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Modelling of a single sculling technique

A single sculling technique in the 2000 m distance regatta is our subject. The mathematical model of rowing technique has been derived from the second dynamics law (1), and the rules describing the hydrodynamic forces (2).

$$m\ddot{x}(t) = 2F(t)\sin\gamma(t) - k_{B,VA}[\dot{x}(t) - \dot{x}_{VA}(t)]^2 \operatorname{sgn}(\dot{x}(t) - \dot{x}_{VA}(t)) \\ - k_{B,AIR}[\dot{x}(t) - \dot{x}_{AIR}(t)]^2 \operatorname{sgn}(\dot{x}(t) - \dot{x}_{AIR}(t)) \quad (1)$$

where the hydrodynamic force F(t) is as follows:

$$F(t) = 0.5\rho_{H_2O}c_{D,OA} \int_{l_{OAmin}}^{l_{OAmax}} \{l_{OA}\dot{\gamma}(t) - [\dot{x}(t) - \dot{x}_{VA}(x)]\sin\gamma(t)\}^2 b_{OA}\, dl_{OA} \\ \left[\frac{1+\operatorname{sgn}\dot{\gamma}(t)}{2}\right]\left[\frac{1+\operatorname{sgn} g(t)}{2}\right] \quad (2)$$

with the adjusting term:

$$\operatorname{sgn} g(t) = \operatorname{sgn}\{0.5(l_{OAmax} - l_{OAmin}) - [\dot{x}(t) - \dot{x}_{VA}(t)]\sin\gamma(t)\} \quad (3)$$

The oar's angle γ vs. time t is the function defined below:

$$\gamma(t) = 0.5(\gamma_{max} + \gamma_{min}) - 0.5(\gamma_{max} - \gamma_{min}) \\ \left\{k_1(t)\cos\left[\frac{2\pi(t-iT)}{T_1}\right] - k_2(t)\cos\left[\frac{2\pi(t-0.5T_1-iT)}{T_2}\right]\right\} \underset{0\leqslant i\leqslant n<\infty}{\forall} \quad (4)$$

$$T = 0.5(T_1 + T_2) \quad (T_1 > T_2) \vee (T_1 < T_2) \vee (T_1 = T_2 = 0.5T) \quad (5)$$

$$(k_1(t) = 1) \wedge (k_2(t) = 0) \underset{iT\leqslant t<iT+0.5T_1}{\forall} \ \underset{0\leqslant i\leqslant n<\infty}{\forall} \quad (6)$$

$$(k_1(t) = 0) \wedge (k_2(t) = 1) \underset{T+0.5T_1\leqslant t<(i+1)T}{\forall} \ \underset{0\leqslant i\leqslant n<\infty}{\forall} \quad (7)$$

The oar's angular velocity is the first derivative of angle γ vs. time t:

$$\dot{\gamma}(t) = \pi(\gamma_{max} - \gamma_{min})\Big\{\frac{k_1(t)}{T_1}\sin\Big[\frac{2\pi(t-iT)}{T_1}\Big] - \frac{k_2(t)}{T_2}\sin\Big[\frac{2\pi(t-0.5T_1-iT)}{T_2}\Big]\Big\} \quad \underset{0\leqslant i\leqslant n<\infty}{\forall} \qquad (8)$$

The system is simulated using MATLAB package. The differential equation (1) containing terms (2)–(8) is solved by ode45 code [1] based on the explicit Runge–Kutta formulae of 4th and 5th orders. The analysis of sensitivity of the regatta result on small changes of the selected parameters and efficiency of rowing was carried out.

Final remarks:

1) This model provides an opportunity to study the effect of different rowing technique's elements with both wind and water flow on the outcome of the regatta result.

2) The technique when the blade dipping and ascend during the active phase of the oar motion is the best.

3) The bigger rowing efficiency occurs when the mean oar's angle is close to 90 deg.

4) In the future this model will be expanded to 6 degrees of freedom including: vertical boat position, boat pitch angle, trunk tilting angle, sliding seat position.

References

[1] L. F. Shampine, M. W. Reichelt. *The MATLAB ODE Suite*. SIAM Journal on Scientific Computing 18 (1997), 1–22.

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