Autonomous vessels: Sensors, estimation and control

We are exploring several topics related to autonomous vessels. These among others consist of

- Optimizing ship operations from a control systems perspective.
- Signal processing algorithms considering new sensors and equipment in different budgets/cost segments.
- Estimation. Without operators present on board, estimation is becoming increasingly important to obtain information.

Rolls-Royce Marine offer assignments this upcoming fall with the possibility to continue the work during the master thesis. The assignments consist of topics related to

- Facilitation of automatic docking, using an estimation approach, with and without active transponders
- Sensor options for autonomous vessels
- Auto trim/draft control for energy efficient vessel transit

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Co-supervisor (day-to-day supervision): postdoc. Torleiv H. Bryne.
Ivar Ihle, Ph.D., Rolls-Royce Marine will also contribute to the supervision.
Sensor coverage in autonomous docking. Number of students: 1

Automatic and autonomous berthing/docking of a ship will require accurate positioning to maximize safety and success while carrying out the docking. This again require access to accurate position, velocity and orientation data. This is typically obtained via redundant sensor systems combing global and local positioning. Such information sources can e.g. be obtained through tight integration of sensors such as
- Global navigation satellite systems (GNSS)
- Inertial measurement units (IMU)
- Range/bearing systems
  - Radio
  - Target guidance/beam

Assignment: Optimal path planning for autonomous docking of ships

GNSS and range/bearing systems typically have quite different error ellipses. Therefore, a combination of these two system that minimizes the area that both systems’ error ellipses cover is beneficial.

Main task:
Development of a path planning algorithm that minimizes the navigation uncertainty in the tight integration of global and local positioning sensors by considering sensor geometry. This is motivated by the desire to maximize the fault tolerance in the event of a sensor fault.

The main concept and algorithms should be developed in the fall during the project thesis work. Extensions and possible experimental validation can be considered for the master thesis.
Sensors and navigation. Number of students: 3

Assignment 1: Tight sensor integration
Tight integration of IMU and aiding sensors. This task will focus on sensor and information fusion. Typical sensors (and information sources) may include

- Dual GNSS with or without differential correction
- Range/bearing system
- Compass
- Combination with elements from heave estimation.
- Magnetometer
- GNSS heading
- Camera (IR)

The main task is to maximize the navigation system performance based on standard and non-standard sensors which typically have not been fused on shipping and offshore vessels. Different configurations should be tested. Known issues with some of the different sensors should be mitigated in the fusion algorithms.

A simulation framework should be developed during the project thesis work. Extensions, experimental validation and verification will be the primary focus of the master thesis.

This assignment will be challenging, especially the master thesis work considering experimental validation, and is a good match for a highly-motivated student.

Assignment 2: Online sensor monitoring and validation
No sensor is perfect. Different sensors applicable for ships have either temporal (slow sample rate) or spatial (noise, bias, prone to errors) issues associated with their measurements.

This assignment should investigate possible algorithms for online signal analysis and fault accommodation. Algorithms should perform

- Online noise/variance calculations
- Fault detection and isolation

The algorithms to be developed should be able to detect standard faults such outliers and jumps, but also more complicated faults such as slow drift (GNSS differential link errors or GNSS spoofing). Possible algorithms could e.g. be based on

- Windowing
- Moving horizon estimation

The noise analysis should be the main priority for the project thesis work. Fault detection and isolation together with experimental validation should be the focus for the master thesis.
Assignment 3. Sensor redundancy principles

Typical sensor redundancy requirements for offshore vessels are based on triple-redundancy. Examples include three gyrocompasses and three independent position reference systems. In order to reduce cost in autonomous vessels dual instead of triple-redundancy in position and heading references are beneficial.

This assignment is twofold.

1. Investigate different budget options for autonomous vessels; a low-cost multiple redundancy sensor solution may perform as well as single high-performance sensor.

2. Investigate the possibility of using dual instead of triple-redundancy by exploiting an IMU and an INS based on low-cost sensors. A vessel model may also be included in this design.

NB: Future solutions should exclude wind sensors since these can be detrimental for positioning.
Typical control objectives for ships in transit will be to ensure that the vessel’s speed and course follows the desired set points. This is typically maintained by the autopilot.

In order to minimize the fuel consumption in transit automatic control of the vessel’s draft, trim (avg. pitch angle) and heel (avg. roll angle) can be carried out to minimize drag forces dependent on load conditions, vessel speed, etc. The overall task consists of a combination of vessel modeling and exploiting information from sensors and control inputs in doing so.

There are assignments for both project and master thesis work.

Project thesis
Two main tasks are to be considered:

- Develop an accurate vessel model including changes of drag and lift forces due to e.g. changes in speed, trim angle, heel angle and draft.
- Make a controller that automatically changes trim, heel and draft of the vessel.

Master thesis
The master thesis work should extend the result from the project thesis.

- Minimize the fuel consumption of the vessel in transit in different scenarios (different vessel speeds, compensating for changes of load conditions, etc.) without interfering with the overall control objectives handled by the autopilot.
- Possible approaches can be based on extremum seeking or model predictive control (MPC). Other methods can also be considered.
- A combination of for example
  - typical ship sensor information,
  - the developed vessel model, and
  - control inputs
  can be exploited dependent of the algorithm choice.

Note: In either extremum seeking or model predictive control an accurate vessel model is needed. For the former strategy, a model is needed for validation, while for MPC an accurate model is needed for the algorithms itself. Therefore, in order to be applicable for the assignment the candidate should be both interested and proficient in modeling.