Distributed Command Filtered Robust Tracking Control of Wave-Adaptive Modular Vessel with Uncertainty

Md. Nur-A-Adam Dony[1], Wenjie Dong[1]

College of Sciences Annual Research Conference

The University of Texas Rio Grande Valley

Abstract

- In this paper, we considered formation control of multiple WAM-Vs with uncertainty. It is assumed that there is parametric uncertainty and non-parametric uncertainty in the model of each WAM-V and the information of the leader WAM-V is available only to a portion of the follower WAM-Vs.
- With the aid of backstepping techniques, Distributed robust tracking controllers are proposed.
- To avoid calculation of the derivative of signals, Distributed command filtered controllers are also proposed.
- Simulation results show the effectiveness of the proposed controllers.

Problem Statement

Kinematics of WAM-V

The kinematics of the j-th WAM-V can be written as

$$\dot{x}_j = u_j \cos\psi_j - v_j \sin\psi_j \quad (1)$$
$$\dot{y}_j = u_j \sin\psi_j + v_j \cos\psi_j \quad (2)$$
$$\dot{\psi}_j = r_j \quad (3)$$

Dynamics of WAM-V

The dynamics of the j –th WAM-V can be written as

$$m_{1j}\dot{u}_j - m_{2j}v_j r_j + d_{1j}u_j + D_{1j} = F_{Lj} + F_{Rj} \quad (4)$$
$$m_{2j}\dot{v}_j + m_{1j}u_j r_j + d_{2j}v_j + D_{2j} = 0 \quad (5)$$
$$m_{3j}\dot{r}_j - (m_{1j} - m_{2j})u_j v_j + d_{3j}r_j + D_{3j} = L_j(F_{Lj} - F_{Rj}) \quad (6)$$

- m_{ij}, d_{ij}, and D_{1j} are unknown.
- The 0-th WAM-V is a leader and the other WAM-Vs are followers.
- The communication between WAM-V is described by a digraph $G^e = \{V^e, E^e\}$
- It is given a desired geometric pattern P defined by constant vectors $[p_{jx}, p_{jy}]^\top (1 \le j \le m)$ which satisfy $\sum_{j=1}^m p_{jx} = 0$ and $\sum_{j=1}^m p_{jy} = 0$

Formation Control Problem

Design a controller (F_{Lj}, F_{Rj}) for j-th follower WAM-V based on its neighbors' state information such that

$$\lim_{t\to\infty} \begin{bmatrix} x_i - x_j \\ y_i - y_j \end{bmatrix} = \begin{bmatrix} p_{ix} - p_{jx} \\ p_{iy} - p_{jy} \end{bmatrix}, 1 \le i, j \le m \quad (7)$$

$$\lim_{t\to\infty} \sum_{j=1}^m \left(\frac{x_j}{m} - x_0\right) = 0 \quad (8)$$

$$\lim_{t\to\infty} \sum_{j=1}^m \left(\frac{y_j}{m} - y_0\right) = 0 \quad (9)$$

In the above problem,

eqn. (7) means that m follower WAM-Vs come into the desired geometric pattern P.

Eqn. (8)-(9) mean that the centroid of m follower WAM-Vs follows the leader WAM-V.

Proposed Controller (Solution)

A. Distributed Controller

With the aid of the backstepping technique, if the leader WAM-V is globally reachable distributed controllers are proposed as

$$F_{Rj} = \frac{1}{2}\left(\delta_{1j} + \frac{\delta_{2j}}{L_j}\right), \quad (10)$$

$$F_{Lj} = \frac{1}{2}\left(\delta_{1j} - \frac{\delta_{2j}}{L_j}\right) \quad (11)$$

Where,

$$\delta_{1j} = -K_3 z_{1j} + \bar{m}_{1j}\dot{\eta}_{3j} - \bar{m}_{2j}v_j r_j + \bar{d}_{1j}u_j - (\rho_{1j}|\dot{\eta}_{3j}| + \rho_{2j}|v_j r_j| - (\rho_{1j}|\dot{\eta}_{3j}| + \rho_{2j}|v_j r_j| + \rho_{4j}|u_j| + \rho_{6j})sign(z_{1j}) \quad (12)$$

$$\delta_{2j} = -K_5 z_{3j} - z_{2j} - (\bar{m}_{1j} - \bar{m}_{2j})u_j v_j + \bar{d}_{3j}r + \bar{m}_{3j}\dot{\eta}_{5j} - ((\rho_{1j} + \rho_{2j})|u_j v_j| + \rho_{5j}|r_j| + \rho_{3j}|\dot{\eta}_{5j}| + \rho_{7j})sign(z_{3j}) \quad (13)$$

B. Distributed Command Filtered Tracking Control Laws

In the proposed controller in the last section, the derivatives of signals are needed. To avoid this, a command filtered controller can be designed

$$\dot{\chi}_{1j} = -r_{1j}|\chi_{1j} - \eta_{3j}|^{\frac{1}{2}} sign(\chi_{1j} - \eta_{3j}) + \chi_{2j} \quad (15)$$
$$\dot{\chi}_{2j} = -r_{2j} sign(\chi_{2j} - \dot{\chi}_{1j}) \quad (16)$$
$$\dot{\chi}_{3j} = -r_{3j}|\chi_{3j} - \eta_{4j}|^{\frac{1}{2}} sign(\chi_{3j} - \eta_{4j}) + \chi_{4j} \quad (17)$$
$$\dot{\chi}_{4j} = -r_{4j} sign(\chi_{4j} - \dot{\chi}_{3j}) \quad (18)$$
$$\dot{\chi}_{5j} = -r_{5j}|\chi_{5j} - \eta_{5j}|^{\frac{1}{2}} sign(\chi_{5j} - \eta_{5j}) + \chi_{6j} \quad (19)$$
$$\dot{\chi}_{6j} = -r_{6j} sign(\chi_{6j} - \dot{\chi}_{5j}) \quad (20)$$

Distributed command filtered controllers are

$$F_{Rj} = \frac{1}{2}\left(\delta_{1j} + \frac{\delta_{2j}}{L_j}\right), \quad (23)$$

$$F_{Lj} = \frac{1}{2}\left(\delta_{1j} - \frac{\delta_{2j}}{L_j}\right) \quad (24)$$

Where

$$\delta_{1j} = -K_3(u_j - \chi_{1j}) + \bar{m}_{1j}\dot{\chi}_{1j} - \bar{m}_{2j}v_j r_j + \bar{d}_{1j}u_j - (\rho_{1j}|\dot{\chi}_{1j}| + \rho_{2j}|v_j r_j| + \rho_{4j}|u_j| + \rho_{6j})sign(w_{1j}) \quad (25)$$

$$\delta_{2j} = -K_5(r_j - \chi_{5j}) - w_{2j} - (\bar{m}_{1j} - \bar{m}_{2j})u_j v_j + \bar{d}_{3j}r + \bar{m}_{3j}\dot{\chi}_{5j} - ((\rho_{1j} + \rho_{2j})|u_j v_j| + \rho_{5j}|r_j| + \rho_{3j}|\dot{\chi}_{5j}| + \rho_{7j})sign(z_{3j}) \quad (26)$$

Graphical Representation

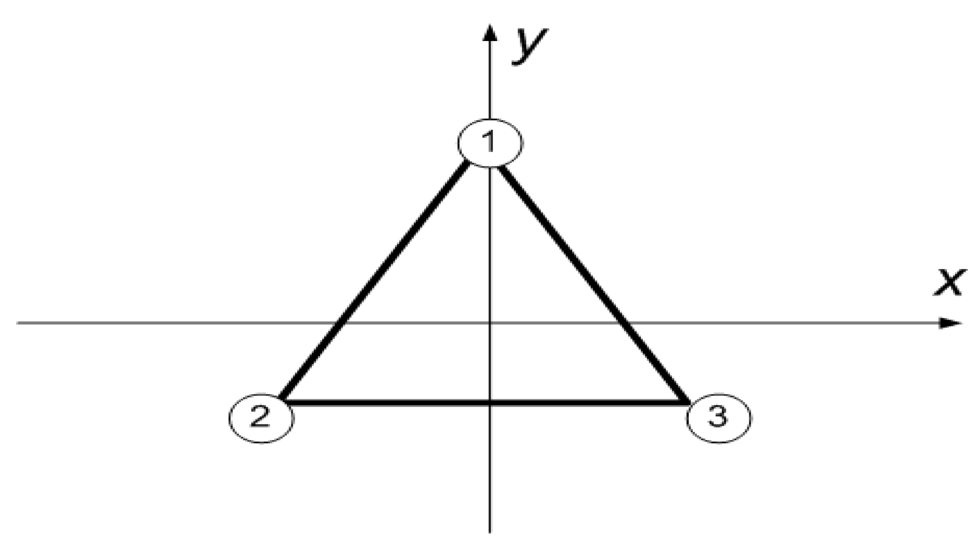

Fig 1: Desired formation of three WAM-Vs

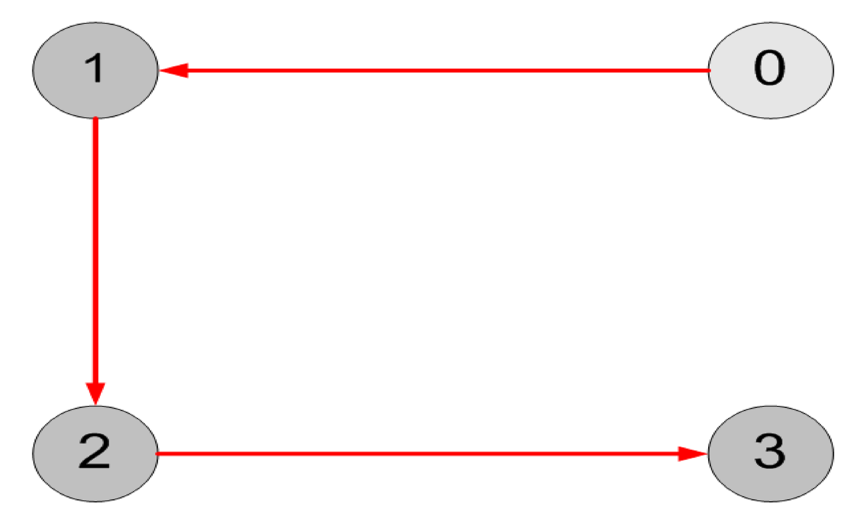

Fig 2: Communication digraph

Simulation Result

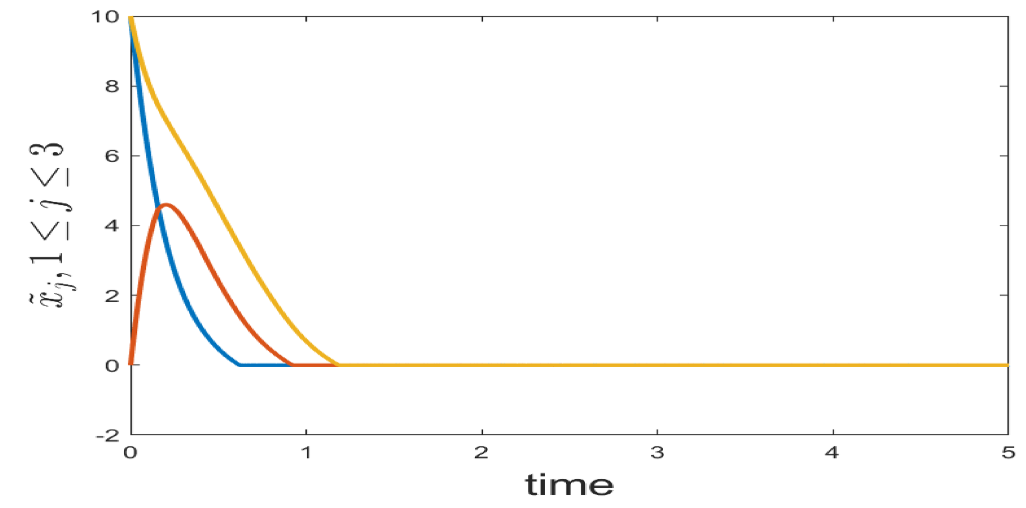

Fig .3: Time response of $\tilde{x}_j$ for $1 \le j \le 3$

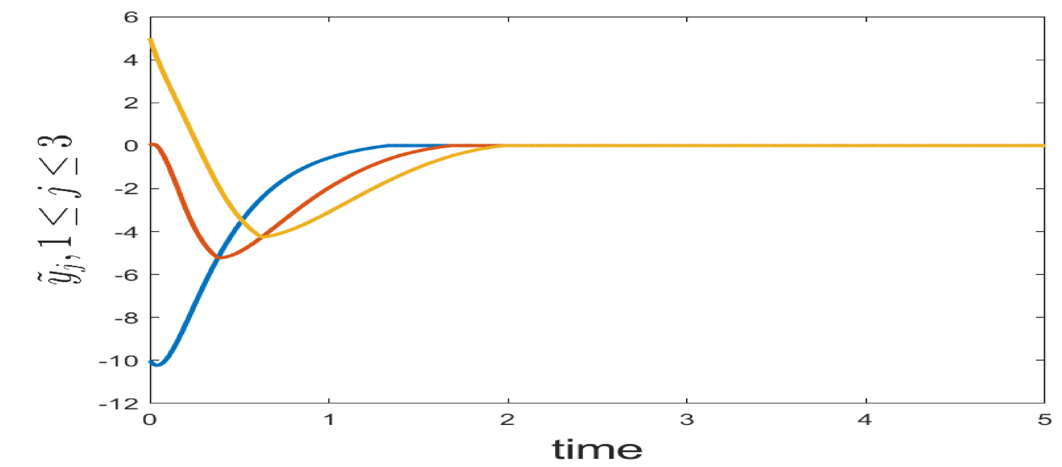

Fig. 4: Time response of $\tilde{y}_j$ for $1 \le j \le 3$

Simulation Result (cont.)

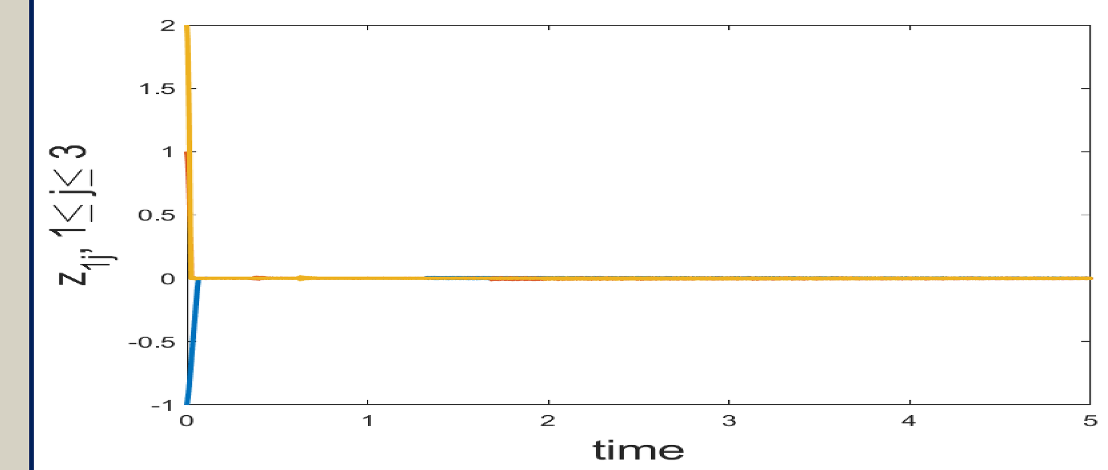

Fig. 5: Time response of z_{1j} for $1 \le j \le 3$

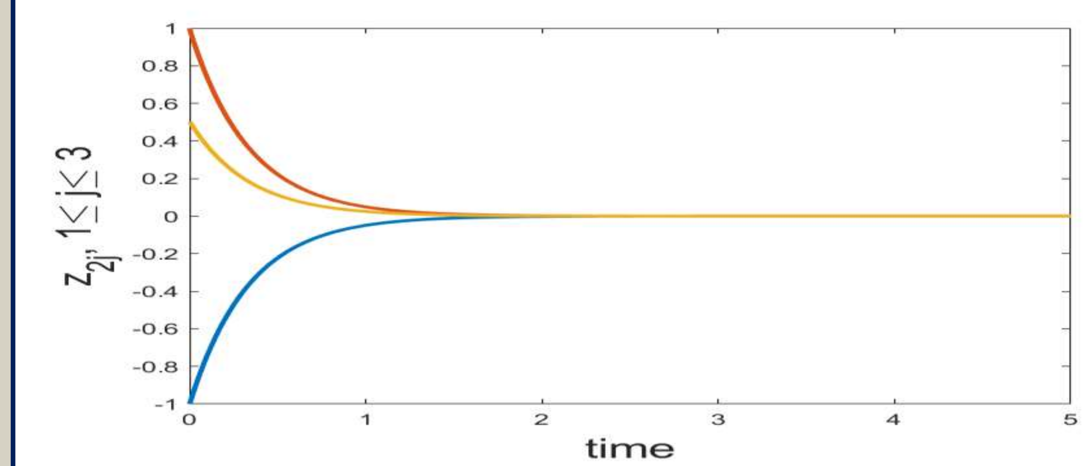

Fig 6: Time response of z_{2j} for $1 \le j \le 3$

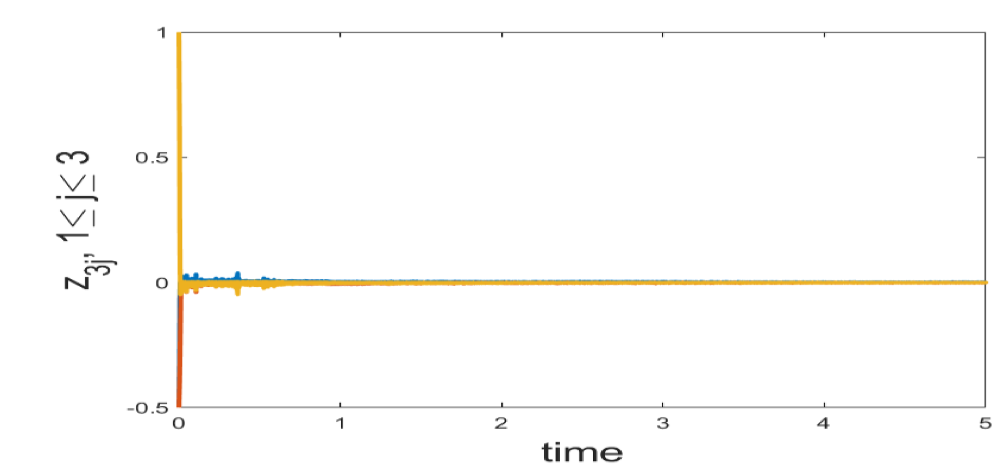

Fig.7: Time response of z_{3j} for $1 \le j \le 3$

Conclusion

- ✓ In this paper, we considered formation control of multiple uncertain WAM-Vs with a leader WAM-V.
- ✓ If inertia parameters are not exactly known, distributed robust tracking laws were proposed with the aid of neighbors' information.
- ✓ To reduce the computation load in controller design, distributed command filtered controllers were proposed. Simulation results show the effectiveness of the proposed results.

References

[1] A. Aguiar, R. Ghabcheloo, A. Pascoal, C. Silvestre, J. Hespanha, and I. Kaminer. Coordinated path-following of multiple underactuated autonomous vehicles with bidirectional communication constraints. *Proc. of Int. Symp. on Communications, Control and Signal Processing, 2006.*

[2] F. Arrichiello, S. Chiaverini, and T. I. Fossen. *Formation control of marine surface vessels using the null-space-based behavioral control, in Group Coordination and Cooperative Control (K. Y. Pettersen, T. Gravdahl, and H. Nijmeijer, Eds.). LNCISS, vol. 336.* Springer-Verlag, 2006.

[3] F. Arrichiello, S. Chiaverini, and T. I. Fossen. Formation control of underactuated surface vessels using the null-space-based behavioral control. *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems,* pages 5942–5947, 2006.