ENSTA Bretagne

SARDINE : a low-cost AUV for detection, localization, tracking and mapping of underwater targets

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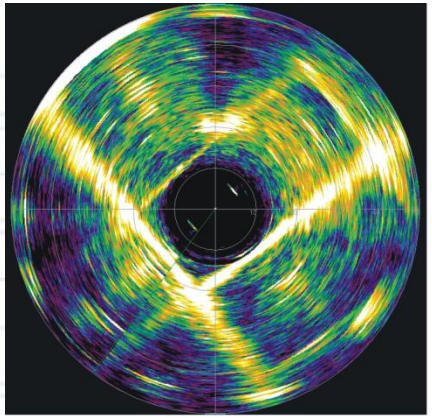
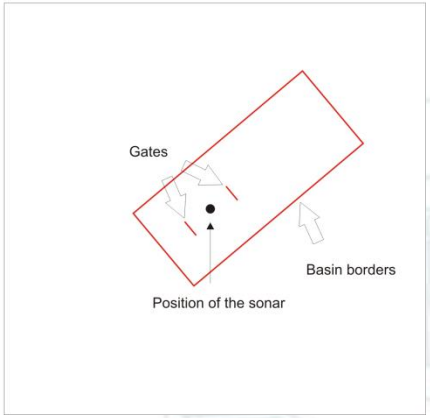
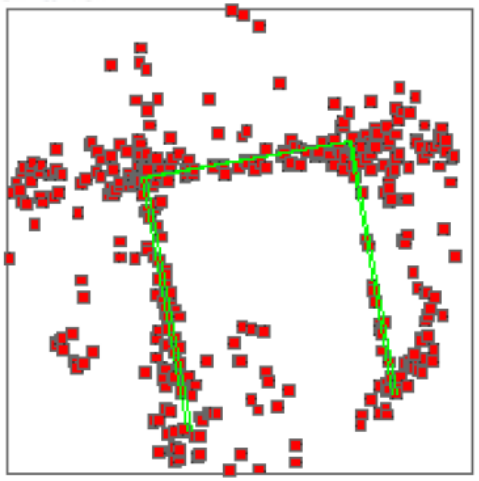
Introduction

Introduction

- Facts
  - There are few demonstrations of cheap autonomous robots able to do survey, cartography, localization tasks, especially in marine and submarine environments
  - Current methods : mainly probabilistics







Introduction

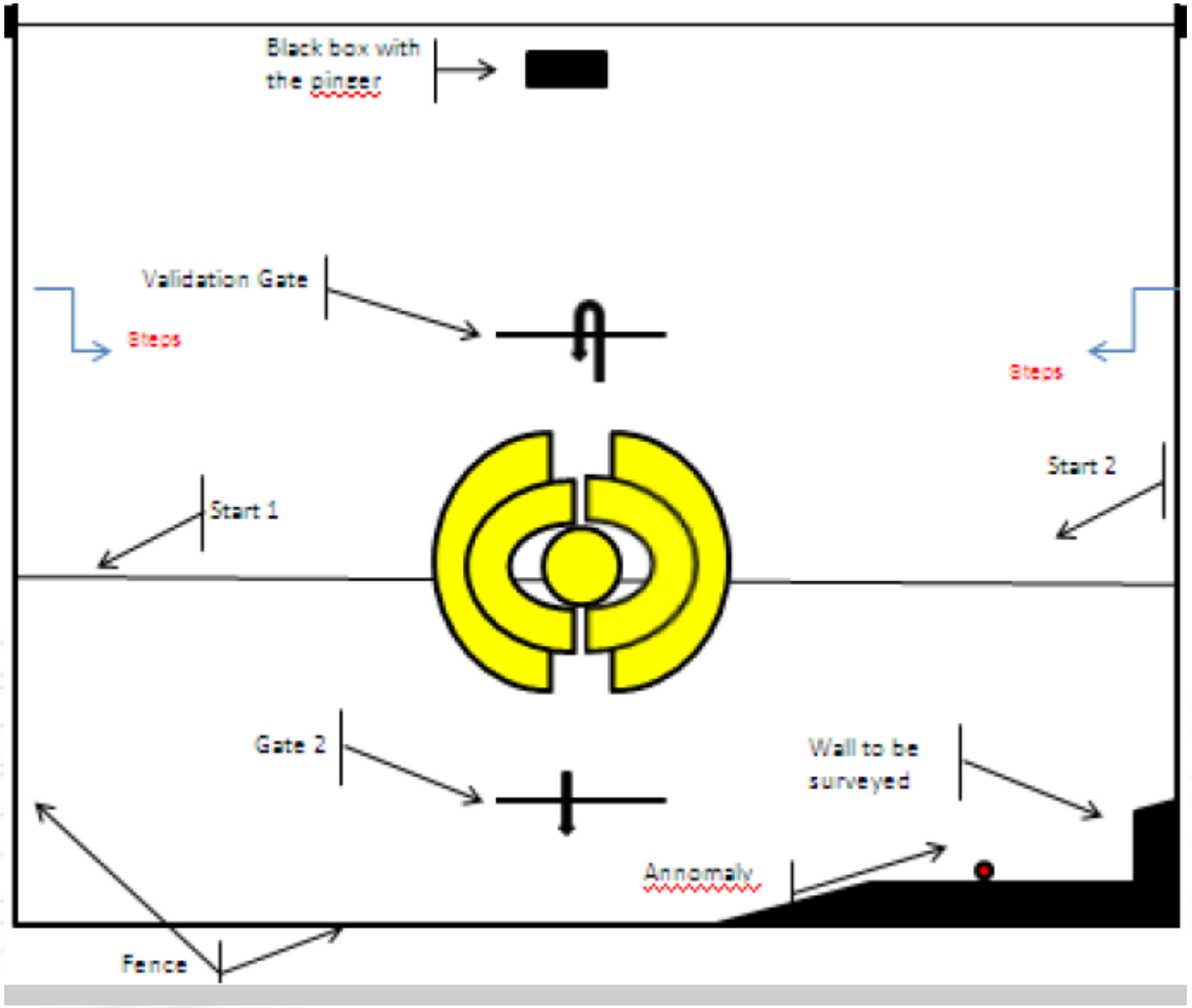
- SARDINE, a low-cost AUV
  - Originally designed in 2010 as an autonomous companion submarine of our other AUV, SAUC'ISSE
  - Equipped to compete in the SAUC-E competition
  - Goal : develop and test new methods from the challenges proposed by SAUC-E or other applications

SAUC-E : detection, localization, tracking, mapping tasks

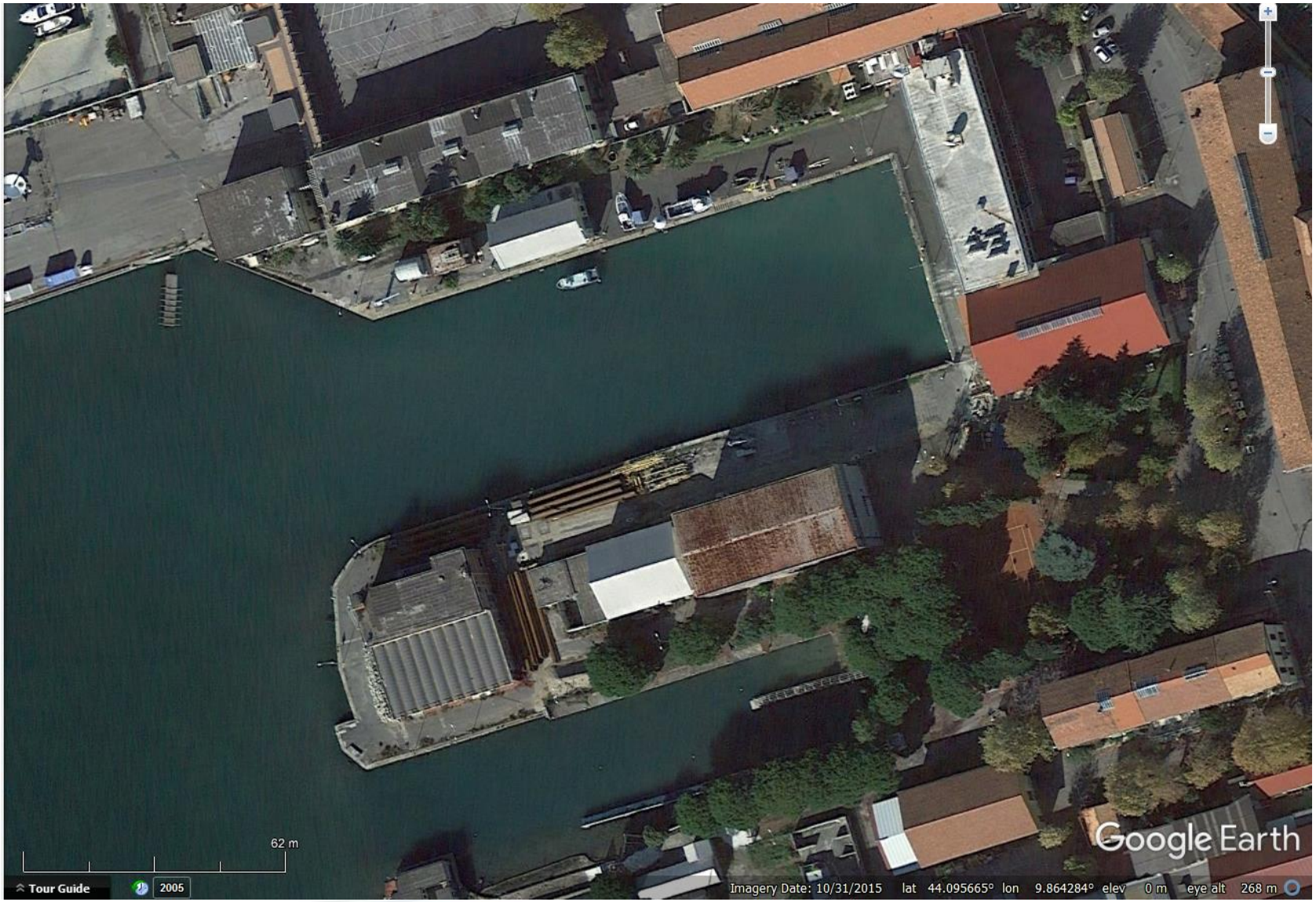
SAUC-E : detection, localization, tracking, mapping tasks

- SAUC-E (Student Autonomous Underwater Challenge - Europe)
  - Autonomous submarine competition
  - Around 10 competitors every year
  - Objets detection, localization, cartography + collaboration with another robot
  - See also euRathlon, RoboSub

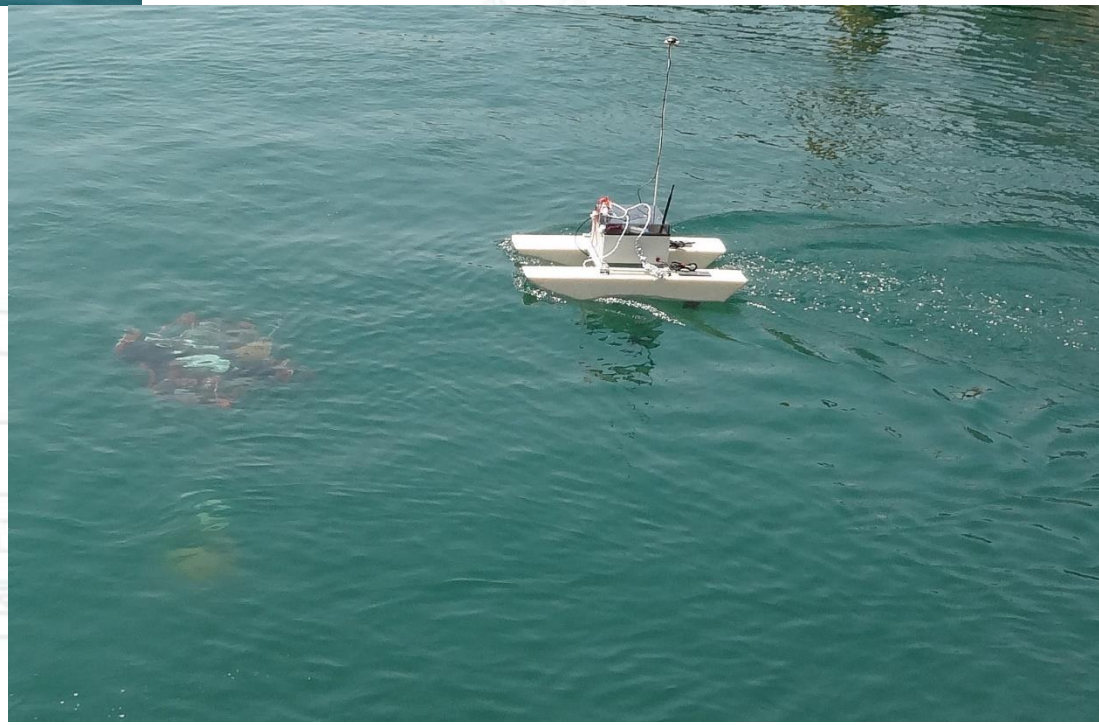
SAUC-E : detection, localization, tracking, mapping tasks



SAUC-E : detection, localization, tracking, mapping tasks

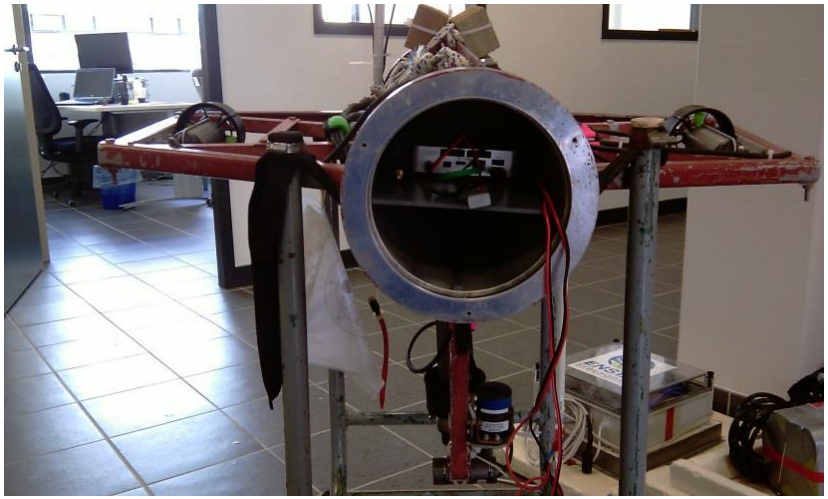


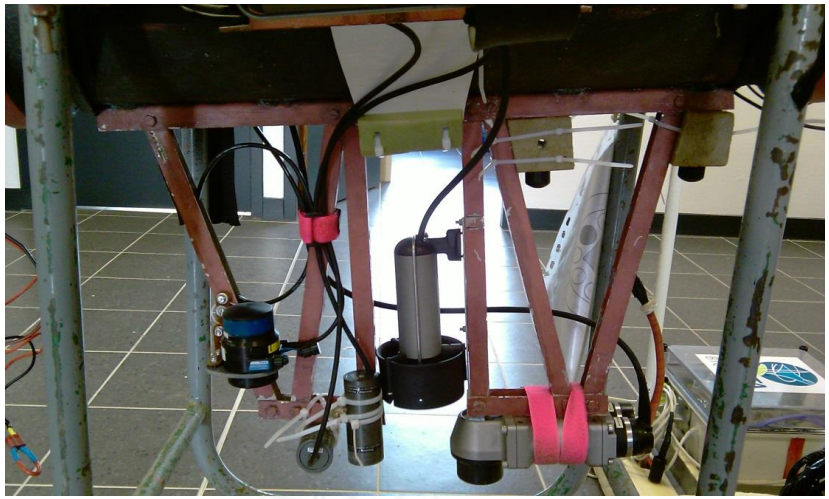

LEONARDO
CONTLAB
YAMAHA
ZEPPELIN

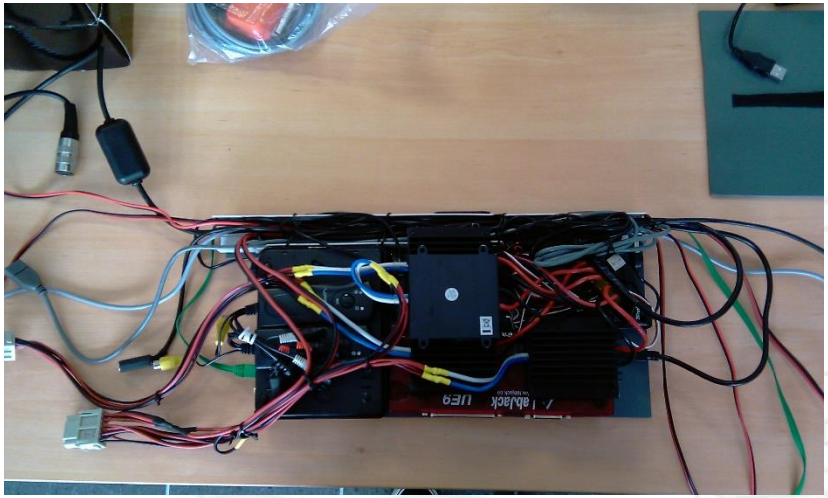


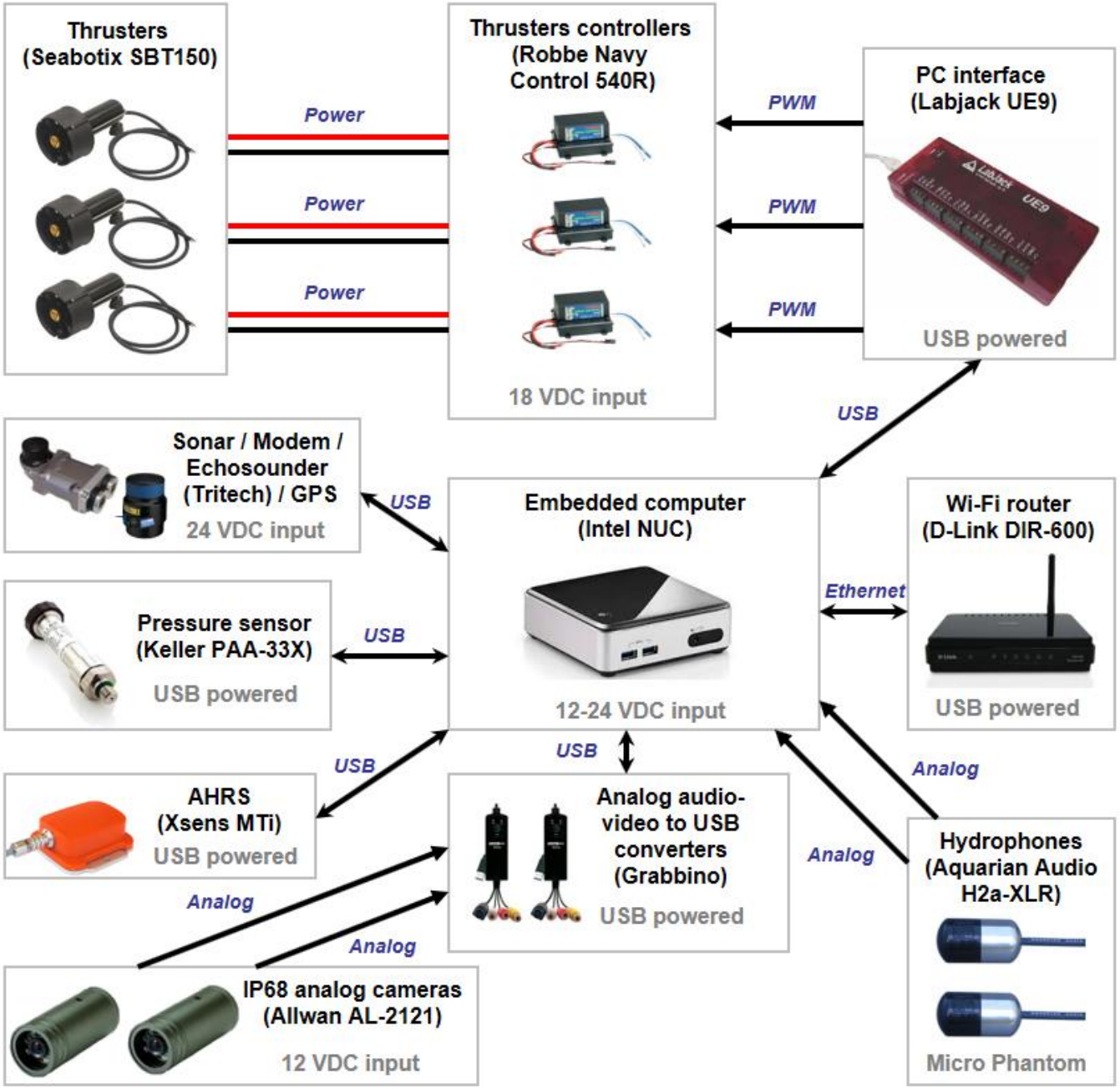
Robot design

Robot design








Thrusters
(Seabotix SBT150)
Power
Power
Power
Thrusters controllers
(Robbe Navy
Control 540R)
18 VDC input
PWM
PWM
PWM
PC interface
(Labjack UE9)
USB powered
USB
Sonar / Modem /
Echosounder
(Tritech) / GPS
24 VDC input
USB
Embedded computer
(Intel NUC)
12-24 VDC input
Ethernet
Wi-Fi router
(D-Link DIR-600)
USB powered
Pressure sensor
(Keller PAA-33X)
USB powered
USB
USB
AHRS
(Xsens MTi)
USB powered
USB
Analog audio-
video to USB
converters
(Grabbino)
USB powered
Analog
Analog
Hydrophones
(Aquarian Audio
H2a-XLR)
Micro Phantom
Analog
Analog
IP68 analog cameras
(Allwan AL-2121)
12 VDC input

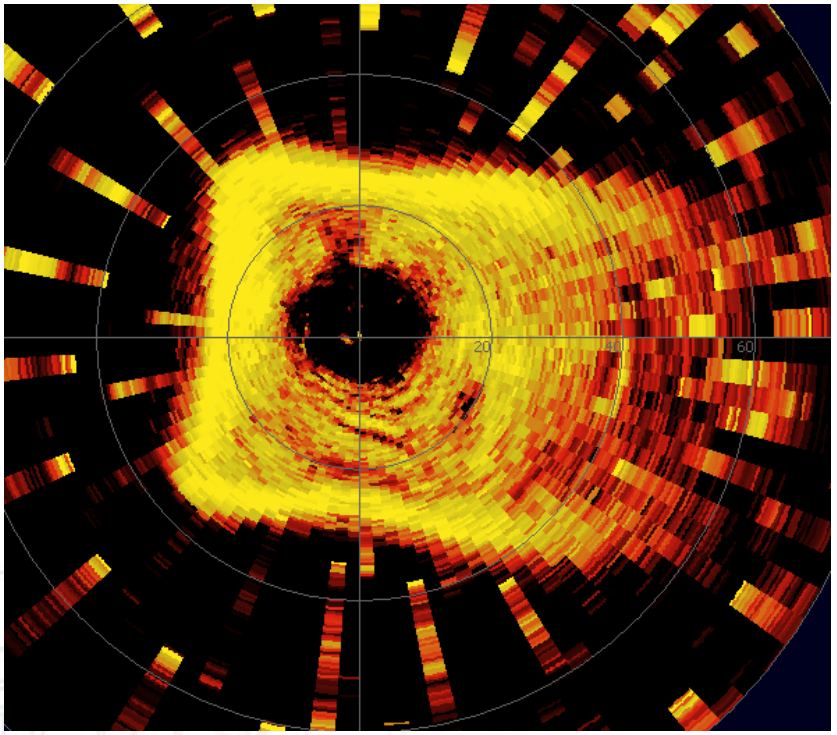
Detection, localization, mapping, tracking, control

Main problem : localization of the AUV

- Depending on context
  - GPS when on surface
  - State equations (using compass and thrusters inputs)
  - Position of the ASV and distance using acoustic modems
  - Static sonar localization (when inside the basin)
  - Relative distance to wall using sonar for wall following

$$
\begin{aligned}
\dot{x} &= v\cos\theta \\
\dot{y} &= v\sin\theta \\
\dot{\theta} &= u_2 - u_1 \\
\dot{v} &= u_1 + u_2 - v
\end{aligned}
$$

Simplified state equations of the AUV



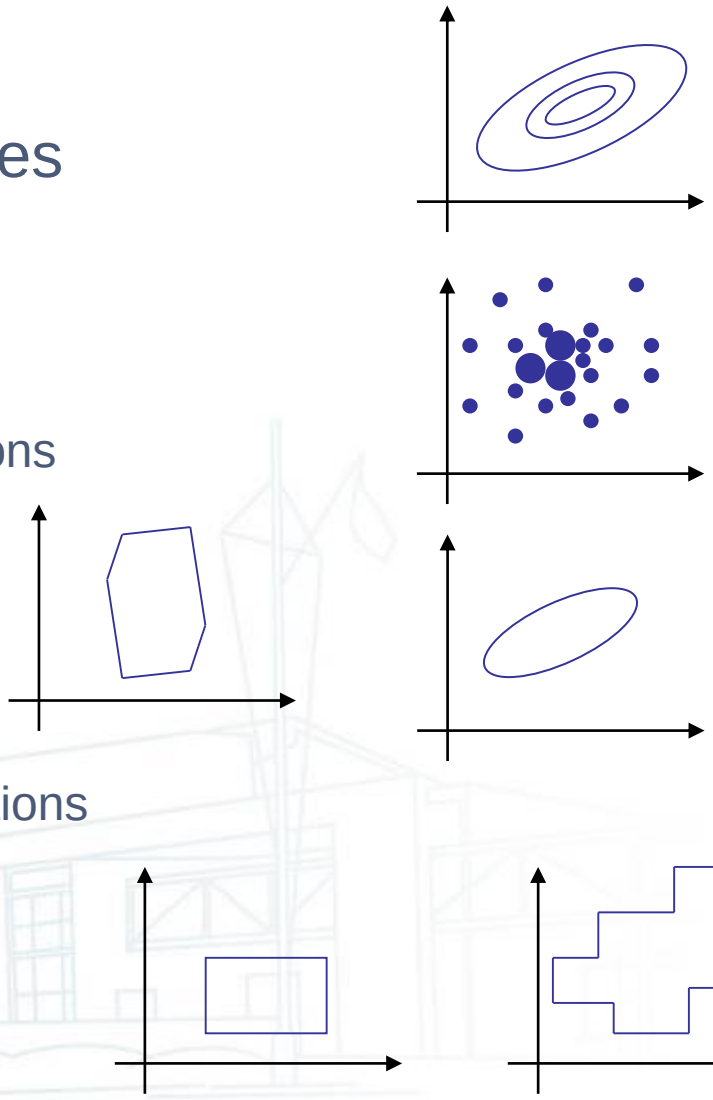
Static sonar localization and mapping

Uncertainties

- Representations of uncertainties
  - Probabilistic methods
    - Gaussian
    - Particles

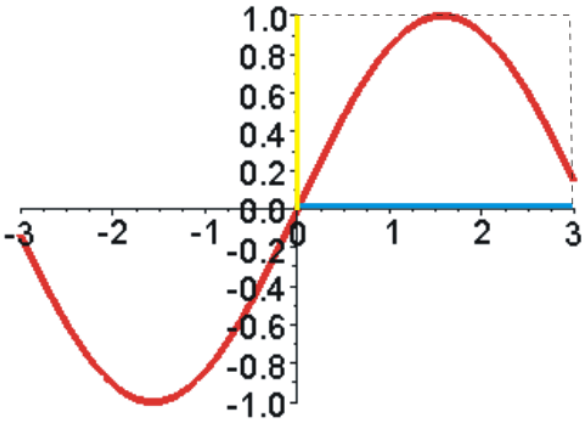
    => Try to get most probable solutions
  - Set-membership methods
    - Zonotopes
    - Ellipsoids
    - Intervals

    => Try to enclose all possible solutions



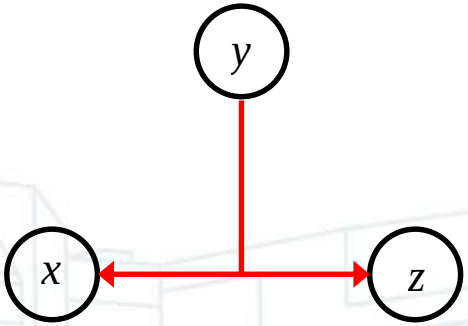
Interval arithmetic to combine different localization methods

- $[-\infty, 2]$, $[-1, 4]$, $[-\infty, \infty]$ are examples of intervals
- Operations $\diamond \in \{+, -, *, /\}$
  - $[x^-, x^+] \diamond [y^-, y^+] =$ smallest interval containing the set of all possible values for $x \diamond y$
  - $[-1, 4] + [2, 3] = [1, 7]$
  - $[-1, 4] * [2, 3] = [-3, 12]$
  - $[-1, 4]/[2, 3] = [-1/2, 2]$
- Multiplication by a number, intersection, union
  - $2[-1, 4] = [-2, 8]$
  - $[-1, 3] \cap [2, 4] = [2, 3]$
  - $[-1, 2] \sqcup [3, 4] = [-1, 4]$
- Image by a function
  - $\sin([0, \pi]) = [0, 1]$



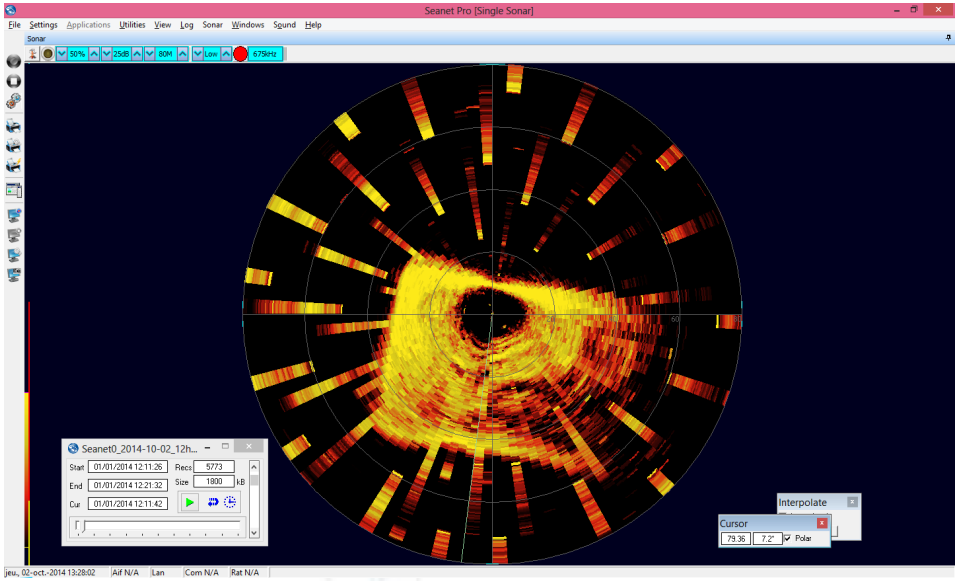
Interval arithmetic to combine different localization methods

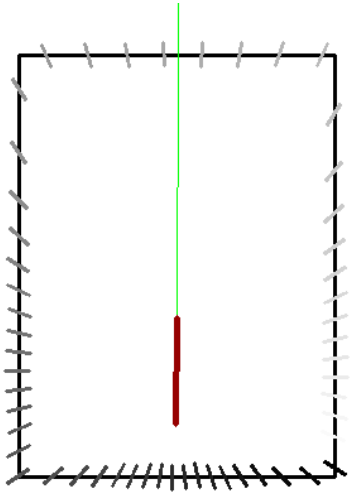
- Contraction
  - If $z^2 = \exp(x) + y$ and $x \in [1,4]$, $y \in [3.1, 3.2]$, $z \in [4,7]$, then
    - $x = \ln(z^2 - y) \Rightarrow x \in [x] \cap \ln\left([z]^2 - [y]\right) = [2.5, 3.9]$

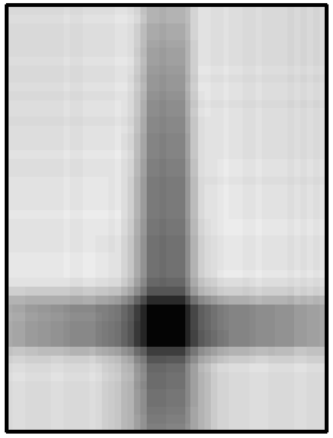


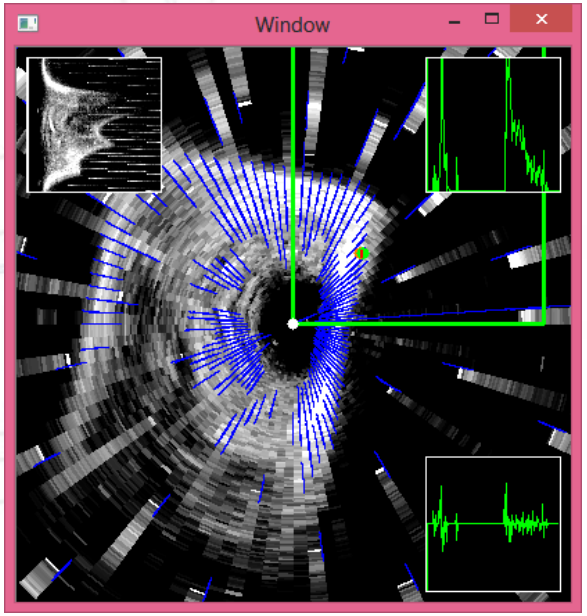
Detail on static sonar localization

- Context : map of the environment known but outliers expected, good compass and a sonar available
- First problem : where are the walls on the sonar image?
- Second problem : where is the robot w.r.t the walls?

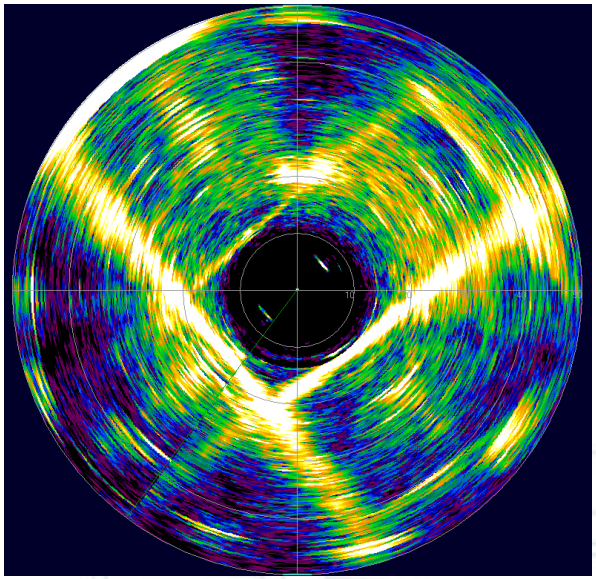


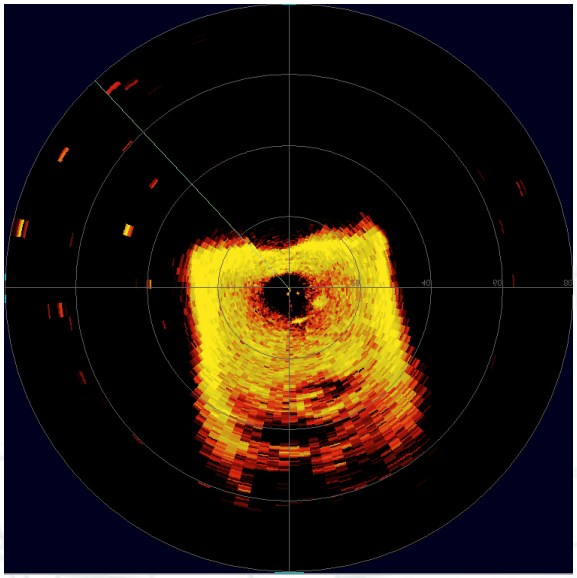


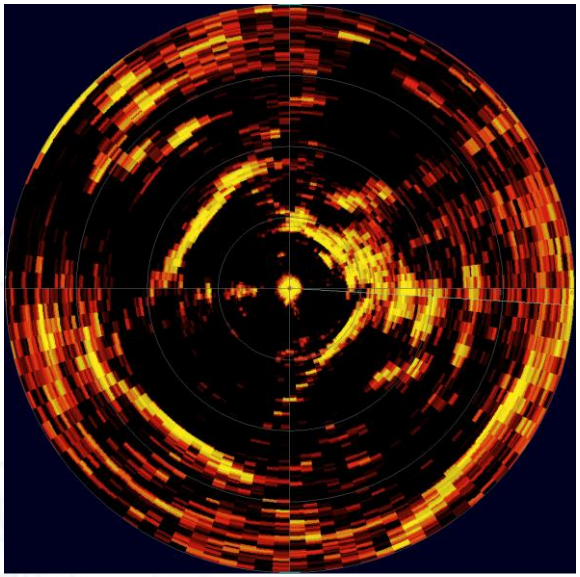




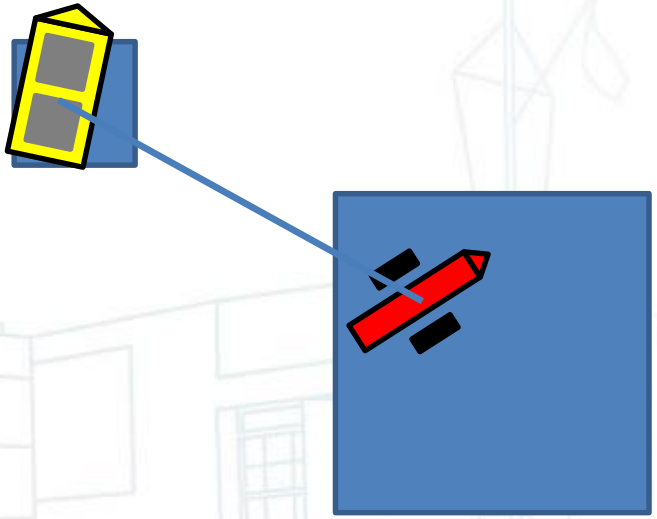
Detail on static sonar localization



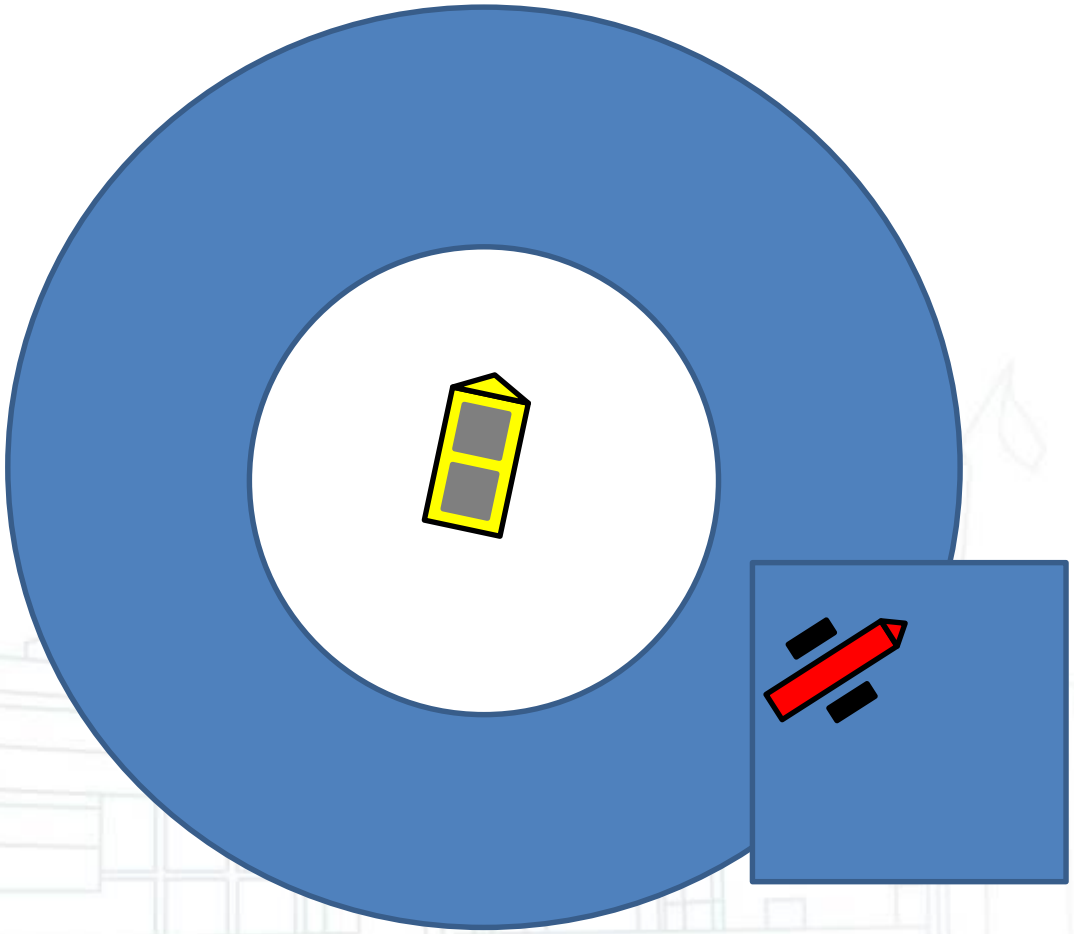




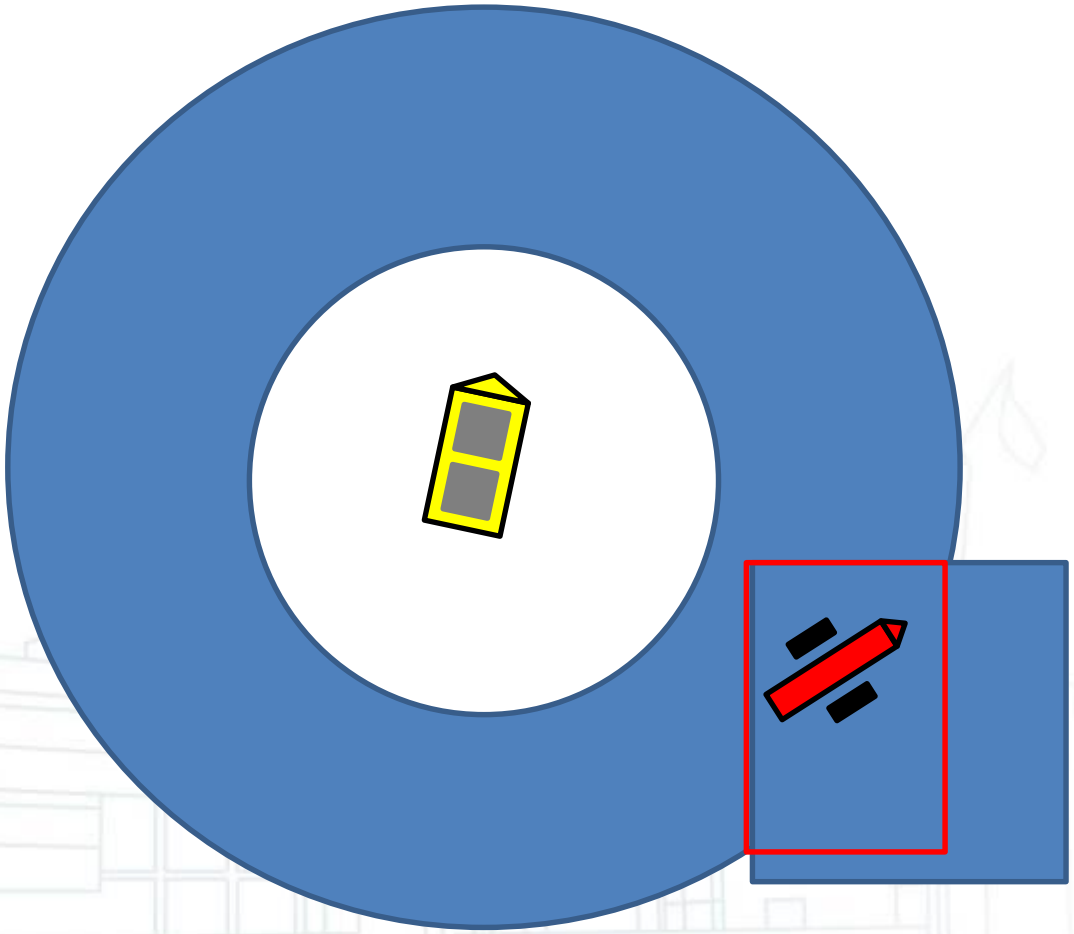
Detail on collaboration with ASV



Detail on collaboration with ASV

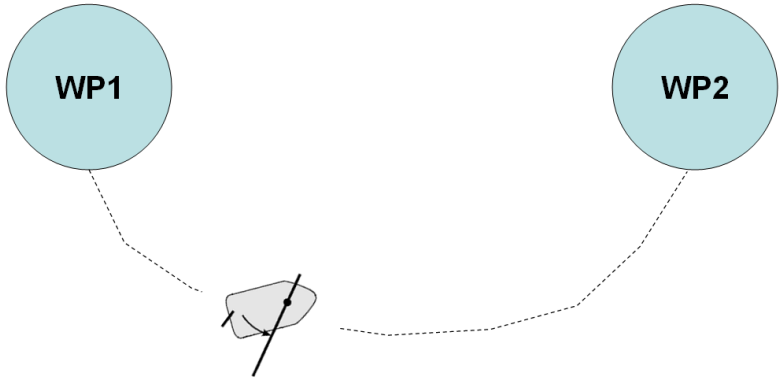


Detail on collaboration with ASV



Detail on control

- From waypoints following to line following
  - Primitive heading control loop
  - Existing approaches : basic waypoint following
    - The robot follows a heading in direction of its waypoint
    - Waypoint reached when in a predefined radius
    - Problem : nothing prevent the drift between waypoints (because of currents...)

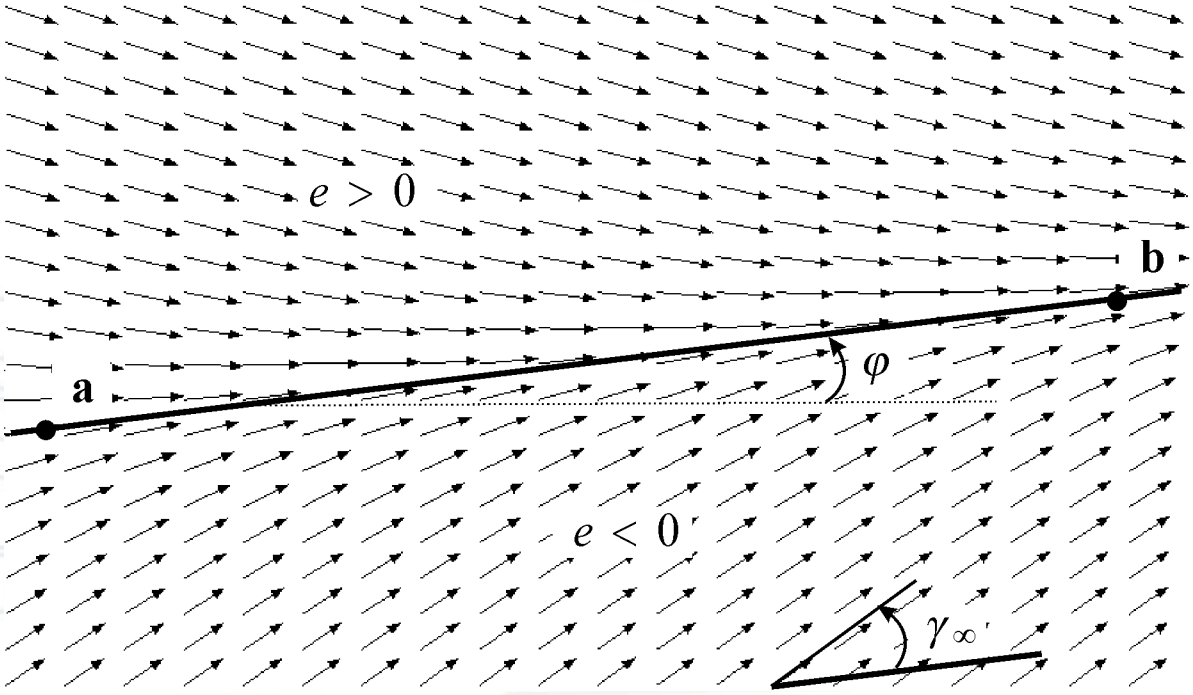


  - => Line following (use the distance to the line)

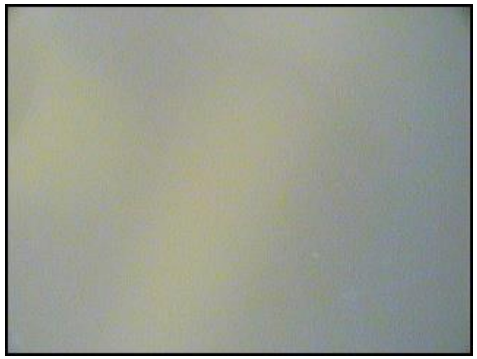
Detail on control : line following

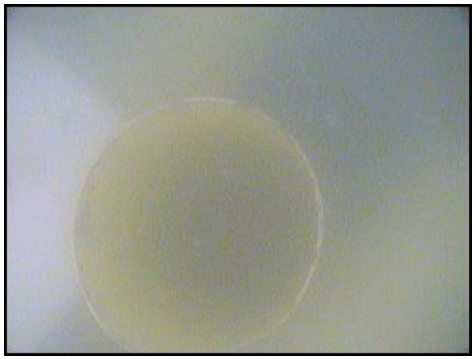
- Line following :
  - Target heading will be the line between the 2 current waypoints, with an attractive angle depending on our distance to the line

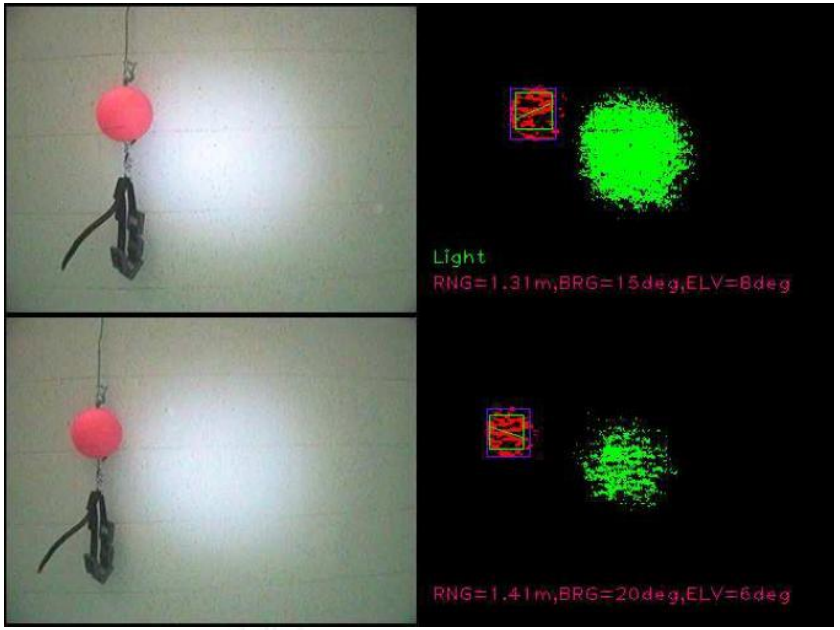
$$e = \det\left(\frac{\mathbf{b}-\mathbf{a}}{\|\mathbf{b}-\mathbf{a}\|}, \mathbf{m}-\mathbf{a}\right)$$
$$\varphi = \text{atan2}(\mathbf{b}-\mathbf{a})$$
$$\bar{\theta} = \varphi - \frac{2.\gamma_\infty}{\pi}.\text{atan}\left(\frac{e}{r}\right)$$

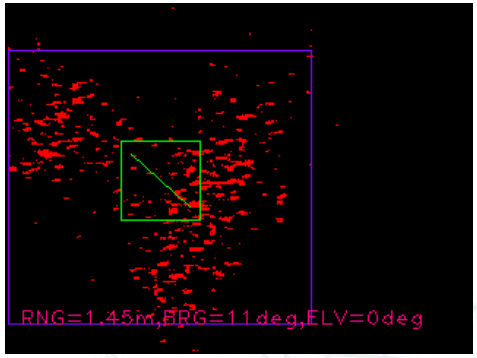


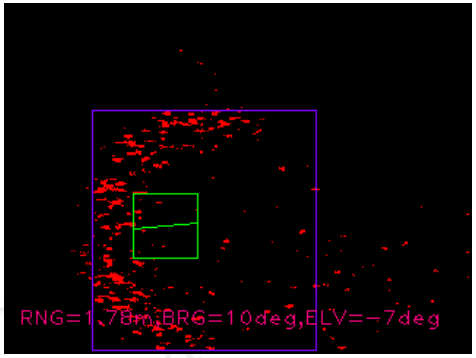
Detection/tracking of objects : HSL

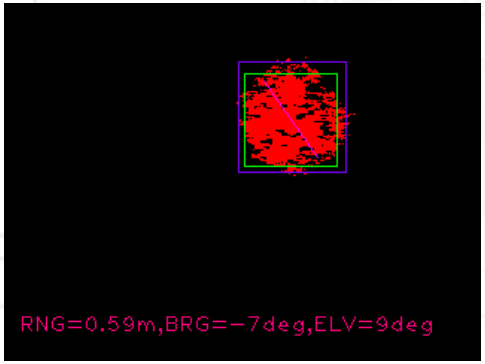


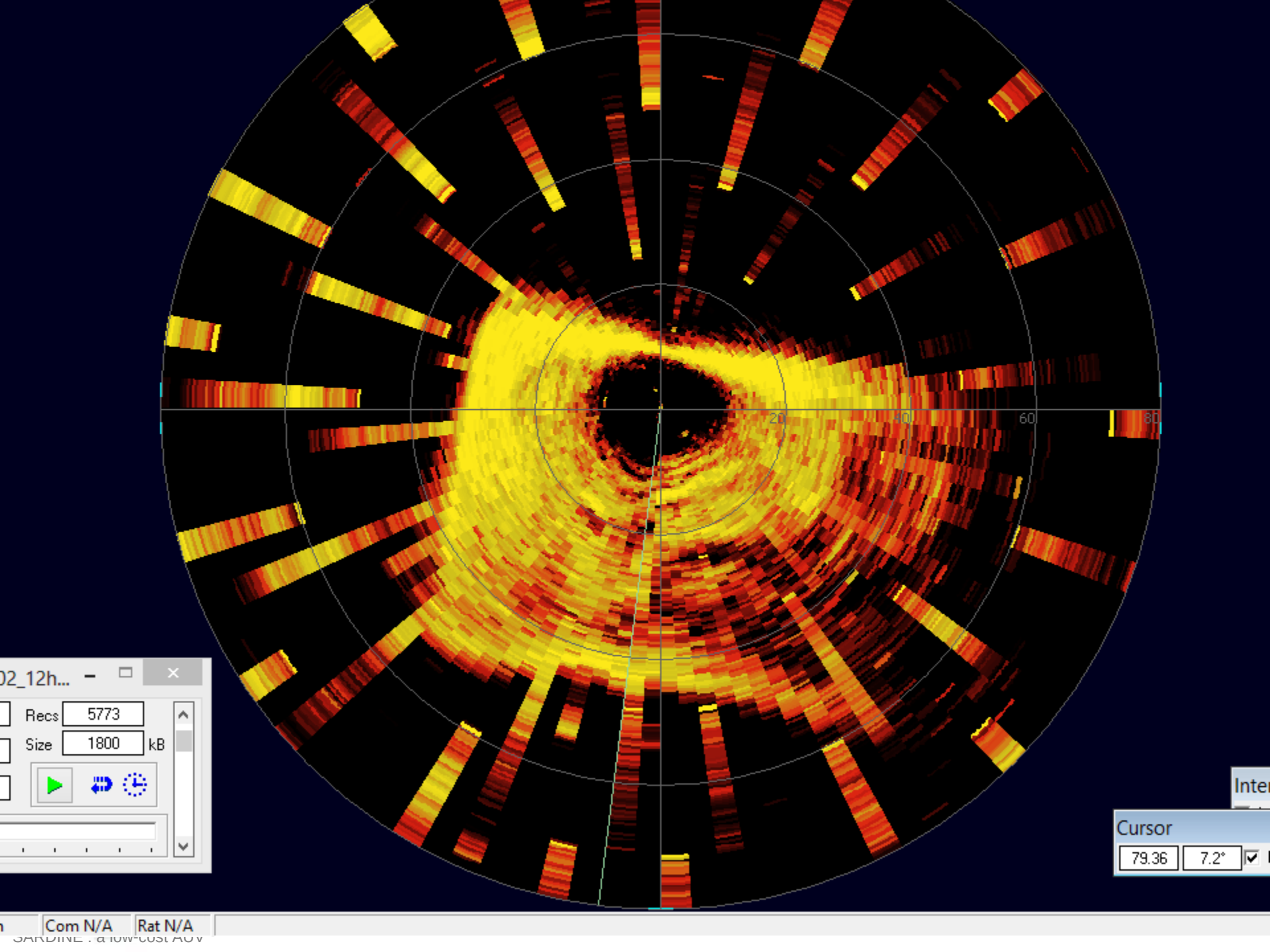




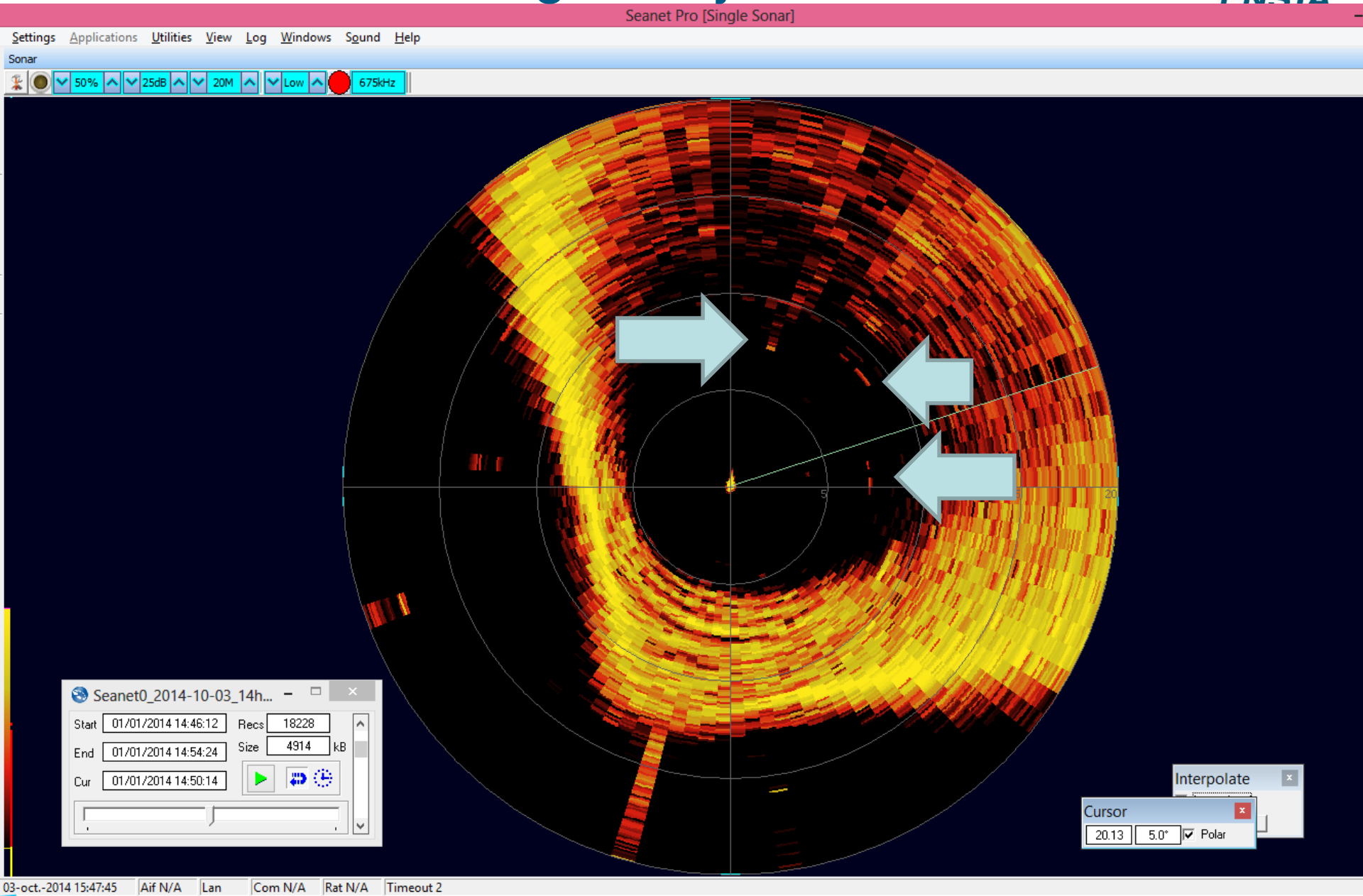


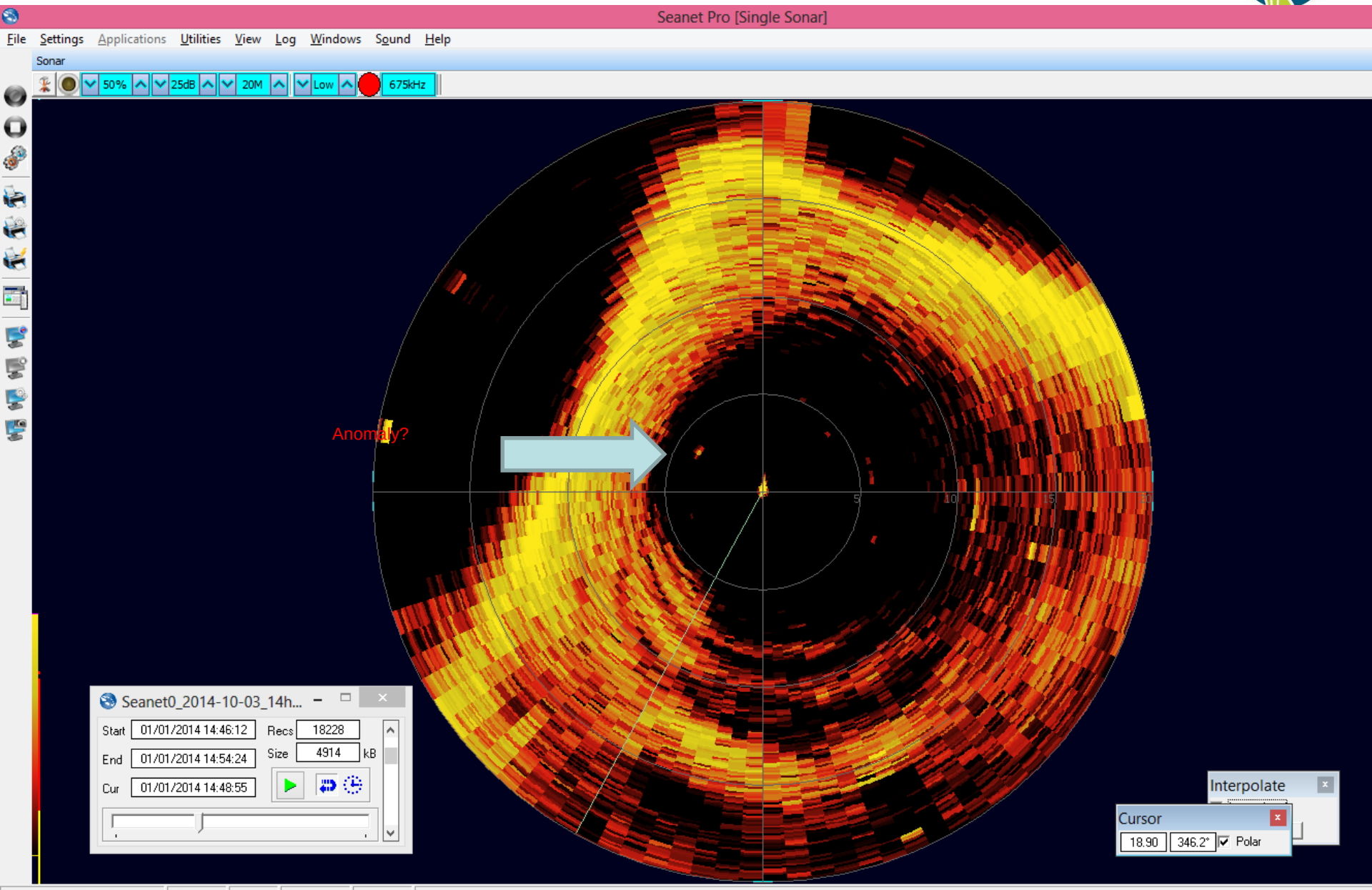




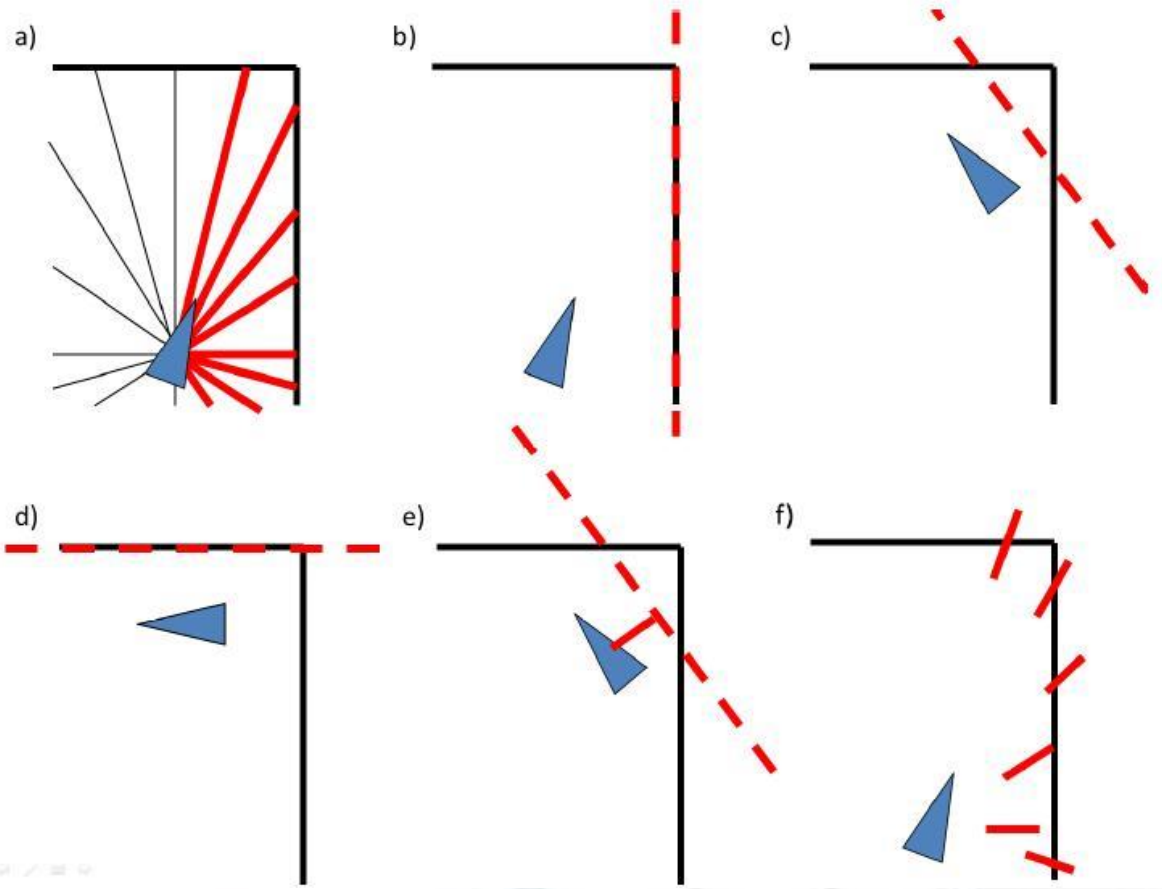

20
40
60
80
02_12h...
Recs
5773
Size
1800
kB
Cursor
79.36
7.2°
Com N/A
Rat N/A

Detection/tracking of objects : sonar

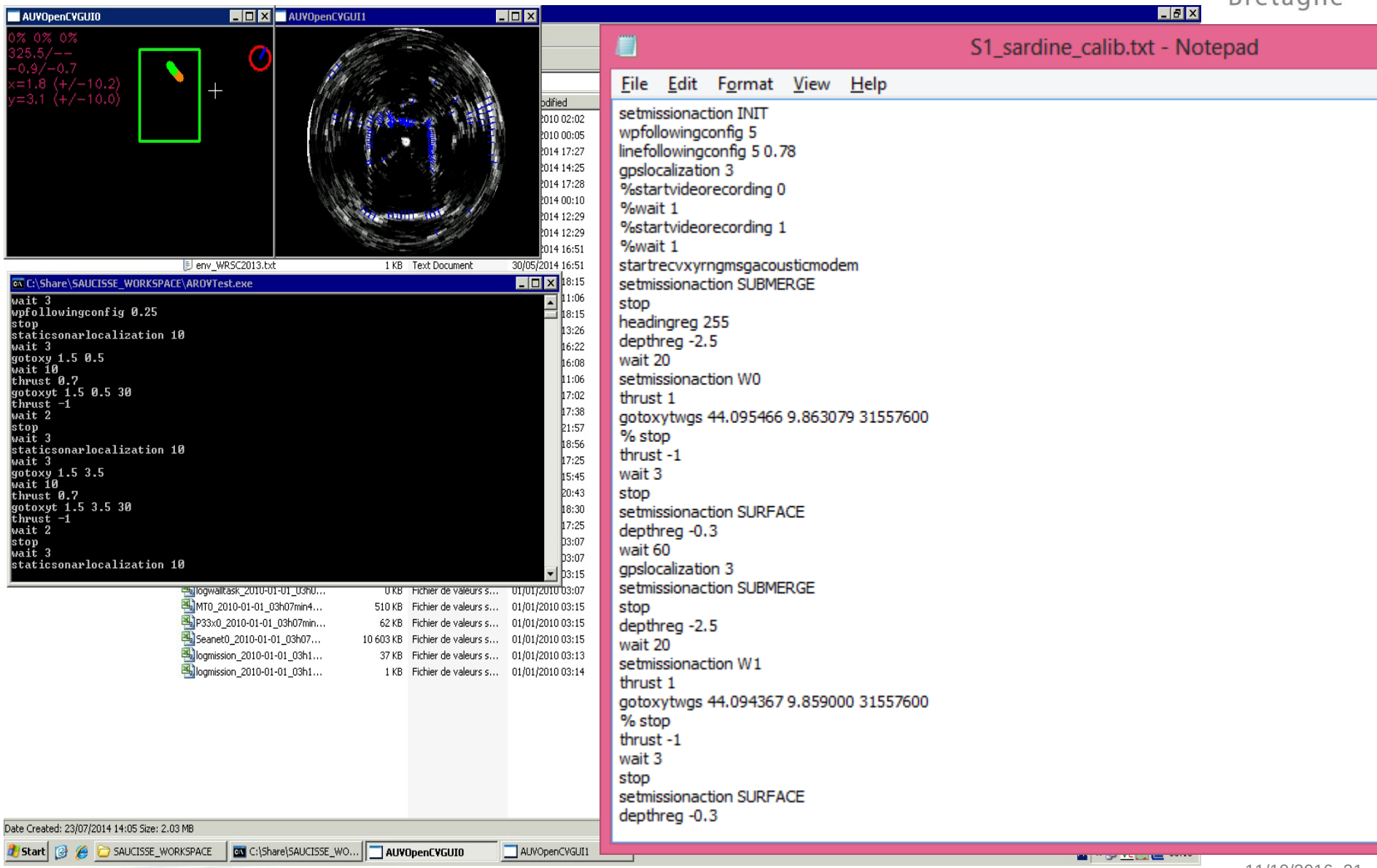



Seanet Pro [Single Sonar]
File Settings Applications Utilities View Log Windows Sound Help
Sonar
50% 25dB 20M Low 675kHz
Anomaly?
Seanet0_2014-10-03_14h...
Start 01/01/2014 14:46:12
End 01/01/2014 14:54:24
Cur 01/01/2014 14:48:55
Recs 18228
Size 4914 kB
Interpolate
Cursor
18.90 346.2° Polar
ven., 03-oct.-2014 15:54:45 Aif N/A Lan Com N/A Rat N/A

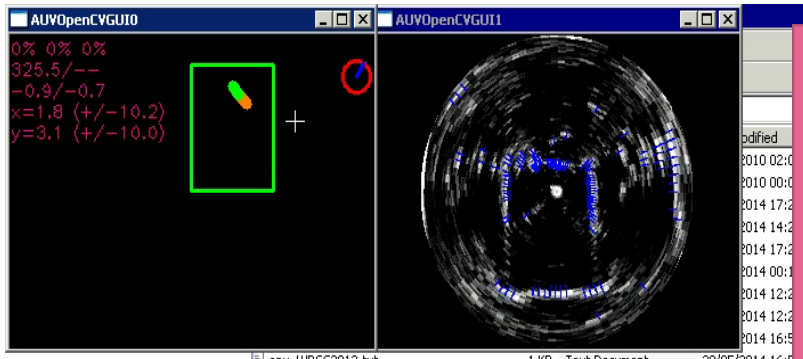
Wall following

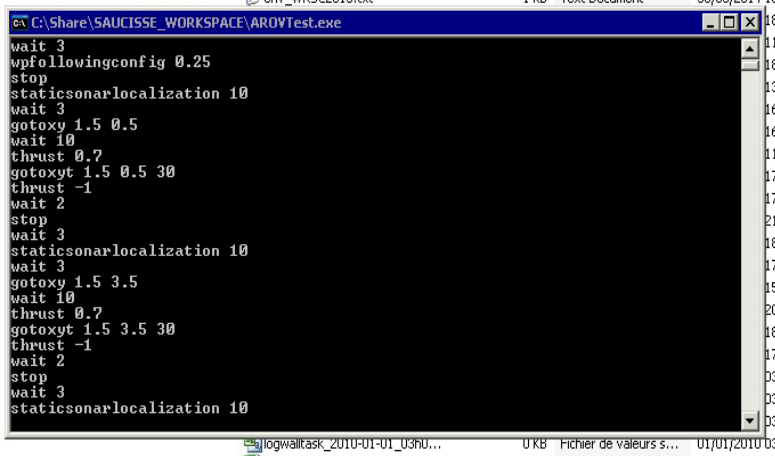


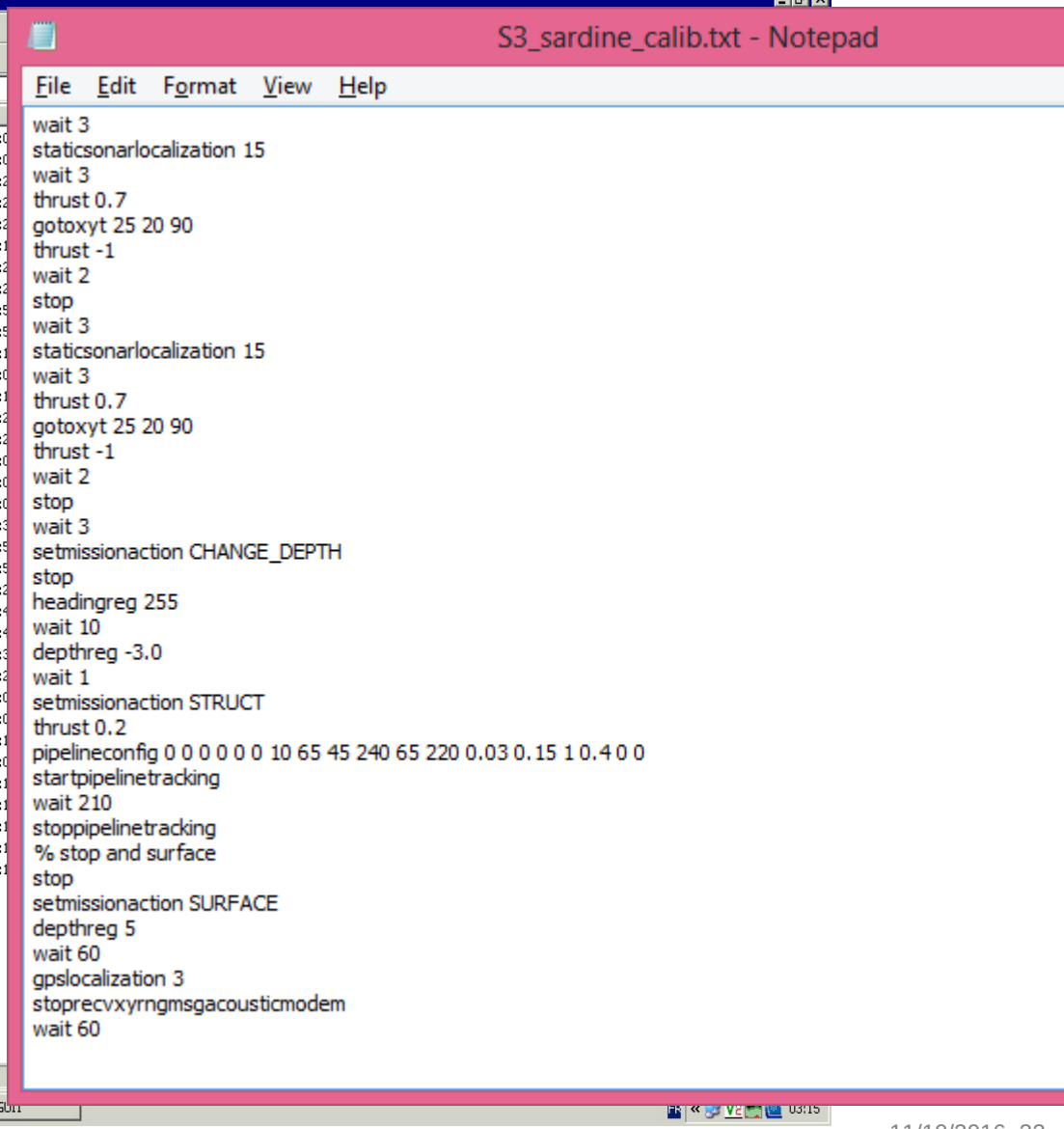
Software and mission specification



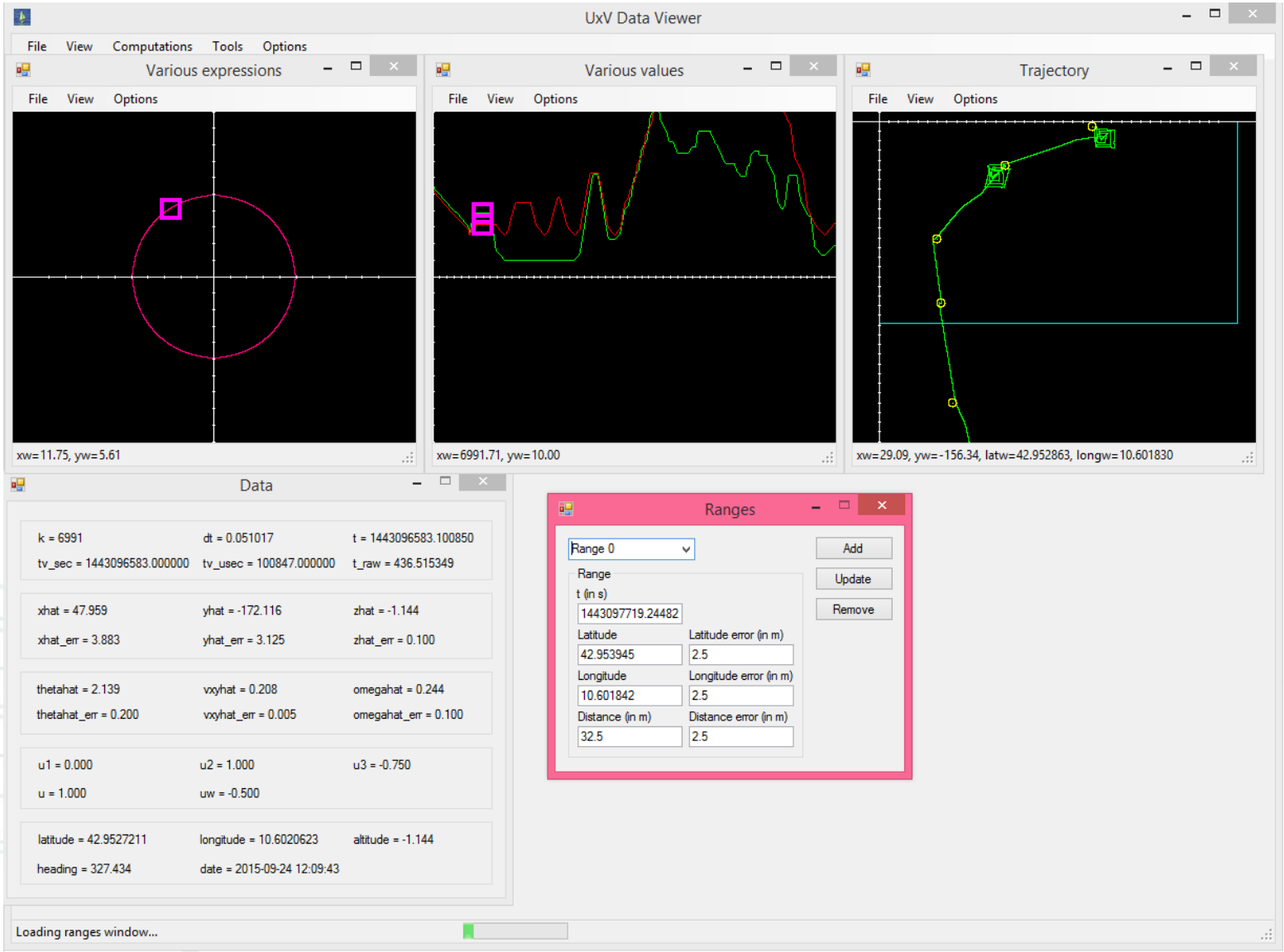
Software and mission specification



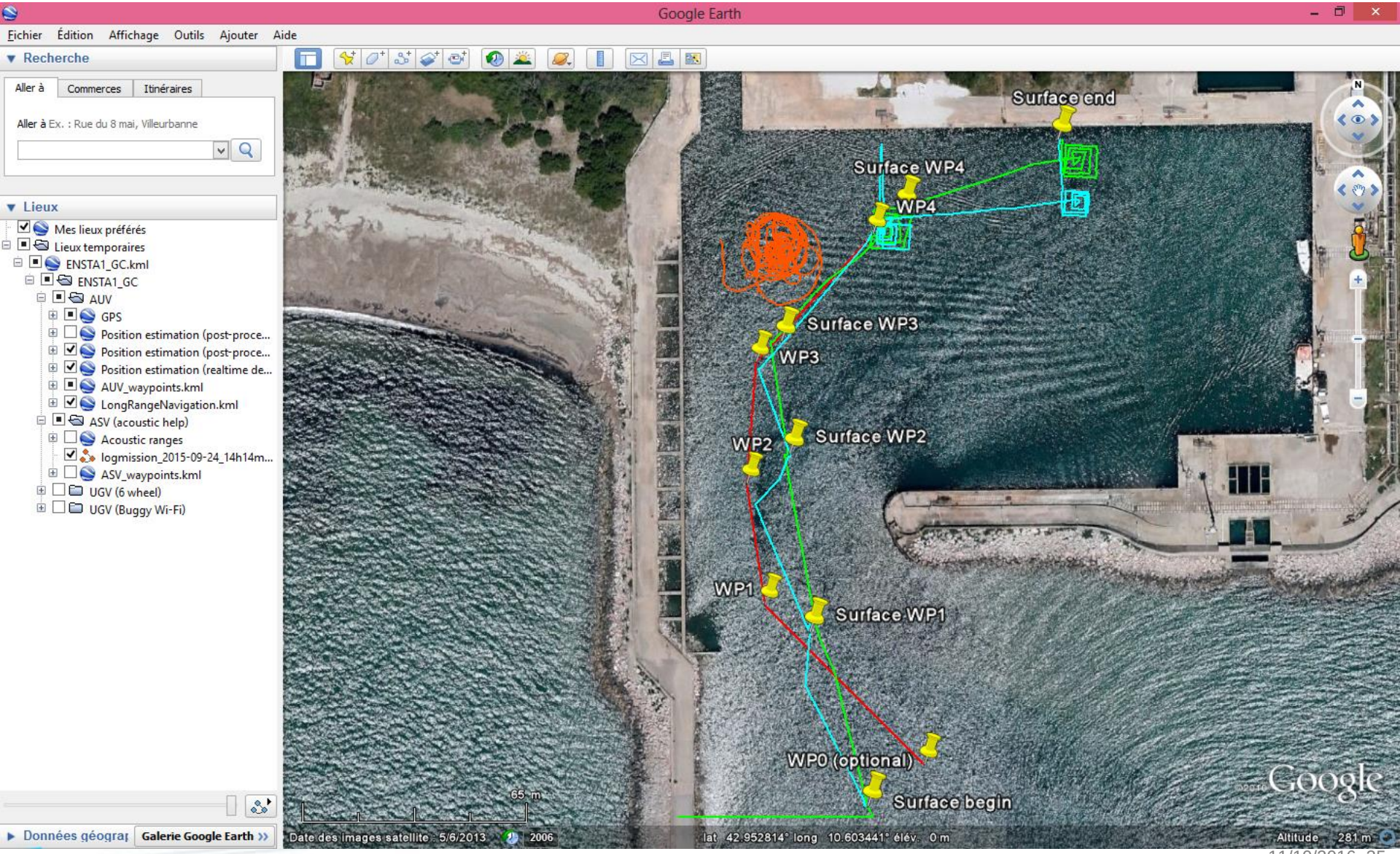




Data analysis




OPI
Surface
OPI
Eurathlon WP3
Eurathlon WP4
UW Structure
Surface
Eurathlon WP2
Surface
Eurathlon WP1
77 m
Image © 2014 DigitalGlobe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LongRangeNavigation.kml
ASV (acoustic help)
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ASV_waypoints.kml
UGV (6 wheel)
UGV (Buggy Wi-Fi)
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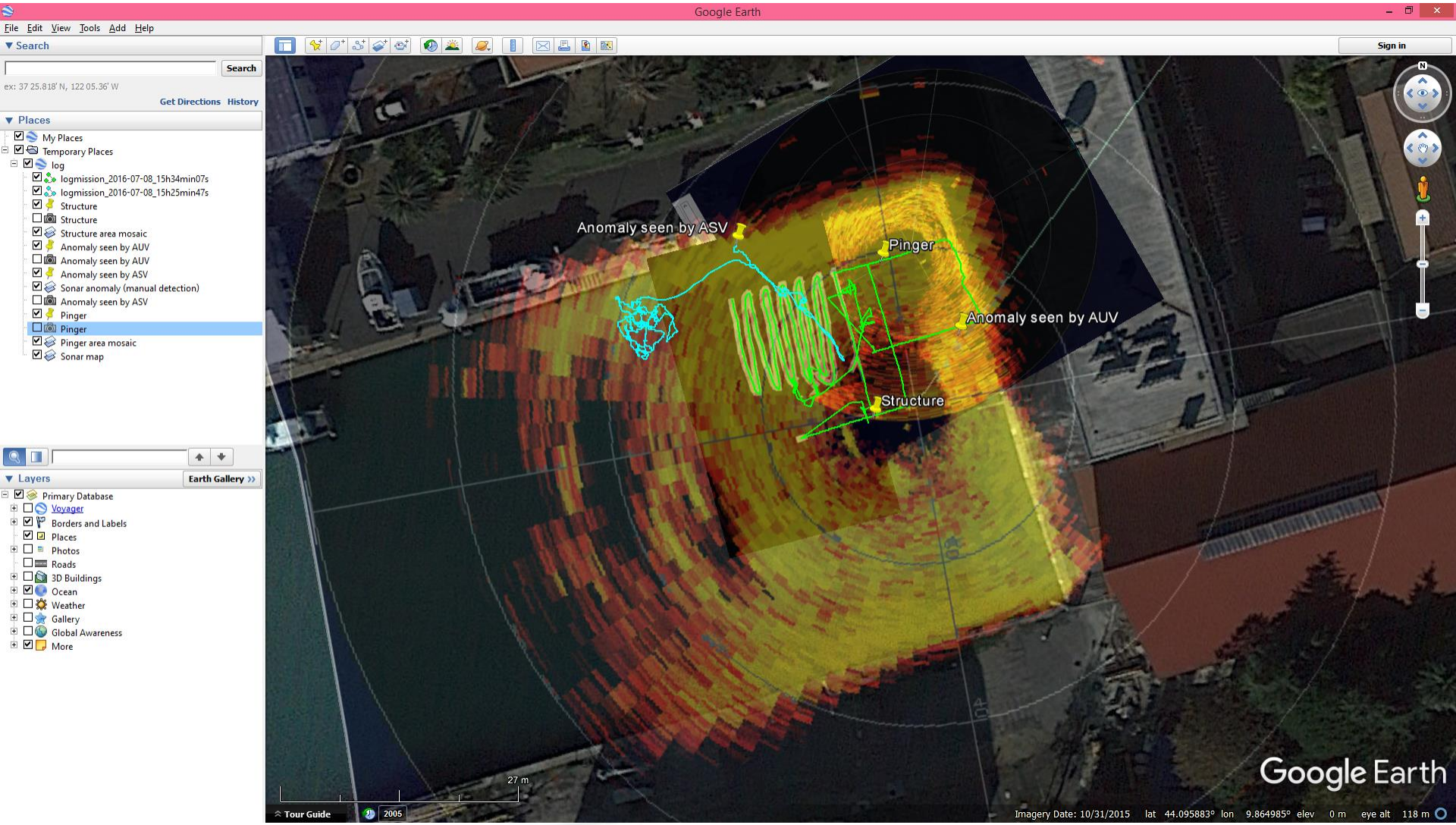
Google Earth
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Structure
Structure
Structure area mosaic
Anomaly seen by AUV
Anomaly seen by AUV
Anomaly seen by ASV
Sonar anomaly (manual detection)
Anomaly seen by ASV
Pinger
Pinger
Pinger area mosaic
Sonar map
Layers
Earth Gallery
Primary Database
Voyager
Borders and Labels
Places
Photos
Roads
3D Buildings
Ocean
Weather
Gallery
Global Awareness
More
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Anomaly seen by ASV
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Anomaly seen by AUV
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27 m
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2005
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Google Earth

Conclusion

Conclusion

- Using low-cost AUVs such as SARDINE, we can demonstrate the efficiency of new methods such as those based on interval analysis
- Our results to the previous SAUC-E (1st in 2016) and euRathlon (2nd in most of 2015 submarine tasks) competitions show that our approach is competitive with others

Questions?