Multi-level DVS Guidance and Output-feedback Path-following Control for Marine Surface Vehicles

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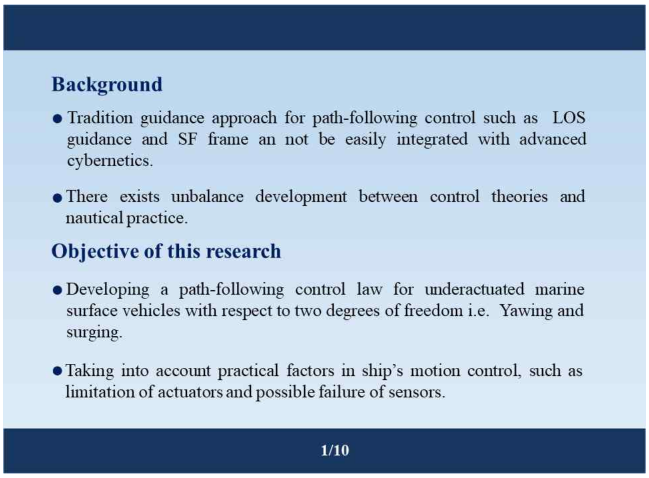
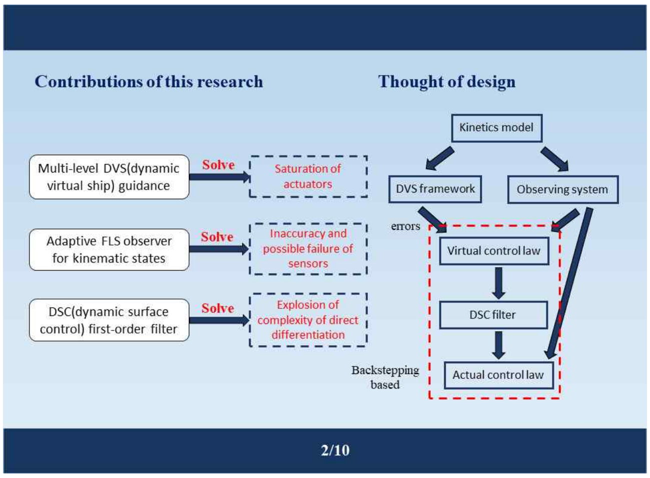
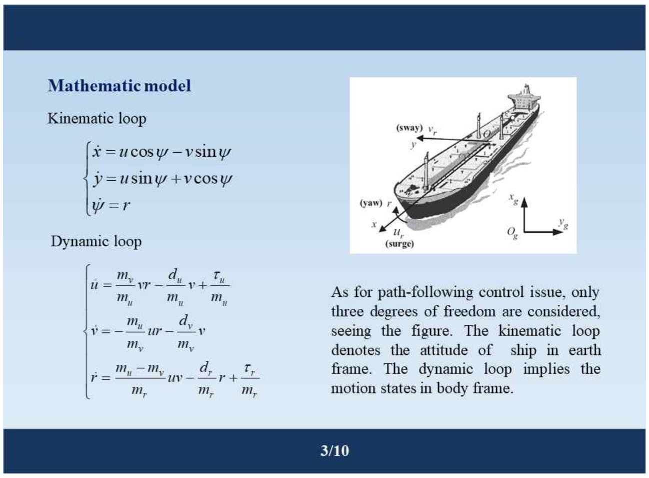
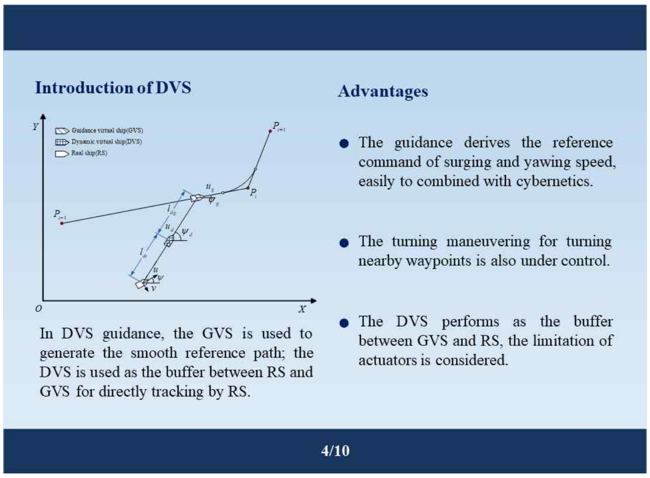
Abstract : *This paper deals with the path-following control for marine surface vehicles with underactuated characteristics. In consideration of practical limitations of actuators, an improved DVS(dynamic virtual ship) guidance algorithm is proposed with the multi-level DVS optionally selected to be tracked. To address the output-feedback control issue, an adaptive FLS(fuzzy logical systems) is devised to online approximate the kinematic states. Based on that observing framework, the path-following control law is thereafter derived. Simulations testify effectiveness of the proposed scheme.*

Key words : *Path Following Control, Underactuated Ships, Multi-level DVS Guidance, Adaptive FLS Observer*









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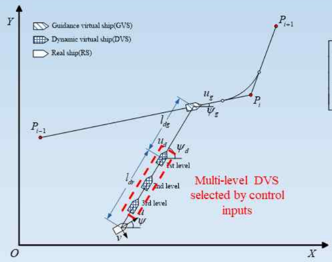
Multi-level DVS guidance



Error system via coordinate transformation

$$\begin{bmatrix} x_e \\ y_e \\ \psi_e \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_d - x \\ y_d - y \\ \psi_d - \psi \end{bmatrix}$$

$$\begin{cases} \dot{x}_e = -u + u_d \cos\psi_e + r y_e \\ \dot{y}_e = -v + u_d \sin\psi_e - r x_e \\ \dot{\psi}_e = -r + r_d \end{cases}$$

Adaptive FLS observer design

$$\begin{cases} \dot{\hat{x}} = \hat{u}\cos\psi - \hat{v}\sin\psi + l_1\tilde{x}\cos\psi - l_1\tilde{y}\sin\psi \\ \dot{\hat{y}} = \hat{u}\sin\psi + \hat{v}\cos\psi + l_1\tilde{x}\sin\psi + l_1\tilde{y}\cos\psi \\ \dot{\hat{\psi}} = \hat{r} + l_1\tilde{\psi} \\ \dot{z}_1 = \hat{W}_1^{\mathrm{T}}\varphi_1 + \dfrac{\tau_u}{m_u} + (l_2 l_1 + 1)\tilde{x} - x_e + l_2 u_e \\ \dot{z}_2 = \hat{W}_2^{\mathrm{T}}\varphi_2 + (l_2 l_1 + 1)\tilde{y} - y_e \\ \dot{z}_3 = \hat{W}_3^{\mathrm{T}}\varphi_3 + \dfrac{\tau_r}{m_r} + (l_2 l_1 + 1)\tilde{\psi} - \tilde{\psi}_e + l_2 r_e \\ \hat{u} = z_1 + l_2\tilde{x},\ \ \hat{v} = z_2 + l_2\tilde{y},\ \ \hat{r} = z_3 + l_2\tilde{\psi} \end{cases}$$

Fuzzy logic system is adopted to approximate the uncertainties of models.

Singleton fuzzification; Product inference; Center average defuzzification

$$\begin{cases} W_1^{\mathrm{T}}\varphi_1(\hat{u},\hat{v},\hat{r},\tilde{y}) = \dfrac{m_v}{m_u} vr - \dfrac{d_u}{m_u} u - l_2 r\tilde{y} \\ W_2^{\mathrm{T}}\varphi_2(\hat{u},\hat{v},\hat{r},\tilde{x}) = -\dfrac{m_u}{m_v} ur - \dfrac{d_v}{m_v} v + l_2 r\tilde{x} \\ W_3^{\mathrm{T}}\varphi_3(\hat{u},\hat{v},\hat{r}) = \dfrac{m_u - m_v}{m_r} uv - \dfrac{d_r}{m_v} r \end{cases}$$

Virtual control laws

$$\begin{cases} \alpha_u = k_x x_e + u_d \cos\psi_e \\ \alpha_{\psi_e} = \arcsin\left(\dfrac{\hat{v} - k_y y_e}{u_d}\right) \\ \alpha_r = k_\psi \tilde{\psi}_e + r_d - \dot{\beta}_\psi \end{cases}$$

Difficult to acquire $\dot{\alpha}_u, \dot{\alpha}_r, \dot{\alpha}_{\psi_e}$

DSC first-order filter

$$\begin{cases} T_u\dot{\beta}_u + \beta_u = \alpha_u + T_u x_e \\ T_\psi\dot{\beta}_\psi + \beta_\psi = \alpha_{\psi_e} \\ T\dot{\beta}_r + \beta_r = \alpha_r + T_r\tilde{\psi}_e \end{cases}$$

Direct control laws

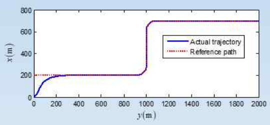
$$\begin{cases} \tau_u = m_u\left(-\hat{W}_1^{\mathrm{T}}\varphi_1 - \tilde{x} + 2x_e + \dot{\beta}_u - k_u u_e\right) \\ \tau_r = m_r\left(-\hat{W}_3^{\mathrm{T}}\varphi_3 - \tilde{\psi} + 2\tilde{\psi}_e + \dot{\beta}_r - k_r r_e\right) \end{cases}$$

Experimental objective

$m_u = 6.0806\times10^6; m_v = 1.0592\times10^7; m_r = 7.1035\times10^9;$

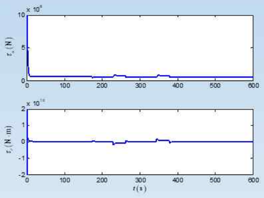
$d_u = 4\times10^4; d_v = 2\times10^6; d_r = 2\times10^{10}$

Experimental results

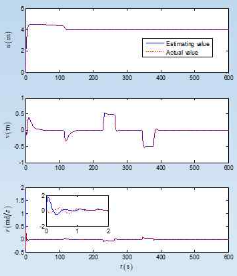


Planar Trajectory

Experimental results



Direct control inputs



Observation results

Conclusion

- The proposed multi-level DVS guidance could further reduce the saturation limitation of actuators.
- The introduction of adaptive FLS observer could replace the function of sensors and controller is structured on the frame of FLS observer.
- The introduction of DSC filter solve the problem of explosion of complexity.