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2.3. SURGE CONTROL LAW

The first sliding surface is a first order exponentially stable surface defined in terms of the vessel's surge motion tracking errors.

$S_1 = \tilde{V}_\chi + \lambda_1 \int_0^t \tilde{V}^\chi(\tau)d\tau,\ \lambda_1 > 0$

Where "~" is used to denote the difference between the actual and desired values

$\tilde{V}_\chi = V_\chi - V_{\chi d}$

The integral of V_χ is used since position variables cannot be defined in the body fixed frame. Hence, the desired motion is specified in the inertial reference frame ($X_d(t)$, $Y_d(t)$) and its time derivatives (X_d, Y_d, $\dot{X}_d$, $\dot{Y}_d$) are related to the desired surge and sway velocities (V_{yd}, V_{xd}) and accelerations ($\dot{V}_{yd}$, $\dot{V}_{xd}$)

$V_{xd} = \cos\theta\, X_d + \sin\theta\, Y_d$
$V_{yd} = -\sin\theta\, X_d + \cos\theta\, Y_d$

$V_{xd} = \cos\theta\, \dot{X}_d + \sin\theta\, \dot{Y}_d + V_{yd}\omega$
$V_{yd} = -\sin\theta\, \dot{X}_d + \cos\theta\, \dot{Y}_d - V_{xd}\omega$

Θ is the actual measured yaw angle provided through feedback in real time and ω is estimated in real-time based on the θ values. Calculate nominal surge control law for zero dynamics by taking the time derivative of the surface and using the equation of motion

$\dot{S}_1 = \dot{V}_x + \dot{S}_{r1} = 0,\ \dot{S}_{r1} = -\dot{V}_{xd} + \lambda_1 \tilde{V}_x$
$\hat{f} = -\hat{m}_{22} V_y \omega + \hat{d}_1 Vx^{\alpha 1} - \hat{m}_{11} \dot{S}_{r1}$

Where "^" is used to indicate the estimated model parameters. The sliding mode control law is normally derived by subtracting a sign function from the nominal control.

$f = \hat{f} - K_1 sat(S_1/\phi_1)$

$$sat(S_1/\phi_1) = \begin{cases} S_1/\phi_1 & \text{if } |S_1| \le \phi_1 \\ sgn(S_1) & \text{if } |S_1| > \phi_1 \end{cases}$$

Where ϕ_1 is a positive constant, which defines a small boundary layer around the surface.
In order to determine K_1, defining the following bounds for the model parameters as

$|m_{ii} - \hat{m}_{ii}| \le M_{ii},\ |d_1 - \hat{d}_1| \le D_i,\ i = 1,2,3$

Assuming no uncertainty in our estimates of exponents α_1 for simplicity.
Define a Lyapunov candidate function that guarantees reaching the set $\{|S_1| \le \phi_1\}$ in finite time and remain inside it thereafter

$V_1 = ½\, m_{11} S_1^2$

The time derivative

$\dot{V}_1 = m_{11} S_1 \dot{S}_1$
$= m_{11} S_1 [\, (f + m_{22} v_y \omega - d_1 v_x^{\alpha 1})/m_{11} + \dot{S}_{r1}]$
$= S_1[(m_{11} - \hat{m}_{22}) V_y \omega + (\hat{d}_i - d_1) V_x^{\alpha 1} + (m_{11} - \hat{m}_{22}) \dot{S}_{r1} - k_1 sat(S_1/\phi_1)]$

The saturation function is equal to the sign function of the set $\{|S_1| > \phi_1\}$. Hence, the following reaching condition is achieved as

$V_1 = m_{11} S_1 \dot{S}_1 \le -\hat{m}_{11} \eta_i |S_i|$

If k_1 is selected as

$k_1 = m_{22} |v_y \omega| + D_1 v_\chi^{\alpha 1} + M_{11} |\dot{S}_1| + \hat{m}_{11} \eta_i$

3. SYSTEM IDENTIFICATION AND MODELLING

System identification techniques have been applied to obtain the USV model and hence controllers are developed subsequently. It consists of four steps –

1. Data acquisition
2. Characterization
3. Identification
4. Verification

The first and most important step is to acquire the input/output data of the system to be identified. Acquiring data is not trivial and can be very laborious and expensive. This involves careful planning of the inputs to be applied so that sufficient information about the system dynamics is obtained. If the inputs are not well designed, then it could lead to insufficient or even useless data.

The second step defines the structure of the system, for example type and order of the differential equation relating the input to the output. This means the selection of a suitable model structure.

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The third step is identification, which involves determining the numerical values of the structural parameters, which minimize the error between the system to be identified and its model. Common estimation methods are least squares, instrumental variable, maximum likelihood and the prediction error method.

Where n_1 and n_2 are the two thrust propellers in revolutions per minutes. Straight line manoeuvres require both the thrusters to run at the same speed whereas the differential thrust is zero in this case. In order to linearism the model at an operating point, it is assumed that the vehicle is running at a constant speed of 3 knots. This corresponds to both thrusters running at 900 rev/min. To clarify this further, let n_c and n_d represent the common mode and differential mode thruster velocities defined to

$n_c = (n_1 + n_2)/2$
$n_d = (n_1 - n_2)/2$

In order to maintain the velocity of the vessel n_c must remain constant at all times. The differential mode input, however oscillates about zero depending on the direction of the manoeuvre. For data acquisition, several inputs including a pseudo random binary sequence are applied to the thruster. The input in the differential mode thruster velocity n_d causes the vehicle to manoeuvre. The acquired data were processed and down sampled to 1 Hz since this frequency was deemed to be adequate for controller design.

System identification was then applied to the acquired data set and a dynamic model of the vehicle is obtained using a prediction error method as

$y(z) = G_1(z)u_1 + G_2(z)u_2$

Where G_1 and G_2 denote the discrete transfer functions from inputs u_1 and u_2 respectively and where y is the output of the system. In this case, only n_d has been manipulated and therefore acts as the sole input to the system. This alters both n_1 and n_2 whereas n_c is maintained to conserve the operating regime. Two models of second and fourth order were identified from the data, however a subsequent simulation study reveals that there is no significant advantage in using a more complex fourth order model. Hence, the second order model in state space form is selected for further analysis and controller design.

4. CONCLUSION

A new simplified concept dealing with ocean waves and safe planning trajectory of USV is introduced.

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