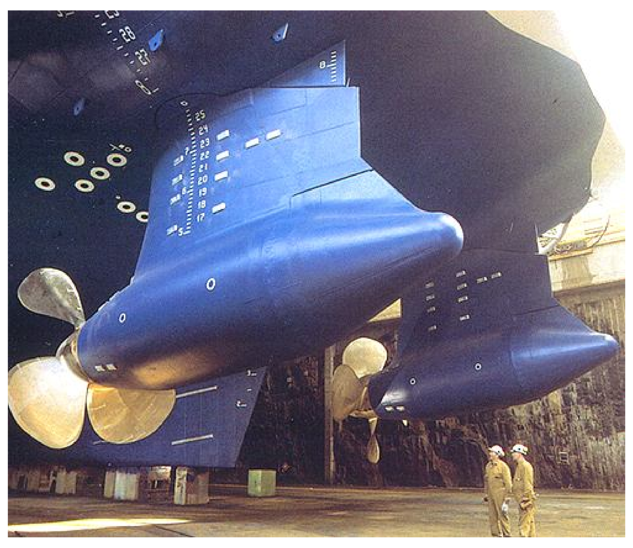

Dynamic Thrust Allocation

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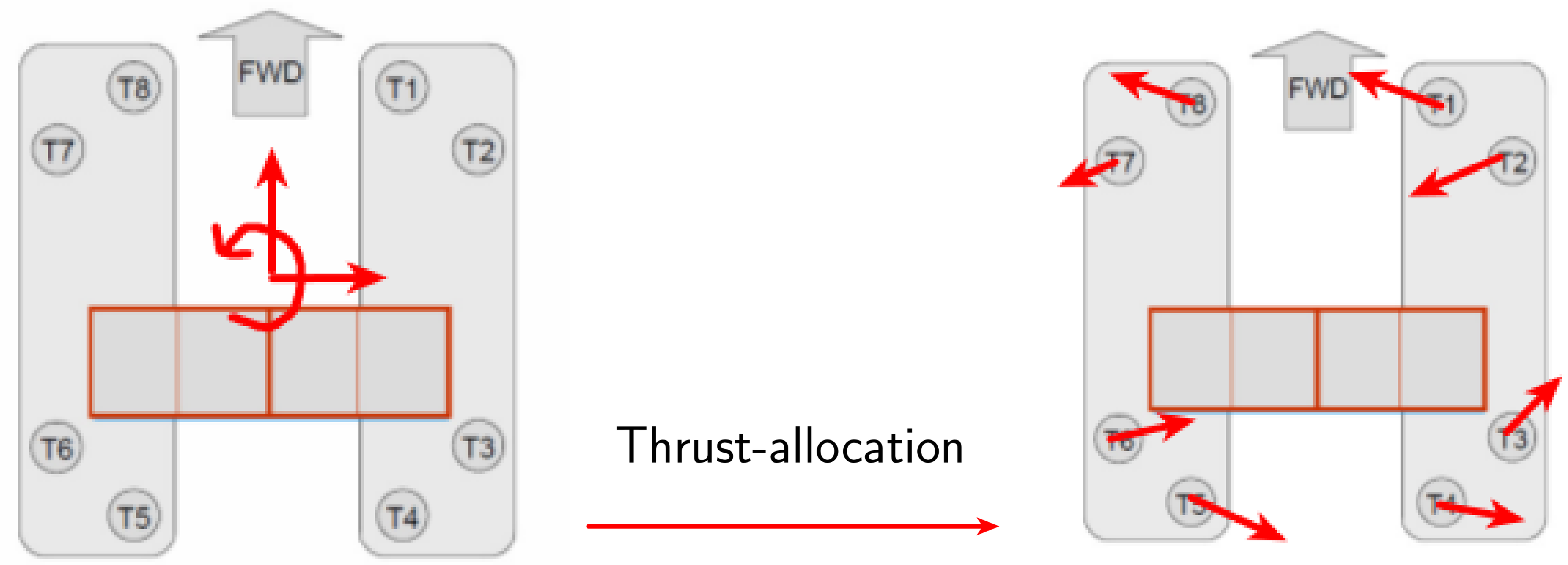
Abstract

Dynamic Positioning (DP) means that a vessel maintains its position and heading exclusively by means of thruster force. A DP-control system is the hardware and software necessary to successfully govern the vessel in order to achieve this. The thrust allocation is a mapping between desired forces in surge, sway and yaw, and actual input to the thrusters. This is normally solved as a static problem, allowing great robustness and simplicity. In this work, a dynamic thrust allocation is developed and simulated, allowing for powerful constraint handling.

Concept of thrust allocation



DP-block diagram

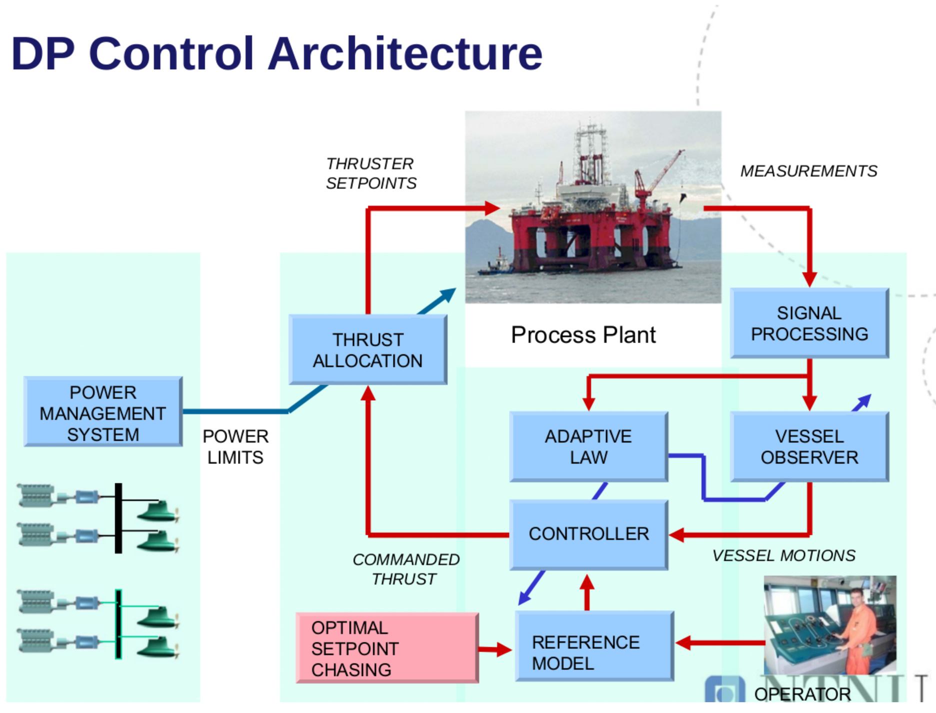


Image Courtesy: Asgeir Sørensen

Thrust Allocation

To facilitate design, a DP-control system is made modular. In this way, any one part can be designed and tested independently, allowing for reuse of designs across vessels, use of common design-practices et cetera. The center of the DP-control systmem is the controller. The controller outputs desired forces in surge, sway and yaw, and assumes that these forces are applied directly. However, these aggregate forces can only be achieved by the combined work of the thrusters. The job of the thrust allocation is to convert these three forces to desired forces for the individual thrusters.

Overactuation

Most DP-vessels are overactuated, meaning there are more thrust forces present than degrees of freedom to control. This leads, in theary, to infinitely many solutions to the thrust allocation problem. This generates both challenge and opportunity, as selecting one of many solutions is a non-trivial task. As for opportunity, this makes it possible to specify other objectives like keeping within contraints or minimizing fuel consumption.

Some Mathematics

When solving the thrust allocation problem statically, a linear map

$$\tau_d = H(t)u \tag{1}$$

between thruster forces u and aggregate desired forces τ_d is used. $H(t)$ is the thruster configuration matrix, containing information about the position and orientation of the thrusters relative to the center of gravity (COG). $H(t)$ is time varying because the thrusters could change orientations, e.g. azimuthing thrusters or rudders. If the system is overactuated, equation (1) can be formulated as an optimization problem

$$\min_u J(t,x,u) \quad \text{subject to } \tau_d = H(t)u \tag{2}$$

where $J(t,x,u)$ is a cost function. This cost function can contain the additional objectives, and is what allows choosing the "best" solution from the many correct solutions. There are many ways of solving (2), including the pseudoinverse and linear-quadratic programming techniques. Here (2) is reformulated into a Lagrangian

$$L(u,\lambda,x,t) = J(t,x,u) + (\tau_d - H(t)u)\lambda \tag{3}$$

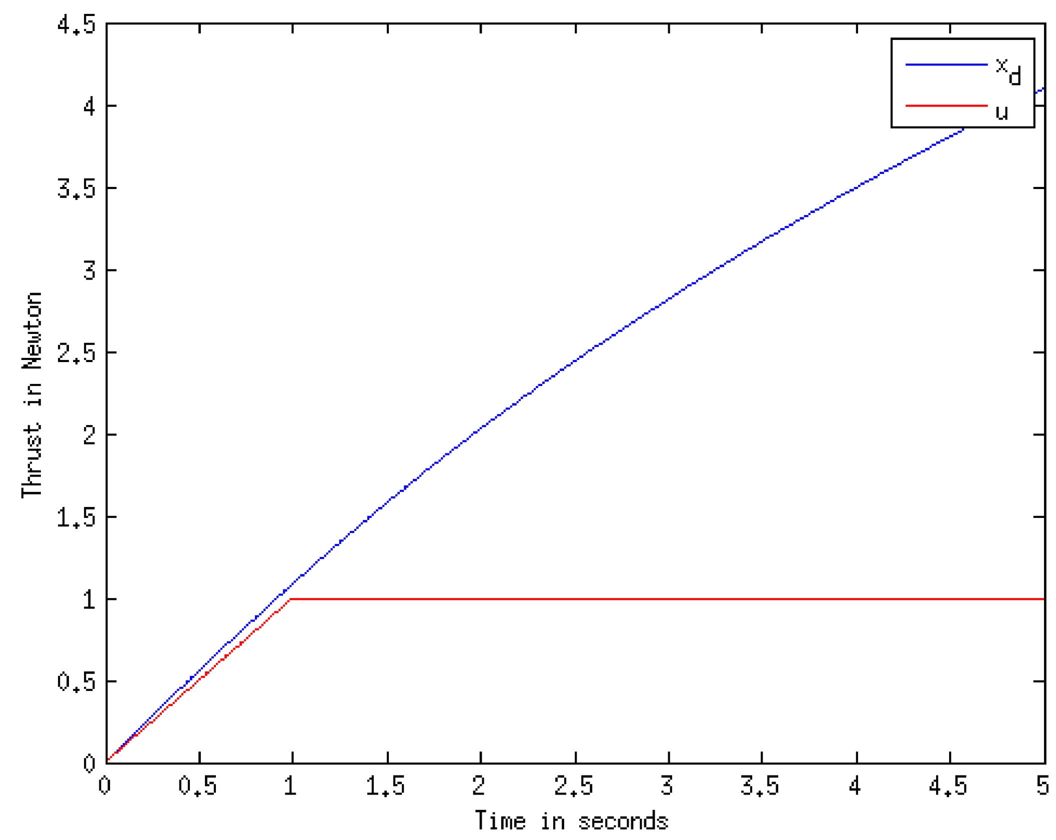
where λ is a vector of lagrange-multipliers. Update laws for λ and u are then constructed, solving 2 in the limit.

(1) and (2) are called static because they assume that once a thruster is given a thrust command, the command is fulfilled immediately. In real life, however, thrusters have large inertia and are subject to delays. This can be modelled dynamically as

$$\dot{x} = -T^{-1}(x-u), \tag{4}$$

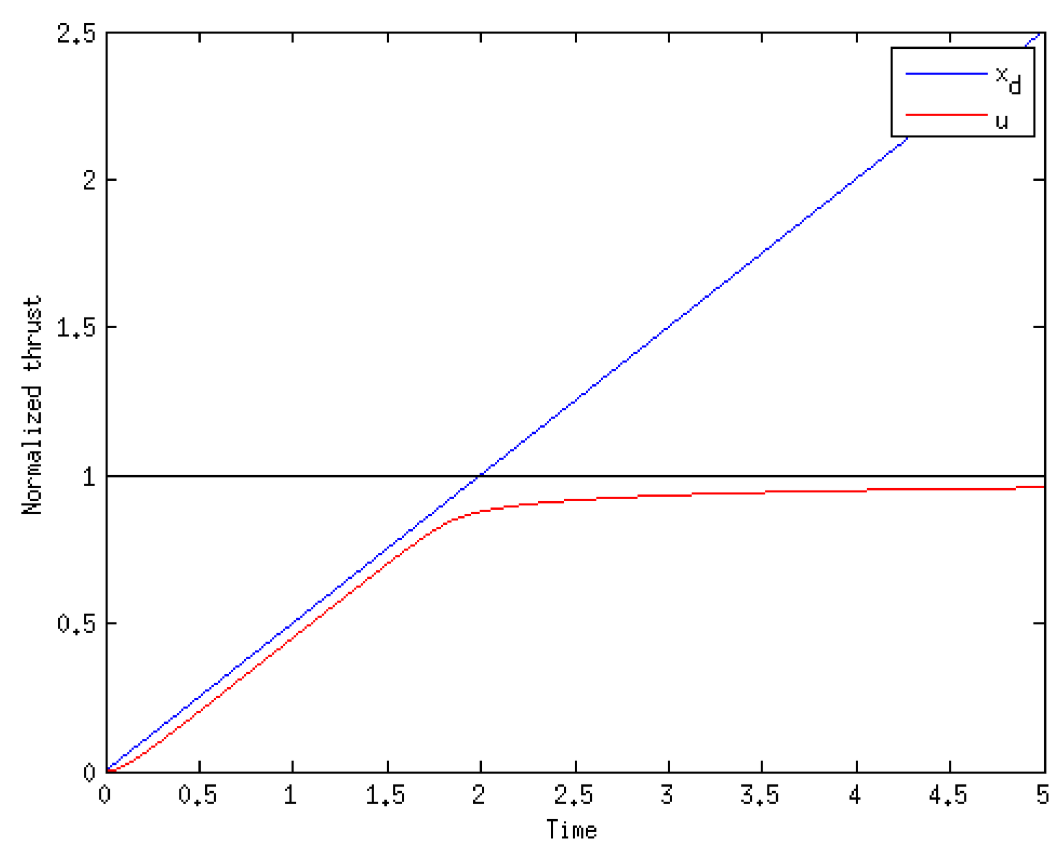
where x is the produced thrust and u is the input from the thrust-allocation.

Direct Saturation



In direct thrust-saturation, u satisfies $|u| \leq c$ directly, so if the control system desires more thrust than can be given, the thrust is simply set to maximum.

Dynamic Saturation



Using dynamic saturation, u can satisfy some cost function $J(t,x,u)$, making it prohibitively expensive to approach the saturation.