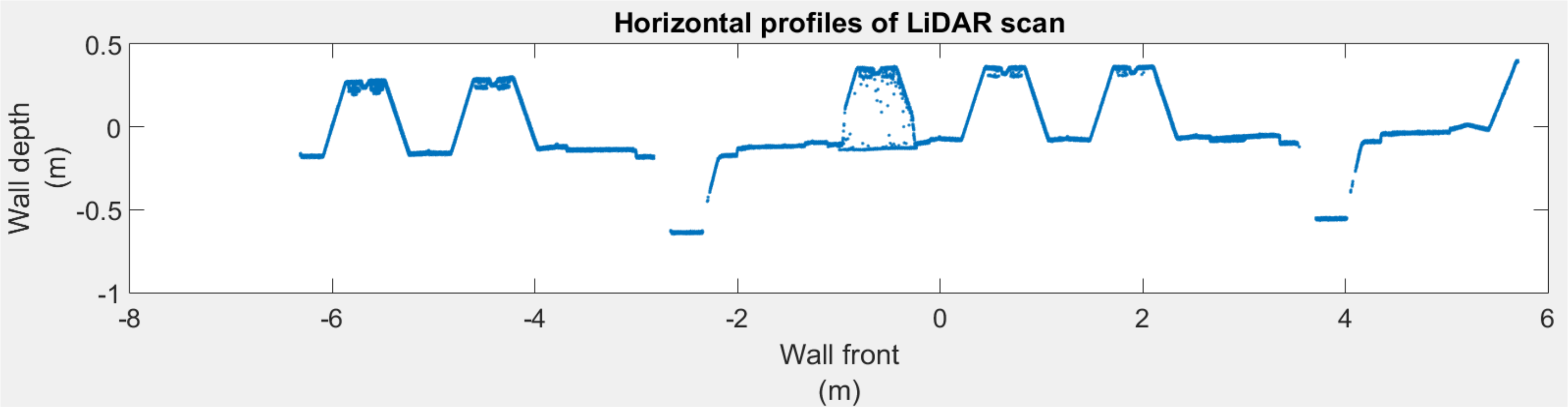
PHASE II

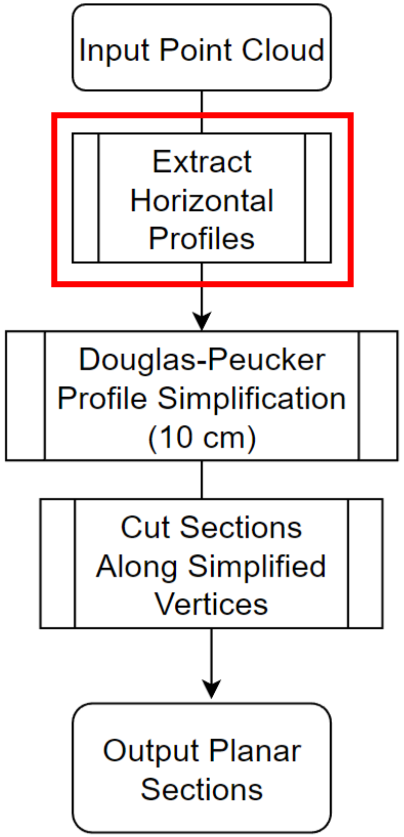


Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II

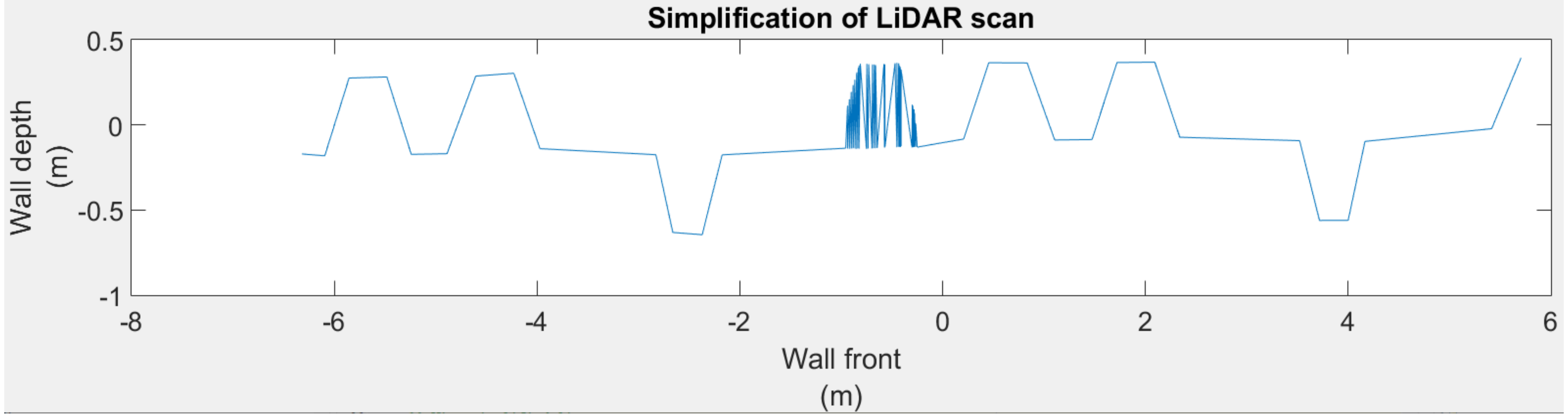


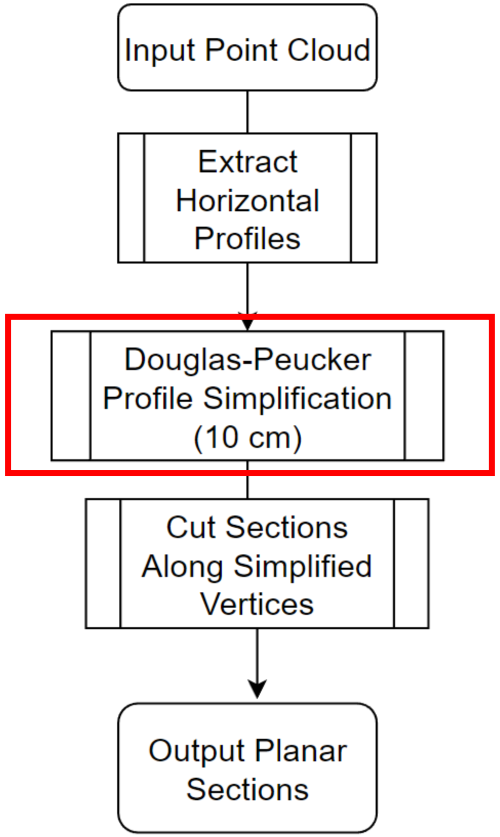


Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II





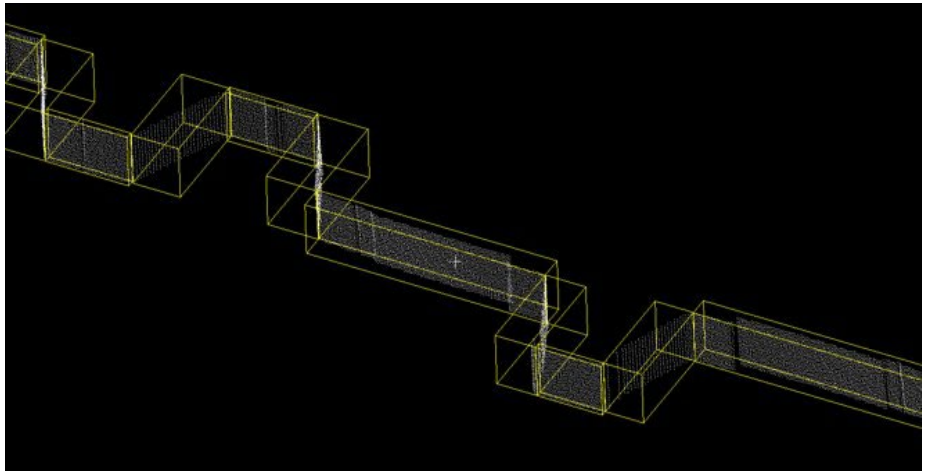
Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II

LiDAR Odometry for Trajectory Adjustment

Feature Extraction



Input Point Cloud

Extract Horizontal Profiles

Douglas-Peucker Profile Simplification (10 cm)

Cut Sections Along Simplified Vertices

Output Planar Sections

Extract *in-situ* planar features automatically.

Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

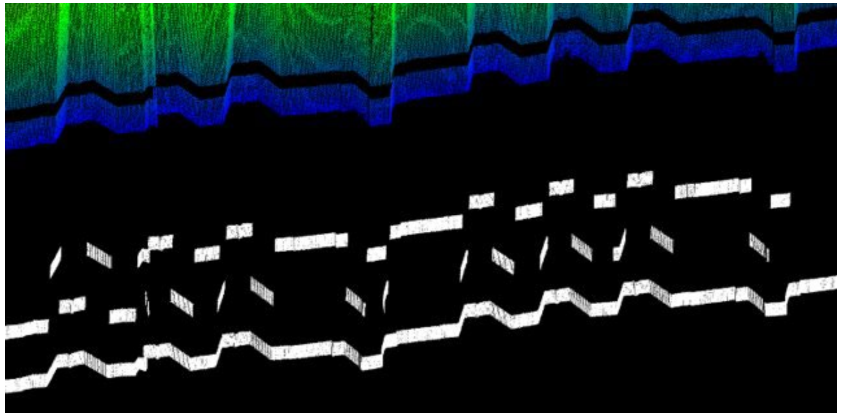
PHASE II

LiDAR Odometry for Trajectory Adjustment

Feature Extraction

Finds hundreds of planes in a georeferenced cloud of **500,000 points** in a few seconds.

This compares very favorably against RANSAC or region growing techniques for **automatic plane extraction**.



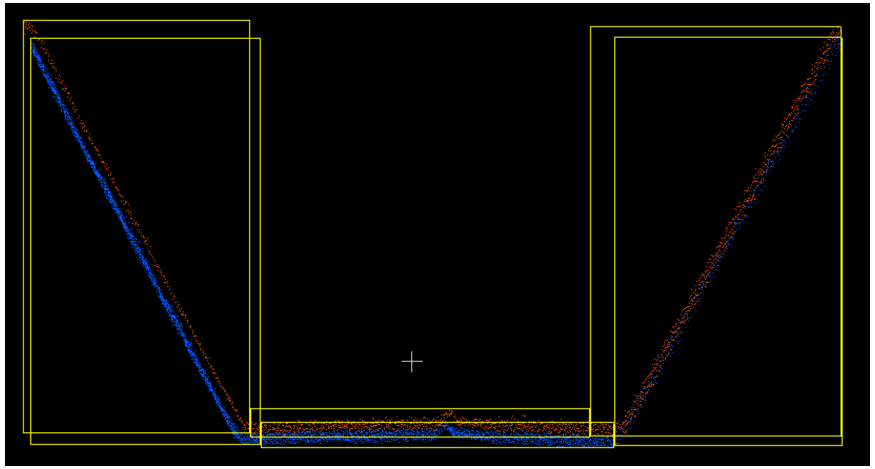
Trajectory Adjustment in GNSS-Deprived Environments (PHASE II)

HYDROGRAPHIC VESSEL

PHASE II

LiDAR Odometry for Trajectory Adjustment

Future Works
Matching extracted planes



Matched planes will be used to adjust trajectory when GNSS signal quality is lost.

Matching planes is a combinatorial problem, not a registration problem.

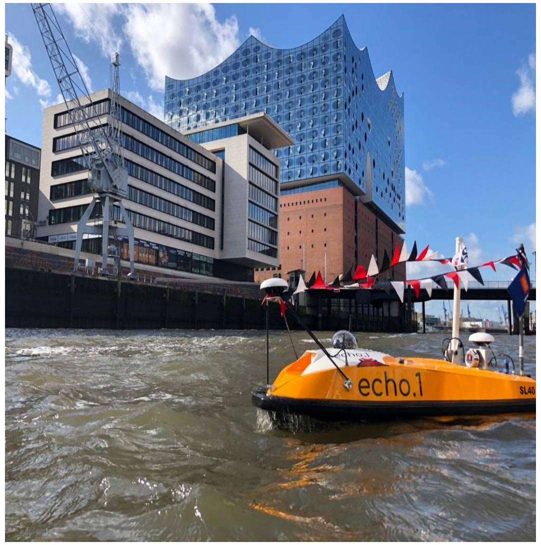
Adaptation of the developed methodology for an ASV (PHASE III)

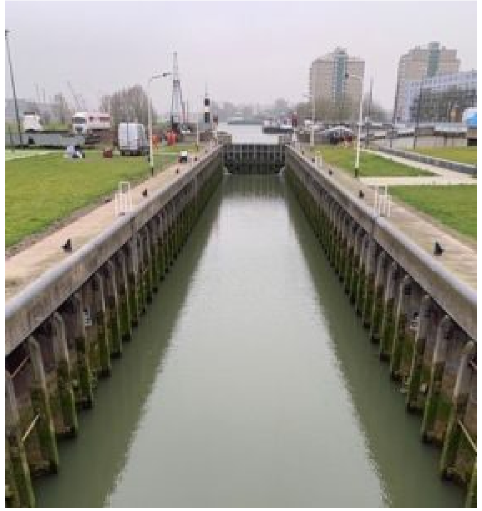
Autonomous Surface Vehicle

PHASE III

Adaptation of the developed methodology

ASV Platform Challenges





SUMMARY and FUTURE WORKS

Marine Mobile LiDAR/SONAR System
for
Inspection of Maritime Infrastructure

To Achieve the Necessary Accuracy for Inspection Task the **Error Analysis** of the System is Crucial

Boresight Estimation

Lever arm Measurement

Trajectory Adjustment
in
GNSS-Deprived Environments

LiDAR Odometry
with
IMU-based Motion Model

ROS (Robot Operating System) Development Environment

Maritime Environment
Specific Conditions

Marine Platform
Different Specifications (Hydrographic Vessel or ASV)

THANK YOU FOR YOU ATTENTION

QUESTIONS?

SPECIAL THANKS TO AMPHIBIAR PROJECT PARTNERS

NSERC
CRSNG

CIDCO
Centre interdisciplinaire de développement en cartographie des océans
Interdisciplinary Centre for the Development of Ocean Mapping

wsp