Towards good experimental methodology for Unmanned Marine Vehicles: issues and experiences

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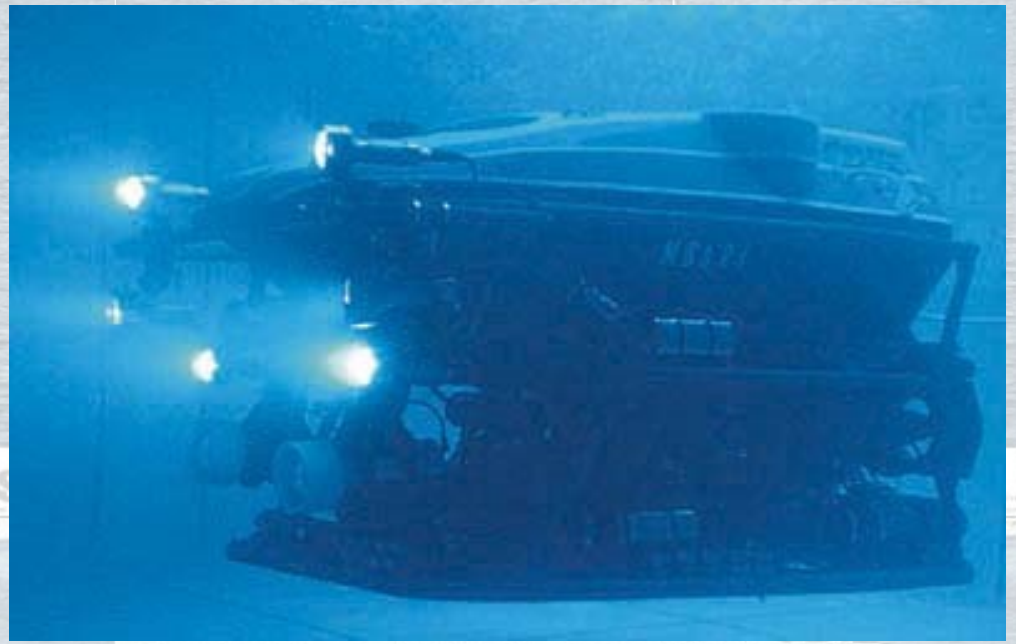
Unmanned Marine Vehicles

ROVs

Remotely Operated Vehicles



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Unmanned Marine Vehicles

AUVs

Autonomous Underwater Vehicles

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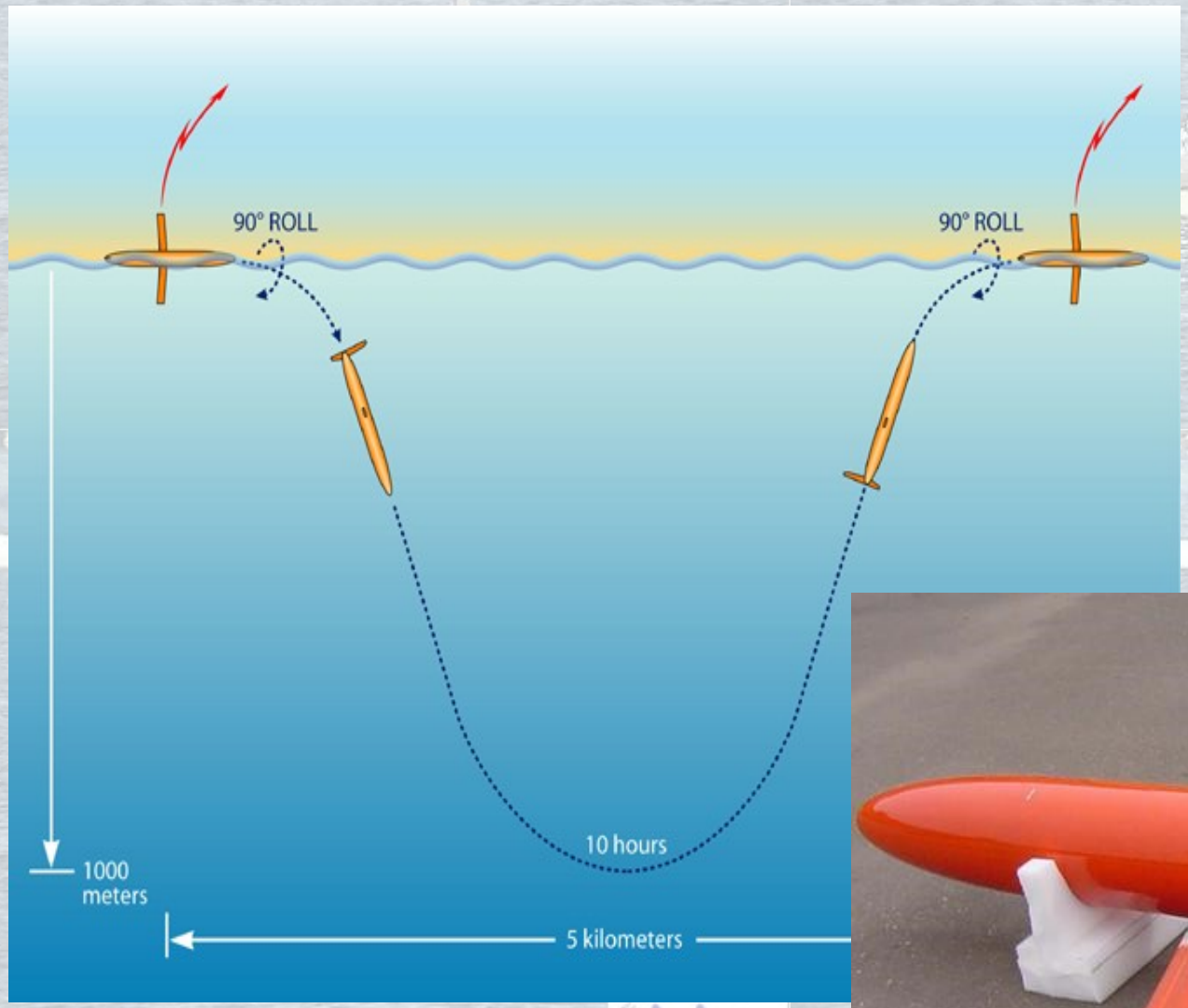
Unmanned Marine Vehicles

Gliders



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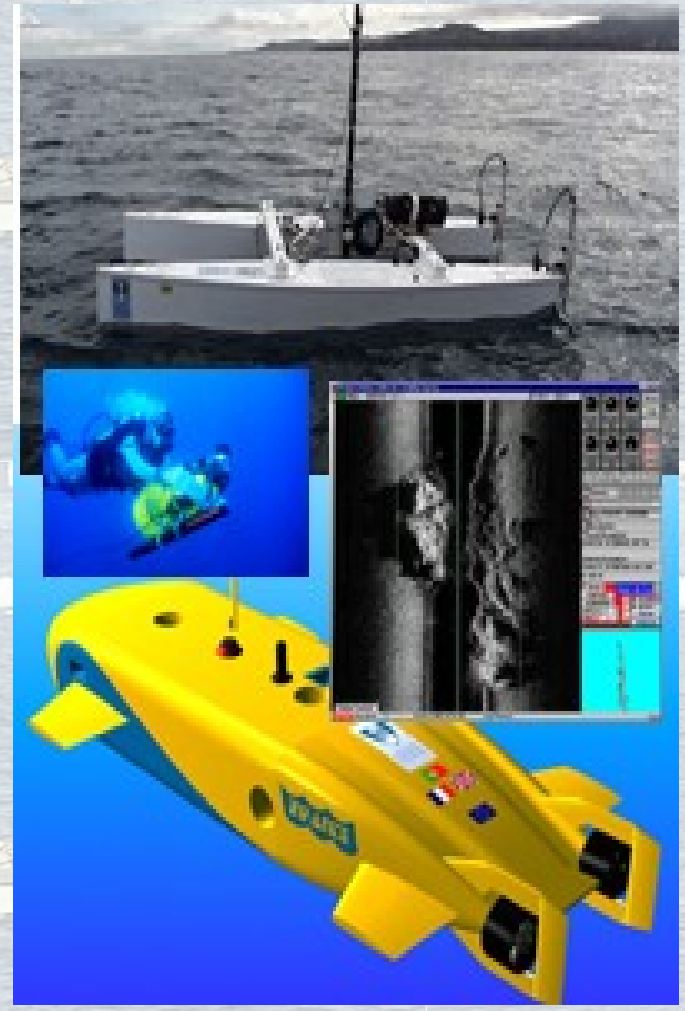
Unmanned Marine Vehicles

USVs

Unmanned
Surface
Vehicles



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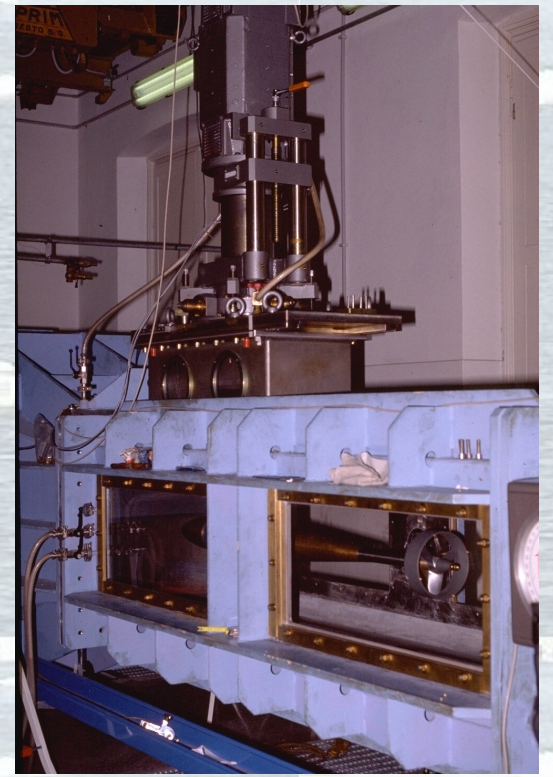
Robotics in marine environment

- The high degree of uncertainty, typical of marine environment, in external disturbance, sensor performance and exerted control action, as well as logistical and operational constraints, makes very difficult the execution of repeatable experiments at sea and the establishment of ground-truthing methodologies.

- Basic issues emerged in the field of identification, guidance and control, motion estimation and environment reconstruction of UMVs in recent years are presented with the adopted practical experimental procedures.

Topic 1: uncertainty in control action (1)

- **Application**: identification of the dynamics of a propeller-propulsed ROV using onboard sensor measurements
- **Physics**: the thrust exerted by a propeller is function of the propeller revolution rate and speed of the water inside the propeller blades
- **Model (static)**: $T = a n|n| - b v_a n$
  - identified in thrust-tunnel tests
- **Model (dynamics)**
  - "an improved understanding of thruster and fluid dynamics under reversing flow conditions would be of considerable interest" - Whitcomb & Yoerger, IEEE Journal of Oceanic Engineering, vol. 24, n. 4, 1999



Topic 1: uncertainty in control action (2)

- **Conventional identification techniques**: step input signals with sign inversions
  - inertial parameters are determined by system behaviour during transients
- **Issue 1**: the speed of the water inside the propeller blades is not known during speed inversions

$$m\dot{x} = -k_x x - k_{x|x|} x|x| + \tau + \eta$$

- **Proposed solution**: decoupling identification of drag and steady-state disturbance vs. inertial terms
  - steady-state maneouvres: drag parameters
  - uniform sign offset sinusoidal input: inertia parameters
    - Caccia, Indiveri & Veruggio, IEEE Journal of Oceanic Engineering, vol. 25, n.2, 2000

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Topic 1: uncertainty in control action (3) logistical issues

- **Issue 2**: high impact logistical needs (time, space, interactions with everyday traffic, weather conditions) to execute suitable maneouvres with some classes of vehicles, e.g. Unmanned Surface Vehicles
  - Caccia, Bruzzone & Bono, IEEE Journal of Oceanic Engineering, vol. 33, n.2, 2008
- **Proposed solution**:

  identification based on self-oscillations
  - Miskovic, Vukic, Bibuli, Bruzzone & Caccia, Journal of Field Robotics, vol. 28, n.1, 2011

Topic 2: repeatable experiments (1)

- **Issue 1**: time requirements
  - example: experiments for identification based on self-oscillations with Charlie USV
    - Genova Prà harbour: recreational traffic and regatta field
      - 120 experiments in two days
        - 5 speeds, 4 relay output, 4 relay switch value
- **Issue 2**: environmental conditions
  - it is possible to measure them, e.g. wind speed and direction

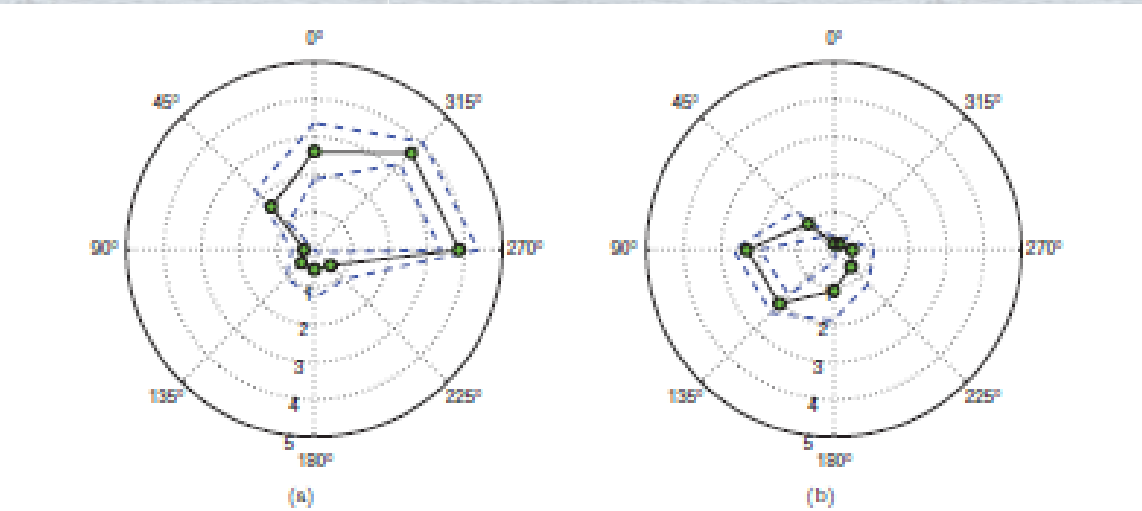
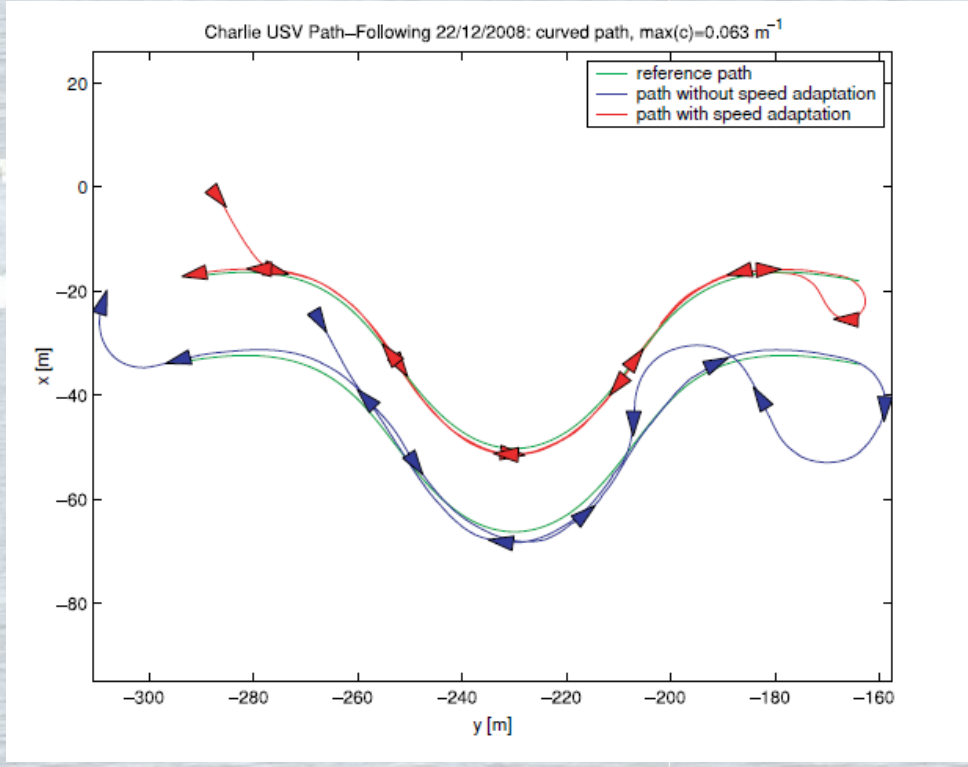


Figure 6. Average wind speed and direction during (a) day 1 and (b) day 2 in meters per second measured in the Earth-fixed coordinate frame show significantly different environmental conditions during the 2 days.

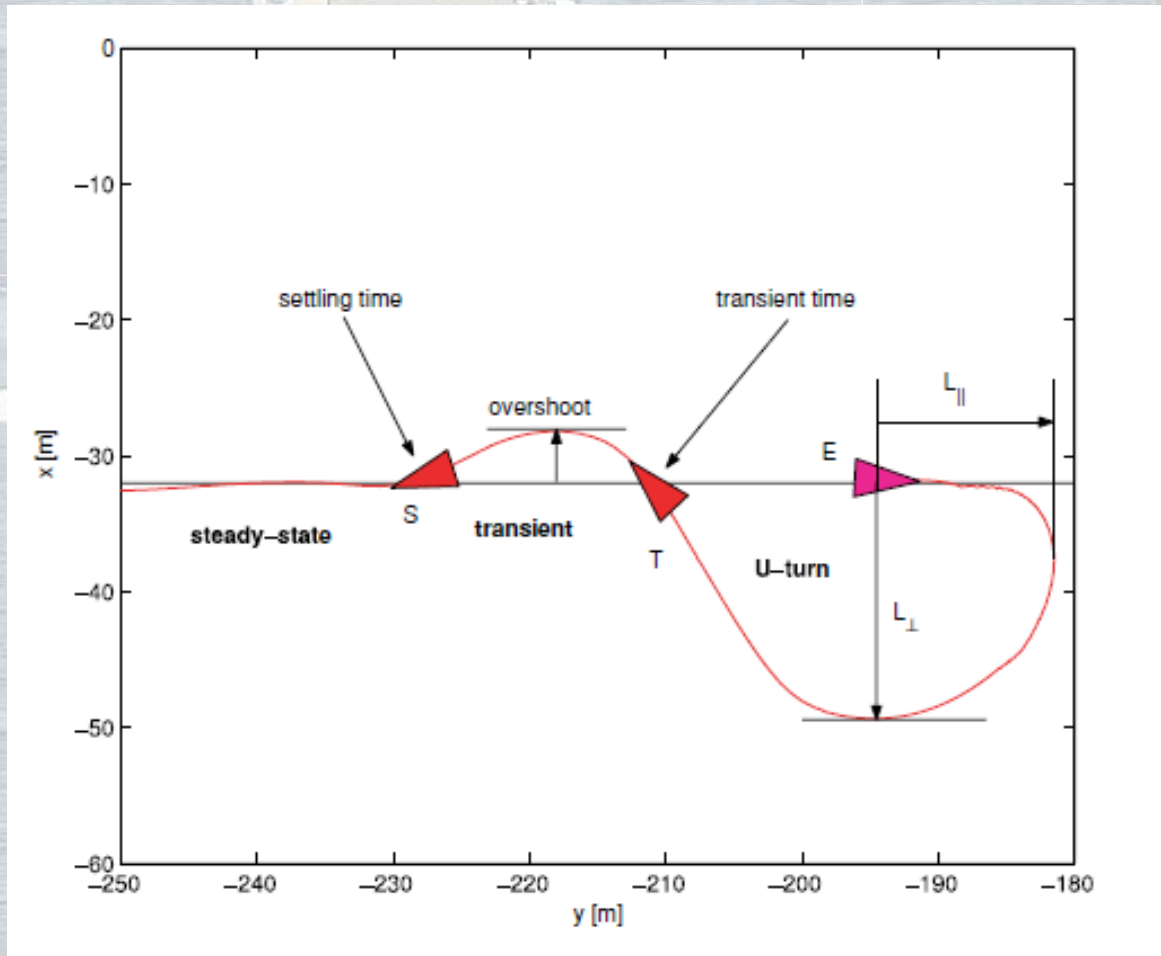
Topic 2: repeatable experiments (2)

- **Issue 3**: reply initial conditions
  - it is very difficult (impossible?) to drive a UMV in the pre-defined starting position and speed
    - *generic solution for path-following*: relative position of the target path with respect to the actual vehicle position
      - attention: logistical constraints, e.g. free area available for tests
    - *feasible, verified solution for path-following*: moving along the same path in opposite directions
      - the vehicle is guaranteed to remain in a stripe around the target path



Topic 3: metrics

- Maneouvring phases and measured quantities, e.g. line-following
  - U-turn (path-approach)
    - $L_{\parallel}$, $L_{\perp}$, $A_{\text{U-turn}}$
  - Transient
    - overshoot
  - Steady-state
    - $\bar{A}_{ss} = \frac{A_{ss}}{\Delta s_{ss}}$



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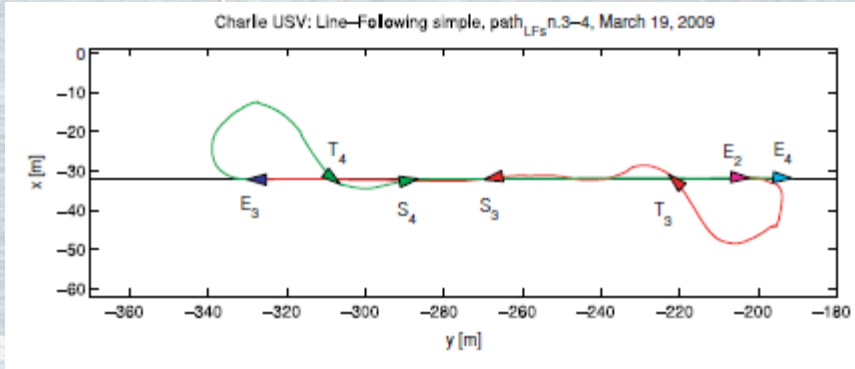
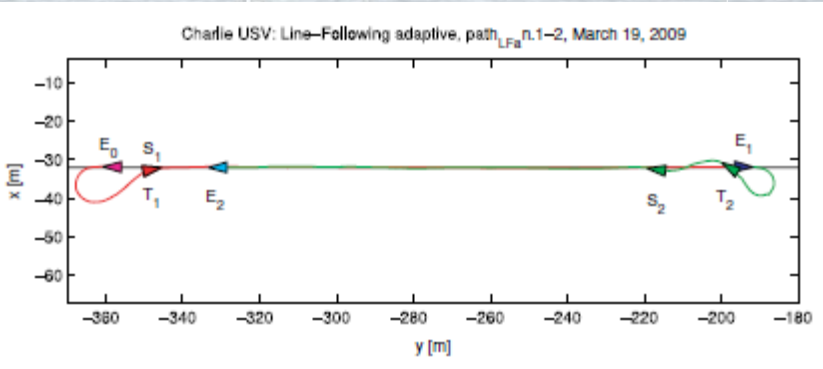
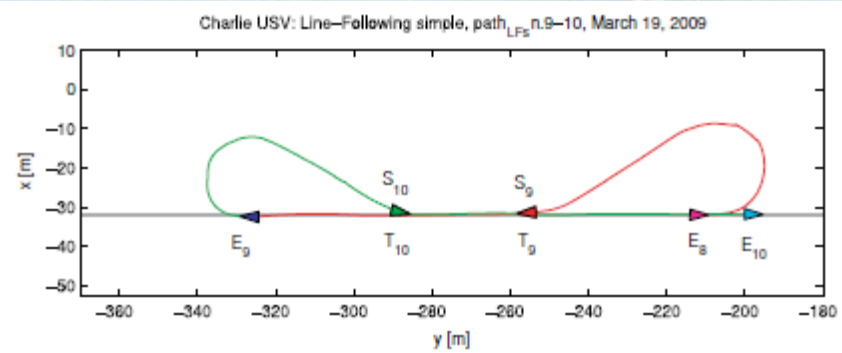
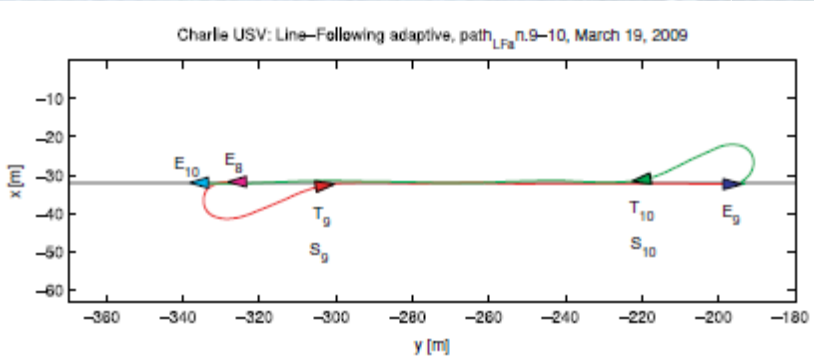
Topics 2 & 3: repeatable experiments & metrics

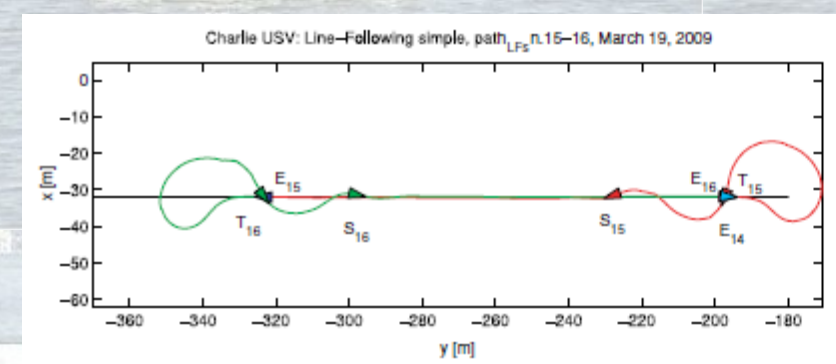
- Straight line-following

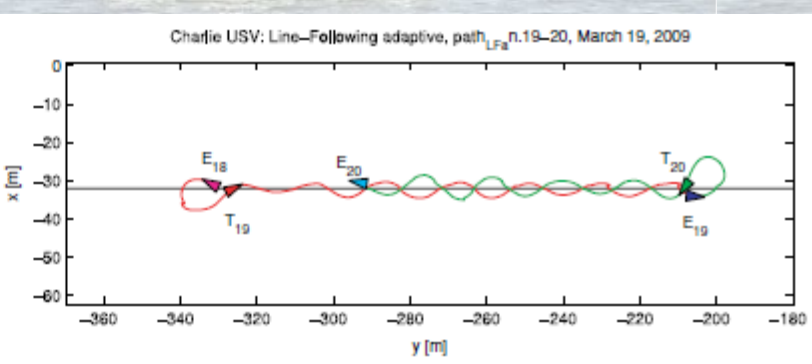






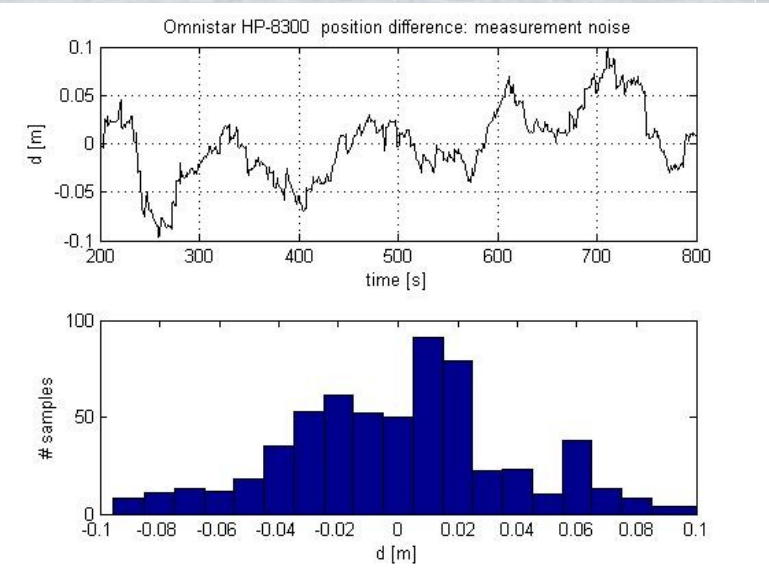






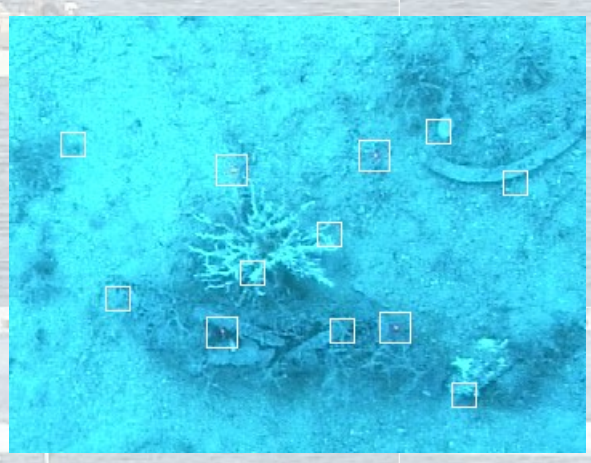
Topic 4: ground-truthing

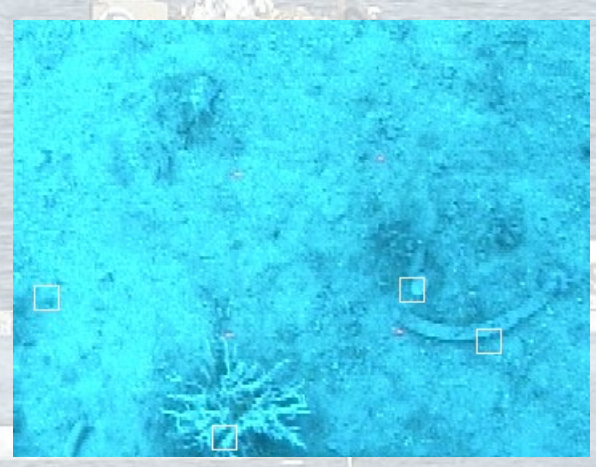
- Case 1: artificial landmarks in the test site
  - example: surface vessel following
    - Goal: to guarantee that the two vehicles are in the same place according to their GPS devices
      - GPS devices could have different time-varying offsets
    - Step 1: measure the offset of two GPS devices
    - Step 2: use artificial landmarks, such as the buoys delimiting the lanes of a regatta field



Topic 4: ground-truthing

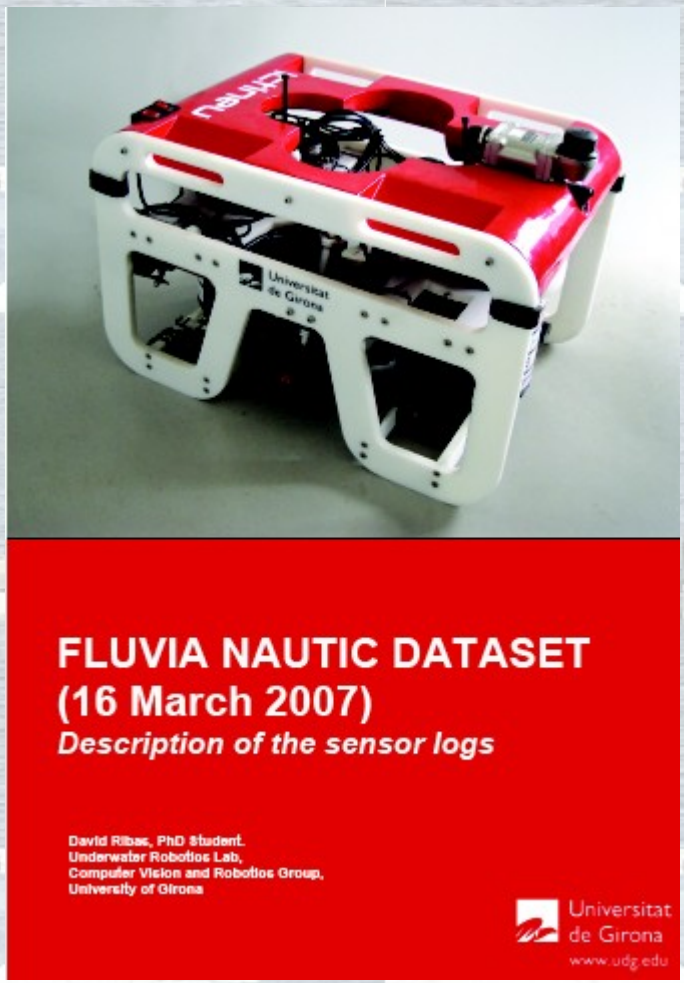
- Case 2: natural landmarks in the test site
  - Example: vision-based motion estimation for ROVs
    - Goal: to check the precision of dead-reckoning based on visual odometry for estimating the motion of ROVs
    - Step 1: determining a human-detectable visual target
    - Step 2: maneouvring the ROV in order to periodically re-visit the detected visual target - **this step is not obvious**
    - Step 3: computing the displacement between two images containg the detected target and compare it with the estimated displacement with dead-reckoning





Topic 5: data sets

- High cost of data acquisition (time, logistics, man-power, UMVs)
  - data are usually made available only after the research group who collected them have published using them
- Available data sets: an example
  - Radish: The Robotics Data Set Repository
    - Standard data sets for the robotics community
    - Name: abandoned_marina
      - Desc: Dataset recorded with the Ictineu underwater vehicle at the Fluvia Nautic abandoned marina near St Pere Pescador (Spain) in 16 March 2007.
      - David Ribas, Underwater Robotics Lab, Computer Vision and Robotics Group, University of Girona, 22 May 2009



Hints from other disciplines

- From a talk with Silvio Parodi, Professor of Oncology, School of Medicine, Università di Genova
  - "The scientist should not neglect the experiments that do not match the expected/hoped behavior of the investigated phenomenon. Not infrequently, at least in the bio-medical world, they are much more than possible outliers. The objective complexity, resource and time requirements of some crucial experiments, make practically difficult to repeat the entire procedure more than 3-5 times. Discarding one of these repeated experiments because of adduced deficiencies / improprieties, *established however only a posteriori*, is formally unacceptable. Even intuitively, a result that could be confirmed only 3/5 times is totally different from a result that could be confirmed 3/3 times!"

focus on *bad* experiments

Conclusions

- Complex logistics, unforeseen environmental conditions, structural uncertainty, determining high resource and time requirements for the execution of experiments, contribute to keep marine robotics results at the level of **naive demonstration of successful case studies**
- Goal: **making marine robotics an experimental science**
- What can be done towards this goal?
  - improving metrics definition
  - defining protocols for the measurement of environmental conditions
  - defining procedures for the repetition of experiments
    - automation of event-based task sequences, i.e. basic mission control, can dramatically help
    - defining methodologies for statistical characterisation of experiments
  - discussing *unexpected* results

From research to industrial issues

- Legal issues
  - lack of rules for the operation of unmanned marine vehicles at sea
    - Issues concerning the rules for the operation of Autonomous Marine Vehicles (AMVs) – A consultation paper. Published by the Society for Underwater Technology,
      available at http://sig.sut.org.uk/urg_uris/URG_AMV_paper.pdf
  - Liability issues
    - insurance policies and rates
    - involvement of classification societies