Technical Presentation

ENERGY OPTIMIZATION FOR AN AUTONOMOUS SURFACE VEHICLE

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La Région Occitanie Pyrénées - Méditerranée

Union Européenne
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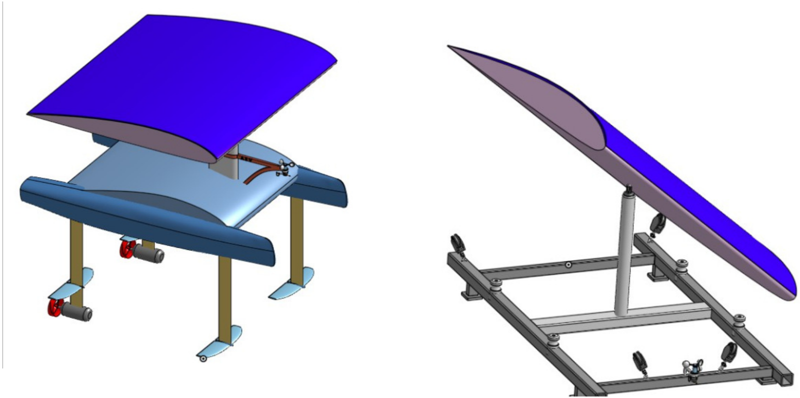
Outline

Outline

Introduction - Autonomous Surface Vehicle



(a) ASV model

(b) Panel orientation model

Figure 1: ASV model and panel orientation

Outline

System Descriptions - Simple model

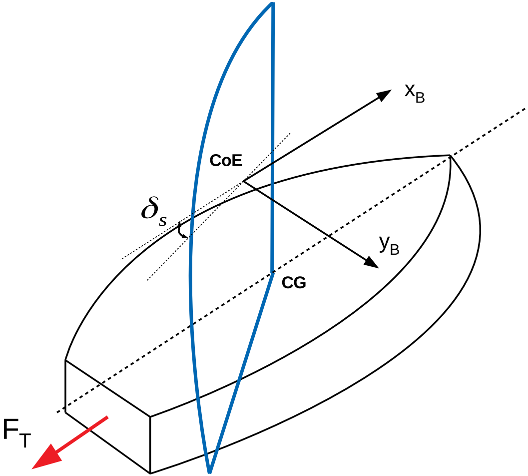


Figure 2: Preliminary ASV model

1. angle of solar-sail panel (δ_s)
2. thrust force (F_T)

System Descriptions - Control diagram

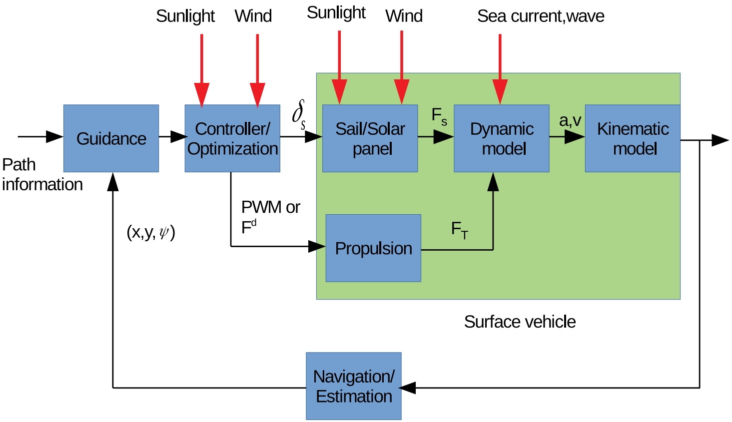


Figure 3: Control diagram

System Descriptions - Power flow diagram

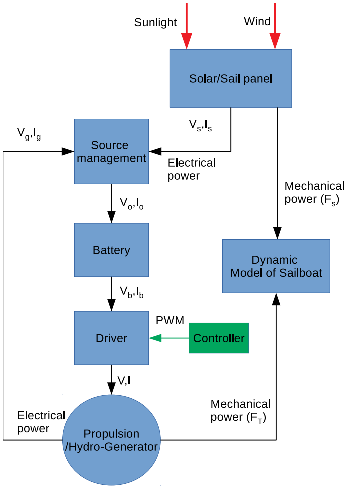


Figure 4: Power flow diagram

1. Electrical energy.
2. Mechanical energy.

Solar models

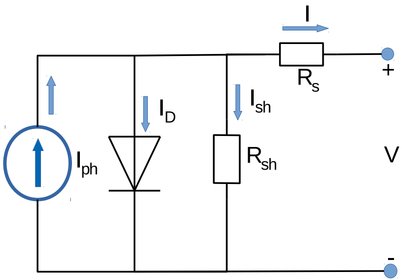


Figure 5: Photovoltaic cell

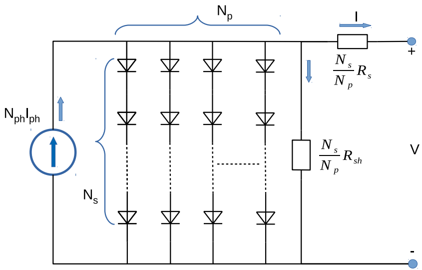


Figure 6: Solar module model

Solar simple model

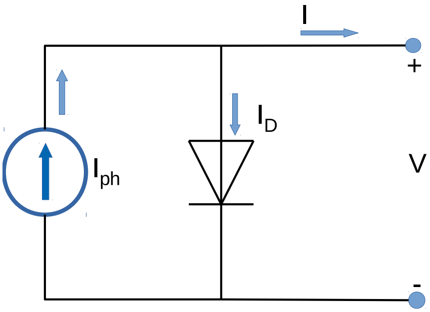


Figure 7: Photovoltaic cell

$$I = I_{ph} - I_D \quad (1)$$

$$= I_{ph} - I_0[\exp(\frac{qV}{NKT}) - 1] \quad (2)$$

$$= [I_{sc} + K_i(T - 298)]\frac{\lambda}{1000} - I_0[\exp(\frac{qV}{NKT}) - 1] \quad (3)$$

Sailing model

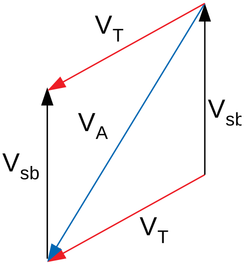


Figure 8: True wind velocity, sailboat velocity, and apparent wind velocity

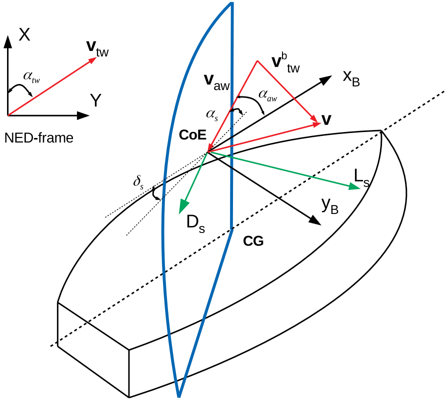


Figure 9: Sailing model analysis

Sailing model

The relation between true and apparent winds:

$$v_{awu} = v_{tw} \cos(\alpha_{tw} - \psi) - u \tag{4}$$
$$v_{awv} = v_{tw} \sin(\alpha_{tw} - \psi) - v \tag{5}$$

The force and torque elements in body-frame:

$$\mathbf{F}_s = \begin{bmatrix} F_{su} \\ F_{sv} \\ \Gamma_{rs} \end{bmatrix} \tag{6}$$

$$= \begin{bmatrix} L_s \sin \alpha_{aw} - D_s \cos \alpha_{aw} \\ L_s \cos \alpha_{aw} + D_s \sin \alpha_{aw} \\ -(L_s \sin \alpha_{aw} - D_s \cos \alpha_{aw}) x_{sm} \sin \delta_s + (L_s \cos \alpha_{aw} + D_s \sin \alpha_{aw})(x_m - x_{sm} \cos \delta_s) \end{bmatrix} \tag{7}$$

Battery model

The charging capability of a battery is given:

$$C_c = \int_0^{t_{cut-off}} I dt \qquad (8)$$

where I is the input current of a battery, $t_{cut-off}$ is the charging time of the battery.

Propulsion model

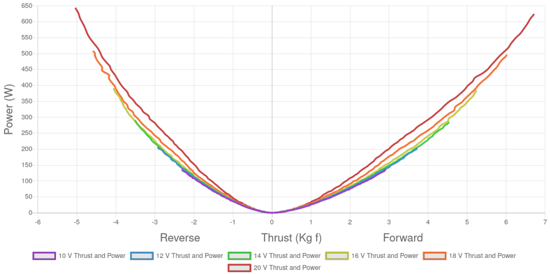


Figure 10: Power and thrust - T200

$P_T = f(F_T) = kF_T^2$
or
$P_T = f(F_T) = k.sign(F_T)|F_T|$ (energy consumption and production)

Sailboat model

Dynamic model:

$$F_u = m_u \dot{u} \tag{9}$$

$$F_v = m_v \dot{v} \tag{10}$$

$$\Gamma_r = I_r \dot{r} \tag{11}$$

Kinematic model:

$$\dot{x} = u\cos(\psi) - v\sin(\psi) \tag{12}$$

$$\dot{y} = u\sin(\psi) + v\cos(\psi) \tag{13}$$

$$\dot{\psi} = r \tag{14}$$

Outline

Problem formulation

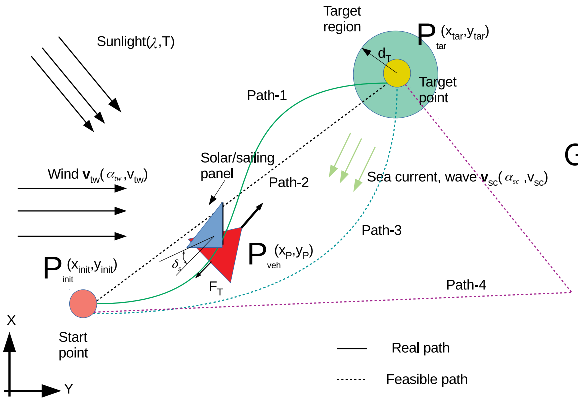


Figure 11: Problem formulation

General objectives:

1. Approach the target point.
2. Minimize energy consumption.
3. Maximize energy production.

Problem solution

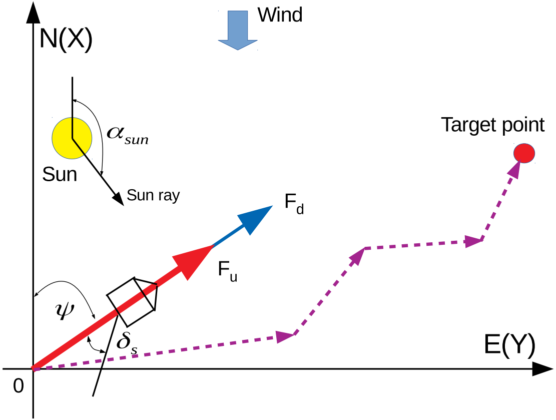


Figure 12: Problem solution

1. Consider only *u*-direction.
2. Divide path into multi desired vectors (F_d).
3. Minimize deviation between F_u and F_d
4. Minimize energy consumption.
5. Maximize energy production.

Problem solution

The objective function:

$$E(\delta_s, F_T) = w_1. \parallel F_d - F_u \parallel_2 + w_2.k.sign(F).|F_T| - w_3.V.I \tag{15}$$

where $w_1, \quad w_2, \quad w_3$ are scalar weights.
The problem is formulated as:

$$\min_{\mathbf{x}} E(\delta_s, F_T) \tag{16}$$

$$s.t \quad \mathbf{x} \in \mathcal{X} \tag{17}$$

where $\mathbf{x} = [\delta_s \quad F_T]^T$ is decision variable, $\mathcal{X}$ is the feasible set. The constraints of δ_s are mechanical limitations and constraint of F_T is the saturation of thruster.

Outline

Preliminary simulations - Parameters

Table 1: Parameters of sailboat for simulations

Notations	Value	Unit
m_u	25900	kg
m_u	25900	kg
I_r	24760	$kg.m^2$
ρ	1.2	kg/m^3
A	170	m^2
x_{sm}	0.6	m
x_m	0.3	m
v_{tw}	5	m/s
α_{tw}	180	deg

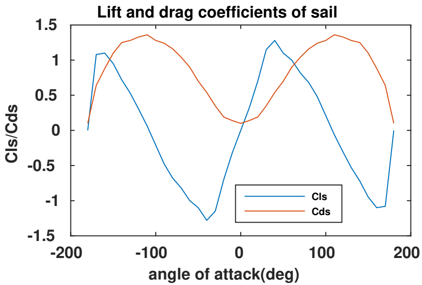


Figure 13: Lift and drag coefficients

1. $\delta_s \in [-90^\circ \quad 90^\circ]$
2. $F_T \in [-500 \quad 500](N)$

Preliminary simulations - Solar current assumption

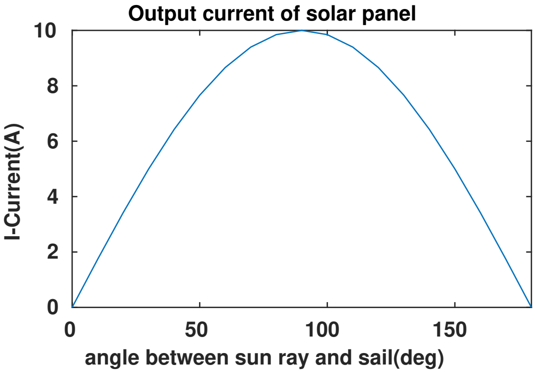


Figure 14: Output current of solar panel

1. if $angle = 0°$ or $angle = 180°$, $I = I_{min} = 0(A)$
2. if $angle = 90°$, $I = I_{max} = 10(A)$

Preliminary simulations - Results - Case 1

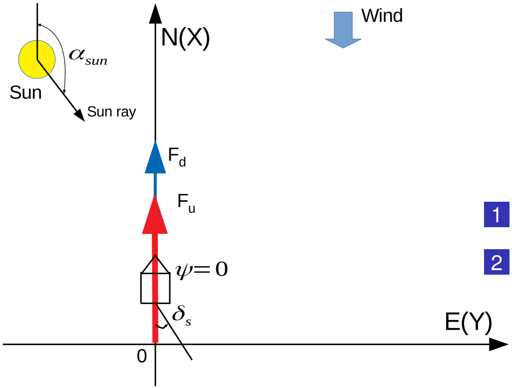
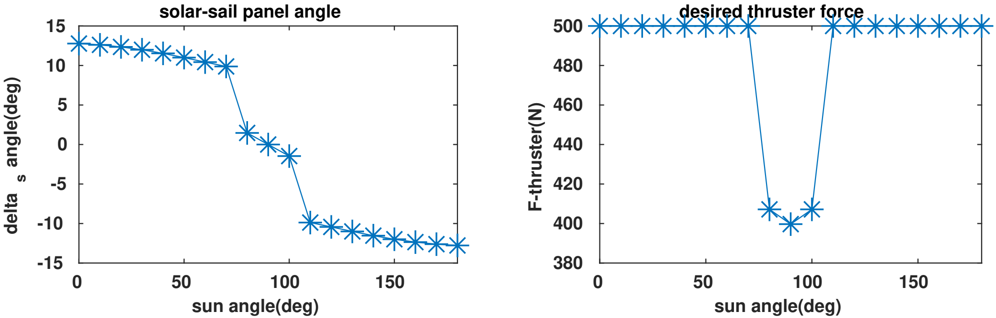


Figure 15: Case 1 - simulation

1. yaw angle $\psi = 0°$
2. sun angle $\alpha_{sun} = [0 : 10° : 180°]$

Preliminary simulations - Results - Case 1



(a) Optimal solar-sail angle (b) Optimal thruster force

Figure 16: Optimal solar-sail angle and thruster force w.r.t sun angle

Preliminary simulations - Results - Case 2

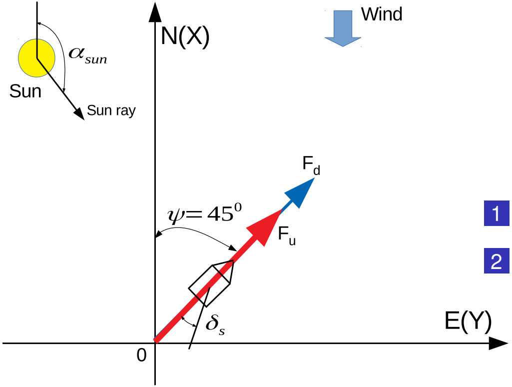
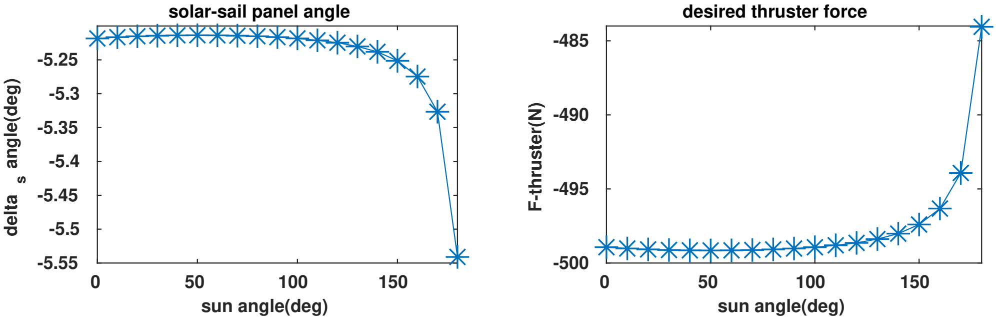


Figure 17: Case 2 - simulation

1. yaw angle $\psi = 45°$
2. sun angle $\alpha_{sun} = [0 : 10° : 180°]$

Preliminary simulations - Results - Case 2



(a) Optimal solar-sail angle (b) Optimal thruster force

Figure 18: Optimal solar-sail angle and thruster force w.r.t sun angle

Outline

Conclusions and Future works

Optimization problem has been formulated and has potential results. Future works are listed as follows:

1. Take into account sea current and obstacle avoidance.
2. Take into account effects of foils of sailboat.
3. Energy optimization in real case of solar energy.

Thank you for your attention

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