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Development of Fault-detection Methods for Guidance and Navigation of Underwater Vehicles

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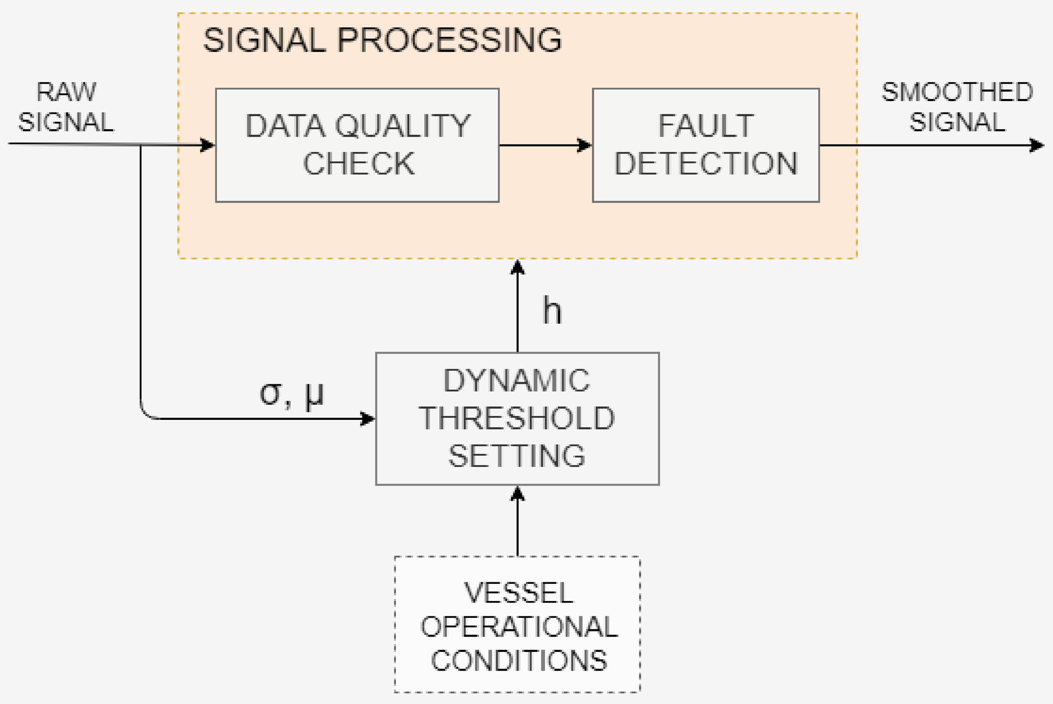
Motivation

When operating with unmanned and autonomous underwater vehicles, a faulty signal may have fatal consequences, such as collision or loss of vehicle. In order to obtain the safest and best possible performance of a control system, it has to work with reliable signals. To ensure this, a dedicated *Signal Processing Module* should be included to continuously monitor sensor measurements, and should be able to alarm the system operator if faults are detected.



The challenge of processing signals related to marine control systems is to include information about all external conditions. How strict the signals should be processed should ideally be dependent on several factors in order to obtain the most accurate possible signal processing. When a marine vessel is subjected to strong environmental forces, an abrupt change in mean may be a weaker indication of fault than if it were operating under calm conditions. This thesis presents a method that incorporates these external operational factors to determine the limits for fault detection.

Problem Definition

When studying signal processing for autonomous subsea operations, how can the limiting thresholds be dynamically set based on available information about the environmental, operational and vessel conditions?

Approach

- Research and test existing methods of fault detection, such as:
  - Limit checking with fixed bounds
  - Interquartile range with adaptive bounds
  - Variance check
  - CUSUM
- Create a platform for generating random test signals and for testing the different algorithms
- Develop a method to dynamically determine the thresholds
- Test the final algorithm in a case study

References

[1] Tristan Perez and Asgeir J. Sørensen and Mogens Blanke: *Marine Vessel Models in Changing Operational Conditions (A Tutorial)*, IFAC Proceedings Volumes

[2] Tristan Perez and Asgeir J. Sørensen and Mogens Blanke: *Vessel Operational Conditions and Formal Specification of Ship Guidance Navigation and Control System Requirements*

Dynamic Thresholds

Marine systems are designed to carry out complex operations in harsh and changing environmental conditions. These conditions have a great impact on the precision needed to safely complete the given task. Strong gusts or a high sea may cause larger variations in measurements than in conditions with no wind and a calm sea. This means that an abrupt change in heading may indicate a fault under some conditions, while it can be expected under harsher conditions.

The method is based on the *Vessel Operational Condition (VOC)* [1], which can be defined as a triplet of attributes as:

$$VOC := \langle VUM,\ Env,\ VC \rangle,$$

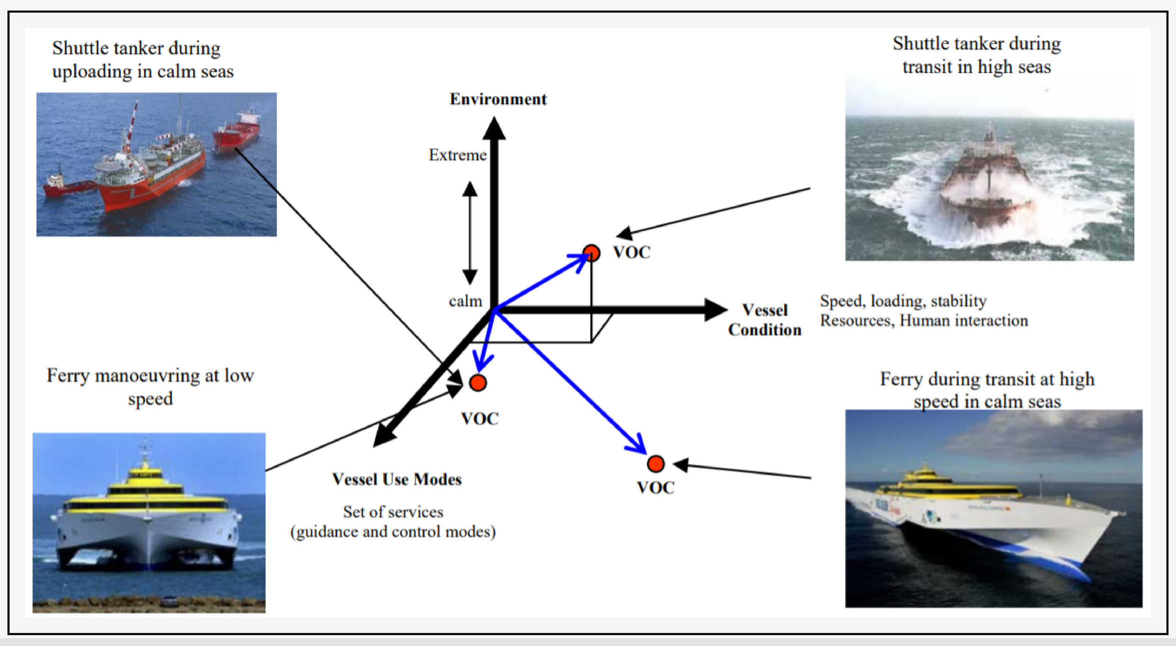
where

- *VUM* refers to the *Vessel Use Mode*, which describes the current task of the vessel. Examples are transit, surveying and pipe lying
- *Env* refers to the state of the environment, including wind, waves and current. These conditions can be roughly classified into calm, moderate or rough conditions
- *VC* refers to the current condition of the vessel. This includes everything from vessel speed, to vessel loading and resources

The final thresholds are determined based on the signal statistics and the vessel operational conditions. A model of the threshold can be written as:

$$\text{Upper} = h = \mu + a \cdot \sigma$$
$$\text{Lower} = -h = \mu - a \cdot \sigma,$$

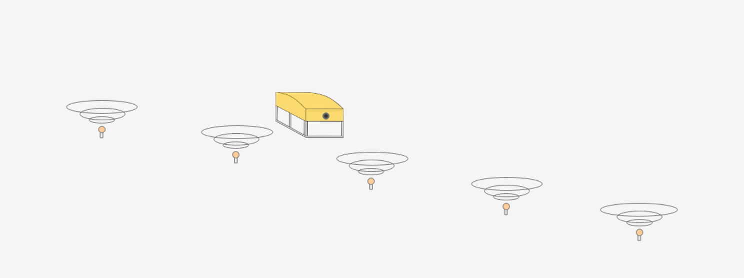
where $a \epsilon [a_{min}, a_{max}]$ is determined based on the current value of *VOC*.



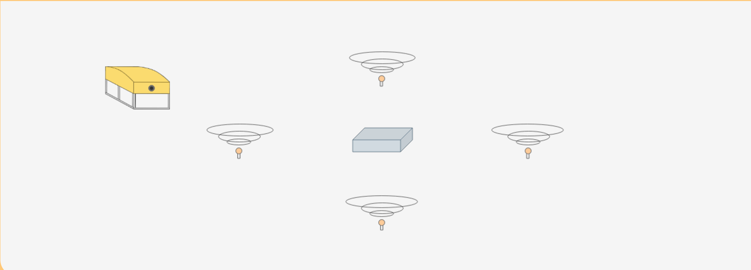
Phases of Operation

The method of dynamic thresholds is tested on a scenario where an ROV returns from an ended mission to its seabed mounted docking station. The operation can be separated into three phases as shown below.

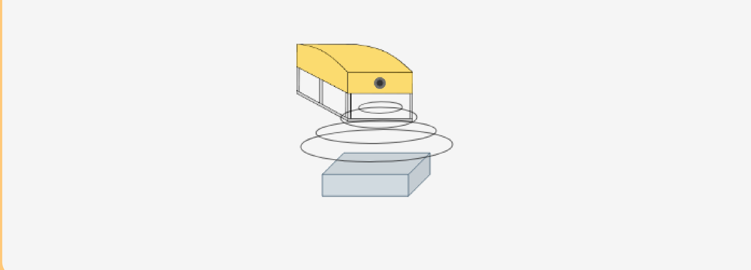
Phase 1: Transit



Phase 2: Maneuvering



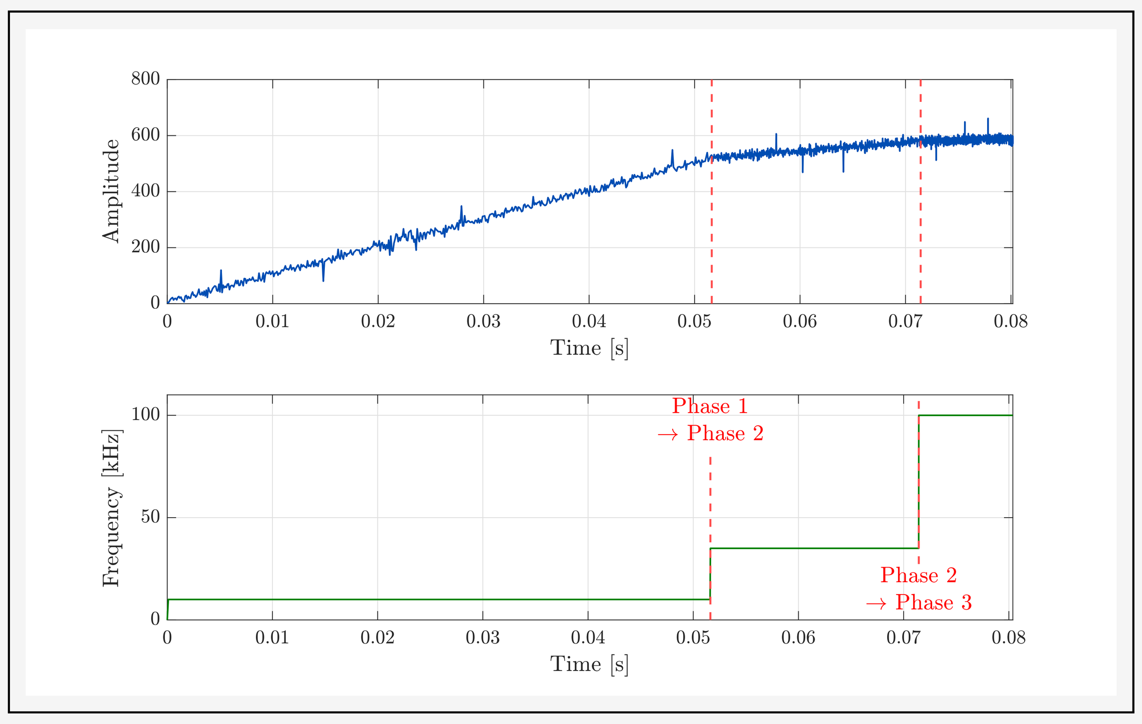
Phase 3: Homing



Each phase is characterized by its own objectives, conditions and incoming signal frequency. By distinguishing between these frequencies, the current phase can be identified at all times, and the corresponding limits can be calculated based on its predefined properties.

Results

The results are obtained by simulating the surge movement of the vehicle as it approaches the docking station while mimicking the change of main sensor system as a change in frequency. The upper figure shows the test signal together with the varying frequency. The outliers added have a constant deviation from the mean value in every phase. The goal is to test that equal deviations have varying severity depending on the phase in which it occurs. The bottom figure shows the resulting dynamic limits together with an alarm function. The peaks in the alarm function indicates that a fault is detected.



The final plots show that the algorithm is able to detect when the ROV enters a new phase and react by calculating the new corresponding thresholds. The added outliers only triggers the alarm in phase 3, which also has the highest demand for accurate measurements as the goal is to safely dock to its station.