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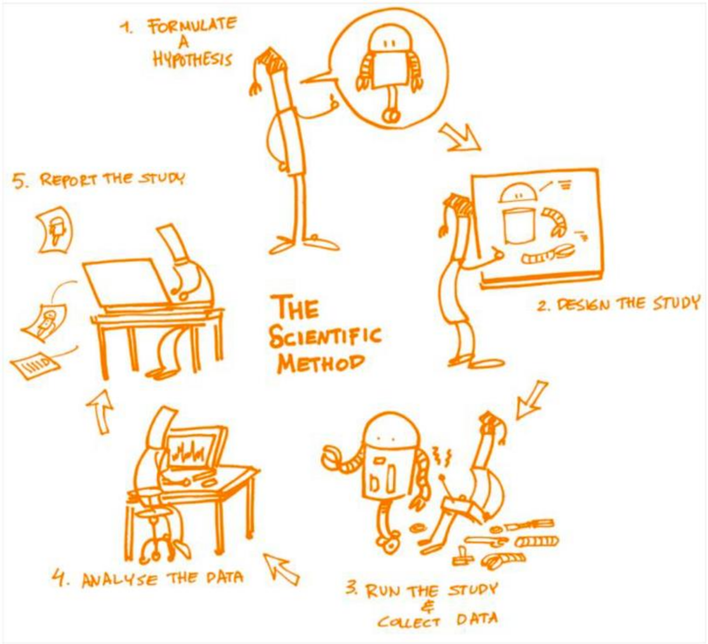

Good Experimental Methodologies in marine robotics

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Marine robotics: a data-centric vision

Economic

Industry

Robots from special tools to standard devices

Standard procedures for system characterisation:
- system dynamics (robotics)
- manoeuvring performance (ITTC).

Experiment replicability and quantitative performance indexes (GEMs)

Autonomous data acquisition

Good Experimental Methodologies

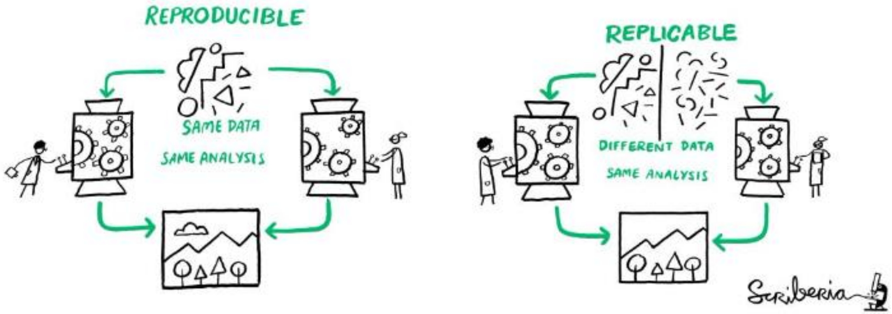
Data Centric Vision

AI-training manoeuvres & data sets

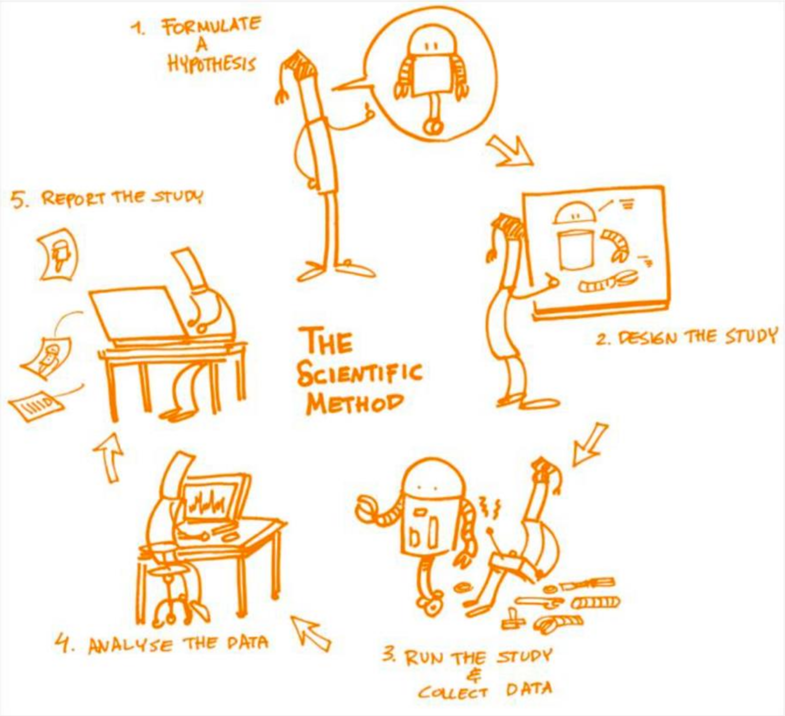
Digital Twin of ocean & platforms

Good Experimental Methodologies

- Concept of reproducibility/replicability as a continuum of practices
- Reproducibility/replicability of results has value both as
  - a mechanism to ensure good science based on truthful claims
  - a driver of further discovery and innovation



Scientific discovery ideal model
vs. marine robotics research practice



Marine robotics usual practice

- formulate a hypothesis
- design the study
  - algorithm design, e.g. guidance law
  - a set of replicable experiments is rarely designed
- implement and run the algorithm
- analyse the data
- write a paper **with some graphs showing that the algorithm is working**
  - data will remain somewhere in our office (hard disk, USB pen, …) in a not well documented format
  - no or poor quantitative measurements of how much the algorithm works well is given

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Marine robotics specificity

This was ok to develop a mature technology that that has proven its usefulness and played the role of game-changer in many fields of application

Temptation to take shortcuts

- Experiments are not carried out in the lab, but at field with a set of (un)predictable constraints
  - environmental conditions
    - waves
    - wind
    - current
  - logistics
    - ship access
    - restricted waters access & traffic in the area
  - Time available to carry out the experiments
    - ship access has high costs
    - human resources devoted to carry out experiments have a significant cost

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Introducing GEM in marine robotics

replicable experiments and operational procedures are strictly linked

Does already exist anything similar in related disciplines?

- Given the function we want to test
  - define suitable performance indexes
    - define variables required to compute them
  - design a set of replicable experiments to measure the defined performance
    - define variables required to understand environmental conditions
  - define operational procedures to perform in-field replicable experiments
  - verify that the robot telemetry and logged data include the above-defined interest variables
  - execute the experiments, saving **FAIR** data
  - analyse the data and compute performance indexes

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Standards for ship manoeuvrability

- IMO "Standards for Ship Manoeuvrability", Resolution MSC.137(76), & "Explanatory Notes to the Standards for Ship Manoeuvrability," MSC/Circ 1053, December 2002
  - Standards were developed for ships with traditional propulsion and steering systems (e.g. shaft driven ships with conventional rudders)
- Standard manoeuvres
  - test speed of at least 90% of the ship's speed corresponding to the 85% of the maximum engine output (safety of maritime navigation)
  - Turning circle
  - Zig-zag test
  - Spiral manoeuvres
- Conditions at which the standards apply
  - deep, unrestricted waters
  - calm environment
  - full load
  - steady approach at the test speed
- Criteria

  based on ship length and test speed
  - Turning ability
  - Initial turning ability
  - Yaw-checking and course-keeping abilities
  - Stopping ability

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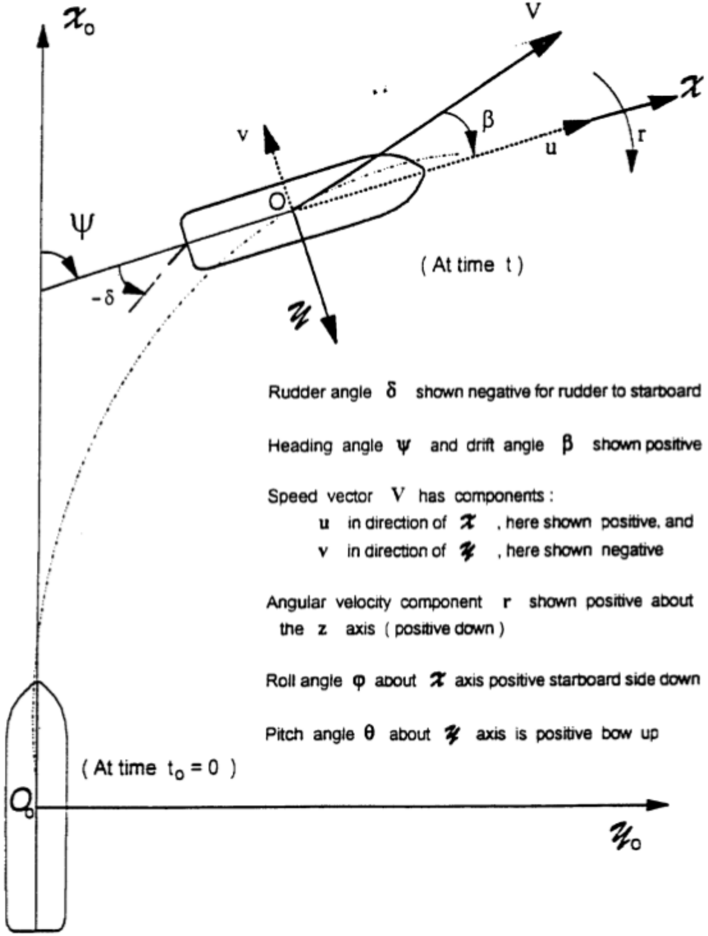
IMO MSC standard manoeuvres: nomenclature

IMO

- turning circle
- zig-zag test
- spiral manoeuvres



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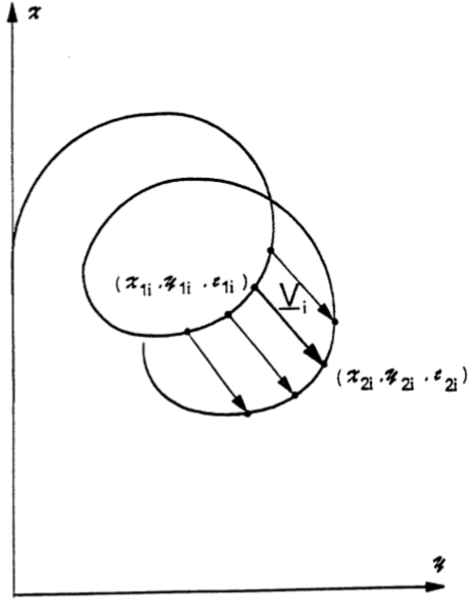
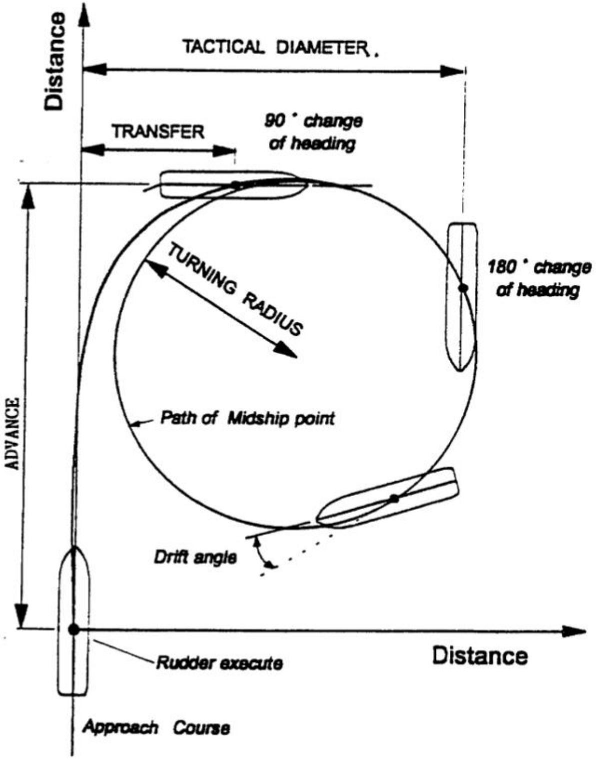
Turning circle manoeuvre

IMO

1.3.1 Turning tests

A turning circle manoeuvre is to be performed to both starboard and port with 35° rudder angle or the maximum design rudder angle permissible at the test speed. The rudder angle is executed following a steady approach with zero yaw rate. The essential information to be obtained from this manoeuvre is tactical diameter, advance, and transfer (see figure 2).





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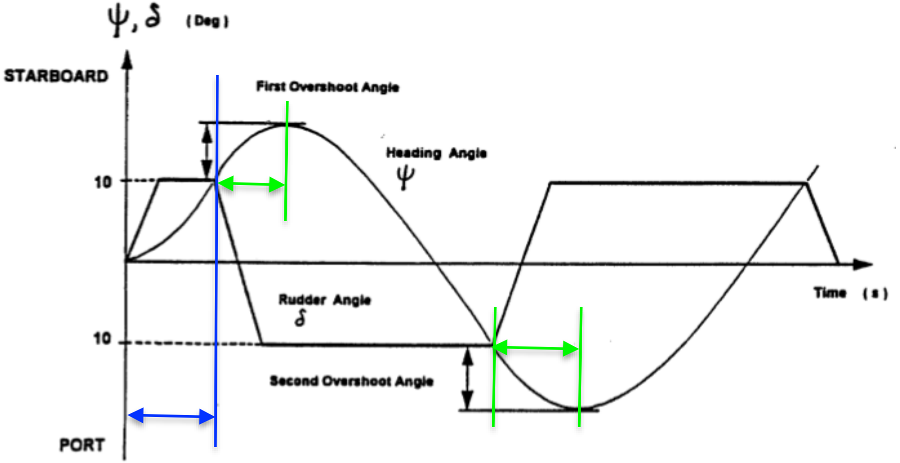
Zig-zag manoeuvre

IMO

1.3.2 Zig-zag tests

1.3.2.1 A zig-zag test should be initiated to both starboard and port and begins by applying a specified amount of rudder angle to an initially straight approach ("first execute"). The rudder angle is then alternately shifted to either side after a specified deviation from the ship's original heading is reached ("second execute" and following) (see figure 3).

1.3.2.2 Two kinds of zig-zag tests are included in the Standards, the 10°/10° and 20°/20° zig-zag tests. The 10°/10° zig-zag test uses rudder angles of 10° to either side following a heading deviation of 10° from the original course. The 20°/20° zig-zag test uses 20° rudder angles coupled with a 20° change of heading from the original course. The essential information to be obtained from these tests is the overshoot angles, initial turning time to second execute and the time to check yaw.



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Pull out and spiral manoeuvres

IMO

3 Pull-out manoeuvre

After the completion of the turning circle test the rudder is returned to the midship position and kept there until a steady turning rate is obtained. This test gives a simple indication of a ship's dynamic stability on a straight course. If the ship is stable, the rate of turn will decay to zero for turns to both port and starboard. If the ship is unstable, then the rate of turn will reduce to some residual rate of turn (see figure A4-1). The residual rates of turn to port and starboard indicate the magnitude of instability at the neutral rudder angle. Normally, pull-out manoeuvres are performed in connection with the turning circle, zig-zag, or initial turning tests, but they may be carried out separately.

2 Spiral manoeuvres

2.1 Direct spiral manoeuvre

2.1.4 The direct spiral is a turning circle manoeuvre in which various steady state yaw rate/rudder angle values are measured by making incremental rudder changes throughout a circling manoeuvre. Adequate time must be allowed for the ship to reach a steady yaw rate so that false indications of instability are avoided.

2.1.6 A direct spiral manoeuvre can be conducted using the following general procedure:

.1 the ship is brought to a steady course and speed according to the specific initial condition;

.2 the recording of data starts;

.3 the rudder is turned about 15 degrees and held until the yaw rate remains constant for approximately one minute;

.4 the rudder angle is then decreased in approximately 5 degree increments. At each increment the rudder is held fixed until a steady yaw rate is obtained, measured and then decreased again;

.5 this is repeated for different rudder angles starting from large angles to both port and starboard; and

.6 when a sufficient number of points is defined, data recording stops.

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IMO vs. marine robotics community

- Different goals
  - IMO - Maritime Safety Committee: improving maritime safety and enhance marine environmental protection
    - test speed is defined on the bases of safety
  - marine robotics community: defining and identifying the vehicle's hydrodynamics to design efficient, effective and reliable GNC systems; characterise guidance and control algorithm performance indexes
- Different vessels
  - IMO - Maritime Safety Committee: the assumption is made that the ship has normal actuators for the control of forward speed and heading (i.e., a stern propeller and a stern rudder). **However, most of the definitions and conclusions also apply to ships with other types of control actuators**
  - marine robotics: small size vessels often with other types of control actuators, **e.g. azimuth of the actuators**

Marine robotics: modeling and identification procedures based on standards for ship manoeuvrability

- **steady state hydrodynamics**
  - turning circle manoeuvres at different surge force and rudder/azimuth angle + pull-out manoeuvres
- **transient dynamics**
  - zig-zag manoeuvres at different surge force and rudder/azimuth angle + pull-out manoeuvres
- **model validation**
  - combined steady state and transient dynamics
    - direct spiral manoeuvres at different surge force and rudder/azimuth angle + pull-out manoeuvres

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Marine robotics: modelling and identification procedures based on standards for ship manoeuvrability

- Key points
  - automatic execution of the tests
  - online validation of the quality of the manoeuvre, e.g. check if steady-state has been reached in order to optimise the time required to execute the tests and the quality of the results
  - accurate description and log of experimental conditions

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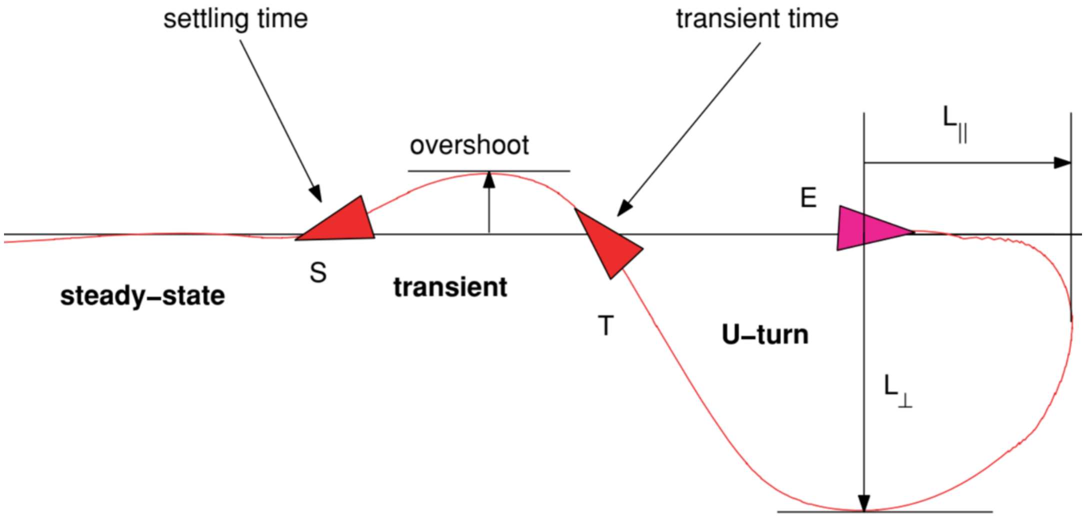
Marine robotics: GEM & performance evaluation

Line-following

- performance indexes



- operational procedures
    - move forward-backward along a straight line
    - change the orientation of the target straight line to work with a full set of environmental disturbances

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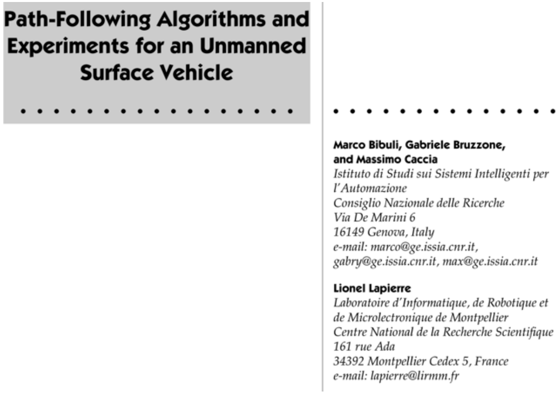
GEM in marine robotics: an example

Journal of Field Robotics



Path-Following Algorithms and Experiments for an Unmanned Surface Vehicle

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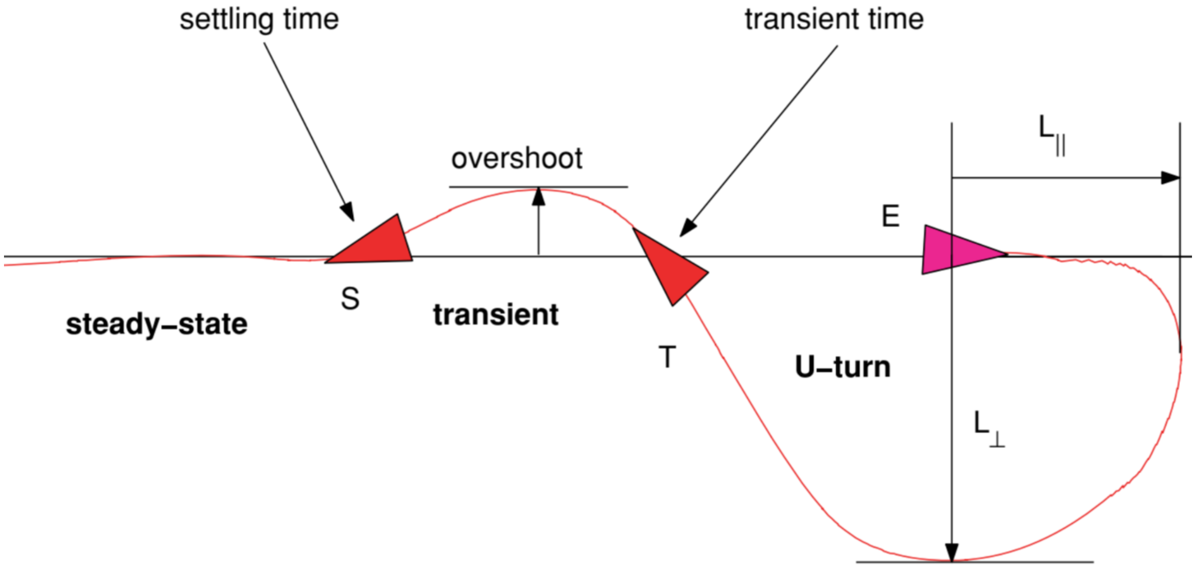
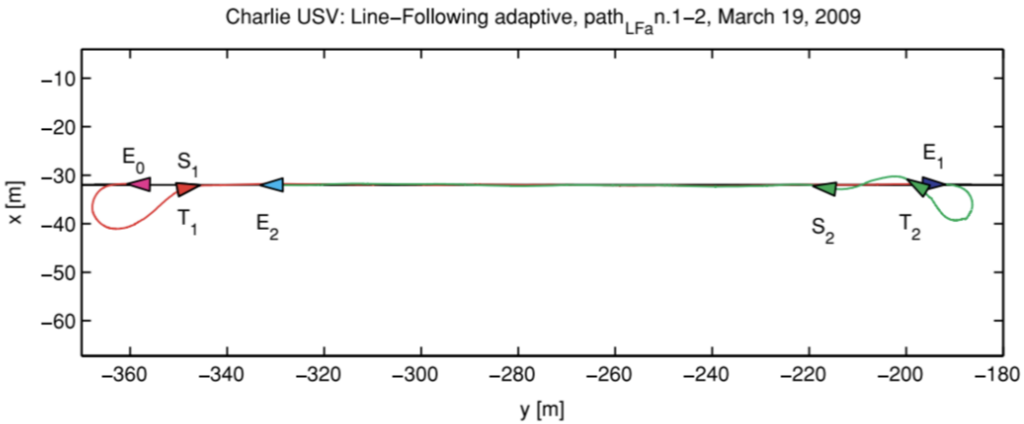
- Task: straight line-following
  - the ASV has to follow a straight line
- Performance indexes



GEM in marine robotics: line-following

- Variables of interest
  - target line (one point on the line and line orientation)
  - estimated ASV position, heading, yaw rate and linear speed
  - reference yaw rate (dual-loop guidance&control scheme)
  - reference surge force and yaw moment



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GEM in marine robotics: line-following

- **Replicable experiments and operational procedures**
    - move back and forth along a segment
        - Safety: this guarantees that the ASV will remain inside a safe area
            - the ASV supervisor manually pilots the vehicle to the ends of the segment visually checking that the operational area is safe
            - the ends of the segment are identified on a map of the test site
        - change the orientation of the target straight line to work with a full set of environmental disturbances
    - additional variables of interest
        - reference and measured actuator rotation speed, azimuth/rudder angle and absorbed current
            - ASV correct hardware behaviour
            - possibility of computing energy consumption-based performance indexes
        - ASV pitch and roll
            - environmental disturbance (waves)