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Adaptive control simulation for multiagent autonomous underwater cleaning robot

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The purpose of this research is to develop an adaptive control system for multiagent autonomous underwater cleaning robots that can handle problems that occur due to large areas of underwater environment cleaning operations, single robot challenges, and ineffective tactics that could cause a system failure. Therefore, the purpose of the research is to develop an adaptive control system for multiagent autonomous underwater cleaning robots that can be used to handle difficulties such as underwater environment cleanliness, single robot issues, and avoiding ineffective approaches that might cause system failure. This research used the MATLAB and Simulink tools to create an adaptive control system and simulate the designed controller with various unknown parameters and disturbances. The results demonstrate the adaptivity, adjustability, and stability of the multiagent underwater cleaning robot's adaptive control system to cope with the underwater environment's situations such water current using simulation.

[**Keywords**: Adaptive control system, Autonomous underwater vehicle, Cleaning robots, Multiagent, Triangular-shaped underwater vehicle]

Introduction

This paper proposed a small and multiagent triangular-shaped Autonomous Underwater Vehicle (AUV). The body structure of the AUV was inspired by Stingray fish[1]. The Triangular-Shaped Autonomous Underwater Vehicle (TAUV) is designed to remove the biofouling growth on fishnets for the aquaculture sector. This research work aims to develop an adaptive control system for multiagent autonomous underwater cleaning robots, simulate the adaptive controller with several uncertain parameters and underwater disturbances, and evaluate the effectiveness of the proposed adaptive control system.

Materials and Methods

The method for developing the proposed adaptive control system for multiagent autonomous underwater cleaning robots is presented in this section. The system's overall block diagram is presented first, followed by the structure design used to construct the robot's mathematical model for simulation[2-4], and finally, the general notation for the autonomous underwater cleaning robot's behavior[5-6].

Research work

The multiagent system architecture is designed in the first phase. The multiagent system is a computerized system made up of multiple intelligent agents that interact with one another. In this research work, three robots work together and interact with one another to complete their objective. The control system algorithm may play a role in this project's intelligence. The system is modelled as a group of independent decision-making entities known as agents. Each agent autonomously evaluates their situation and takes actions based on a set of rules.

The second phase is required to work on the multiagent system. The mathematical model and control method are created using MATLAB and Simulink in this phase. The mathematical model consists of two types: kinematic model and dynamic model. All the multiagent robots, underwater environments, and external disturbances were applied in the mathematical model. The decentralized control algorithm, based on self-adaptive concepts in biology, is the most often used. The control algorithm is based on constructing a control sequence that reduces a performance criterion involving a predicted output sequence using a model to estimate the process's performance on a future horizon. Multiagent frameworks can carry out planned and collaborative operations.

Finally, the simulation's performance in terms of adjustability, stability, and adaptivity to its surroundings will be validated. Figure 1 shows the phases of research work that need to be pursued to achieve the research work's concept.

Structure design

Solidworks, a Computer-Aided Design (CAD) platform, was used to generate the underwater robot 3D model. It was constructed to acquire the robot's mass properties from a rigid computer model provided in Solidworks. This underwater robot has a triangular structure and is propelled by two thrusters. As shown in Figure 2, the Stingray fish inspired this underwater robot design.

The notation of the Autonomous Underwater Cleaning robot

The inertial frame (i-frame) and the body-fixed frame (b-frame) are two reference frames commonly used in underwater vehicle motion studies. The b-frame is the vehicle's moving coordinate frame, and the i-frame is the non-rotating frame. There is also a reference frame known as the wind frame that is used to define hydrodynamic forces and moments. Figure 3 illustrates the 6 Degree of Freedom (DOF) illustrations and a description of the fixed body and inertial coordinate systems[7].

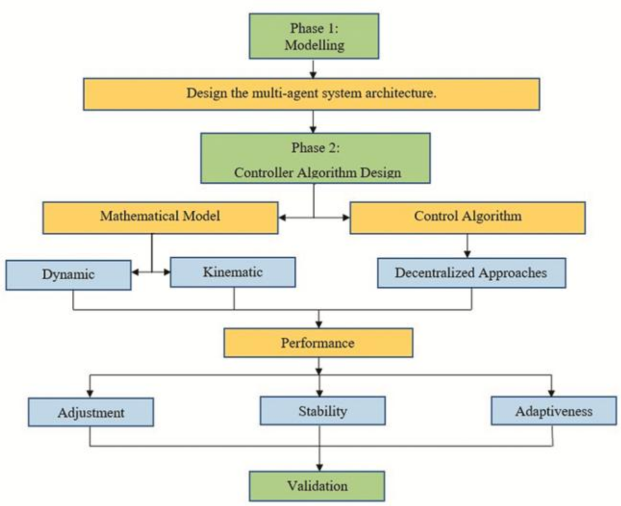

Fig. 1 — The phases of the research work

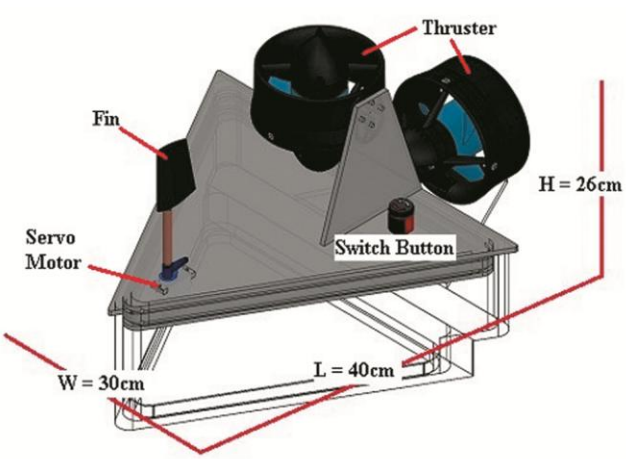

Fig. 2 — 3D model of underwater robot design

Results and Discussion

The evaluation of four different system designs for the underwater cleaning robot is presented in this section.

Open-loop control system

An open-loop system generates the output simply in response to the input signal without the use of feedback. This system is used to demonstrate the underwater robot's nonlinear motion control system without providing feedback. The produced simulation results for this system, as shown in Figure 4, demonstrate the robot's nonlinear movement without a proper direction, and it shows that the robot moves freely in the simulation result.

Closed-loop control system

For this research, a closed-loop system with a Linear Quadratic Regulator (LQR) was used. The LQR is one of the simple controllers to build and one of the best in terms of performance and robustness, so it is a good substitute for assessing the closed-loop behavior of this nonlinear model.

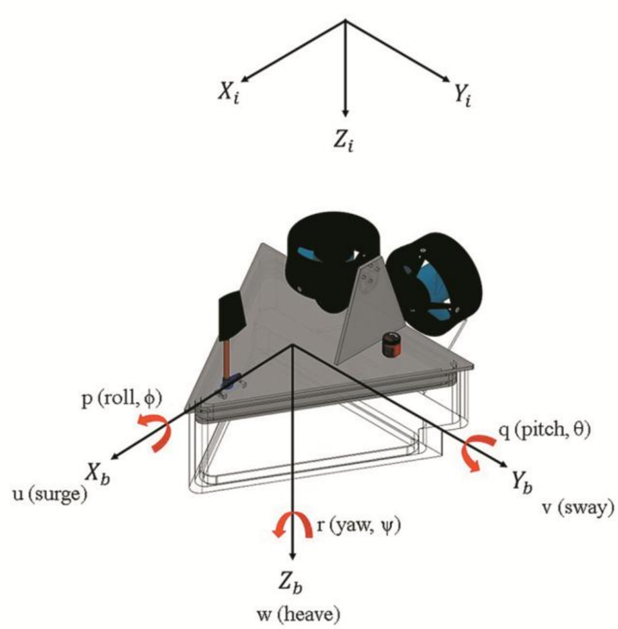

Fig. 3 — 6 DOF illustrations

Figure 5 illustrates the position as a result of the closed-loop simulation. The LQR setpoint control stabilizes the nonlinear system and achieves satisfactory tracking performance even in noise and disturbances. The graph result was not constant at the initial sample time, as shown in Figure 5. The controller seemed to interact with the LQR afterwards, and the result became constant and stable at one point till the simulation ended.

Adaptive controller of Model Predictive Control

Model Predictive Control (MPC) is a type of advanced process control that regulates a process using a set of constraints and predicts how the system

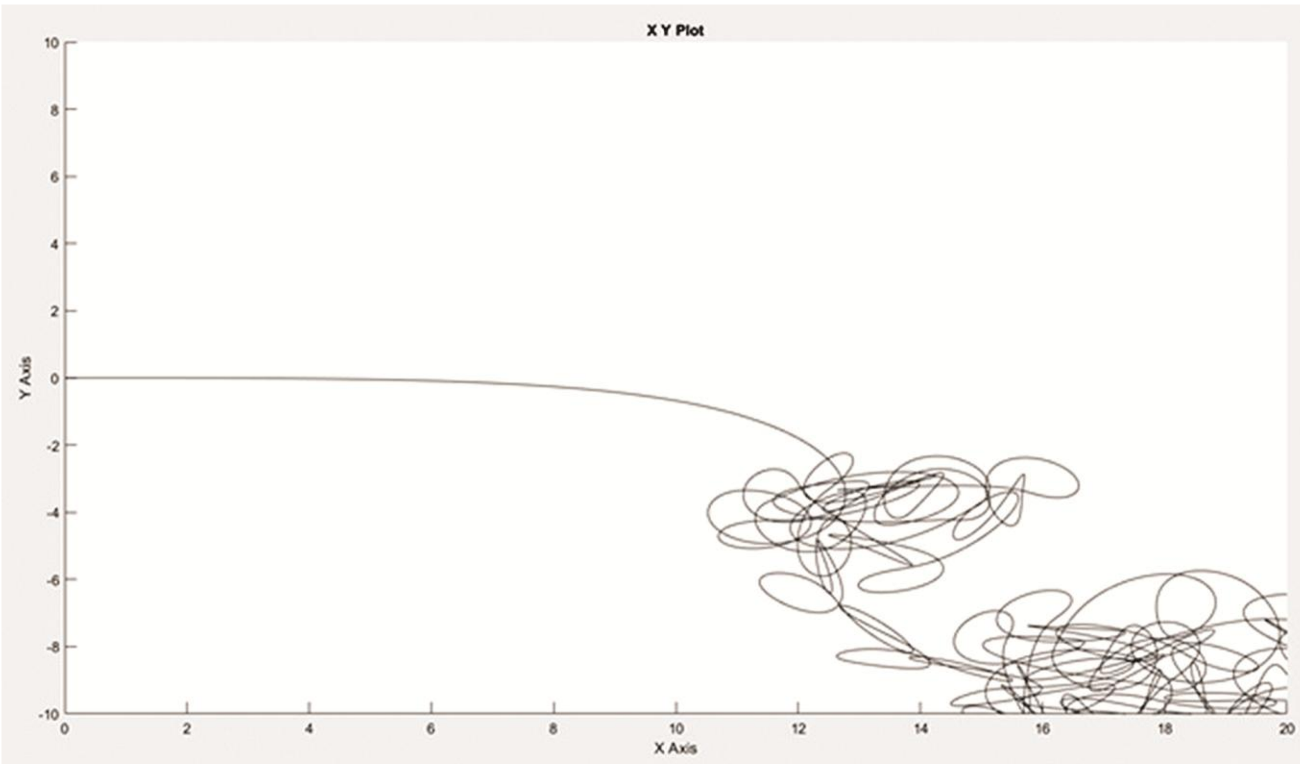

Fig. 4 — The simulation of open-loop control system

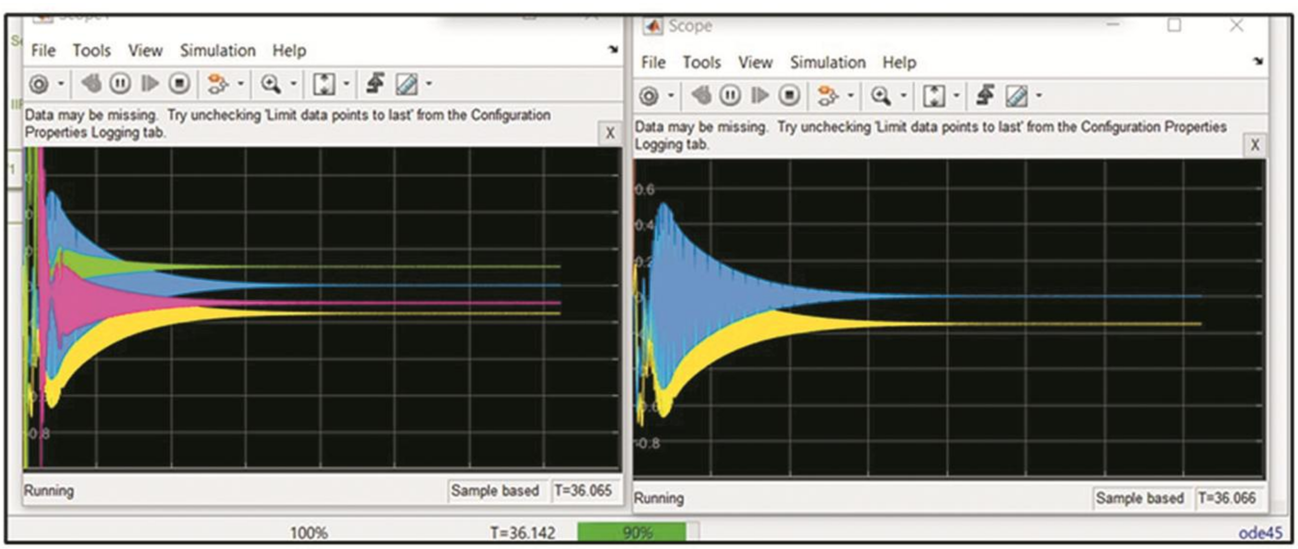

Fig. 5 — Closed-loop control system

will behave in the future. As shown in Figure 6, the MPC circuit was constructed for three agents by applying continuous work to a closed-loop LQR circuit.

Setting the sample time is the initial step in designing the MPC's parameters. The sample time, Ts, set in the MPC design in this research was 0.1 seconds (s). As a result, the app imports and linearizes the plant from the Simulink model and utilizes it as an internal model after the MPC is defined and linearized using the sample time that has been set. The prediction horizon in this research was set at 10. The graph responses become slower when the prediction horizon in the MPC design setting is increased to 15 or 20. As a result, the MPC design's prediction horizon was set to 10 in Simulink. The optimizer finds the ideal sequence of control inputs that drives the predicted plan output as close to the setpoint as possible, relying on the MPC controller's predictions about future plan output. Control horizon refers to the number of controls in a time step. The control horizon can be taught to the optimizer as a free variable that must be computed. The fewer the computation moves, the smaller the control horizon. As a result, selecting a control horizon that is too large contributes to the computational complexity. Setting the control horizon to a prediction horizon of 10 to 20 and a minimum of two to three control horizon steps is the best option.

The physical limitations of the vehicle determine the input constraints. The angle of attack between the wind frame and the fin-fixed was considered to be 45 degrees. As a result, the minimum and maximum values were set to pi/4 radian for the input constraints. The attack angle was then set to 22.5 degrees per second for the minimum and maximum limit rate of change, resulting in pi/8 radian. Finally, MPC has a variety of objectives. The outputs should track as close as possible to the setpoint, but at the same time, smooth control movements to avoid forceful control manuals requires. The default input weight has been fixed at 0, and it does not need to track a target. The default weight value has also been maintained. If a smaller input increment is required, it can also be adjusted. Because position tracking is the primary objection, the y(1) position weight was set at 2.8, and the y(2) angle weight was a divided value of 10 from the y(1) position weight value, which is 0.28. After all the MPC parameters were set, the input and output responses for the plant model of each of three vehicles shown in Figure 7.

Multiagent system model

Figure 8 shows how the adaptive control structure of a single robot was improved by adding two more controller circuits and connecting them all together. The connecting of the three control system circuits reveals that the multiagent system model has three agents. The connection between the three agents represents their interaction, which shares control inputs from one agent to the next such that their

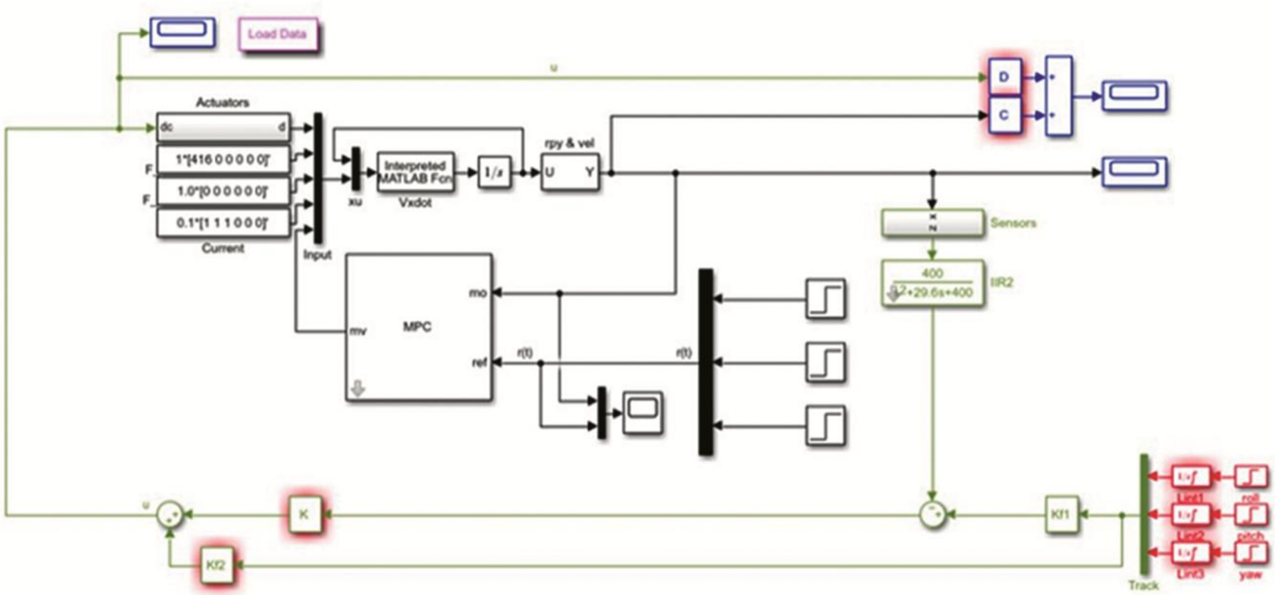

Fig. 6 — MPC controller simulink circuit

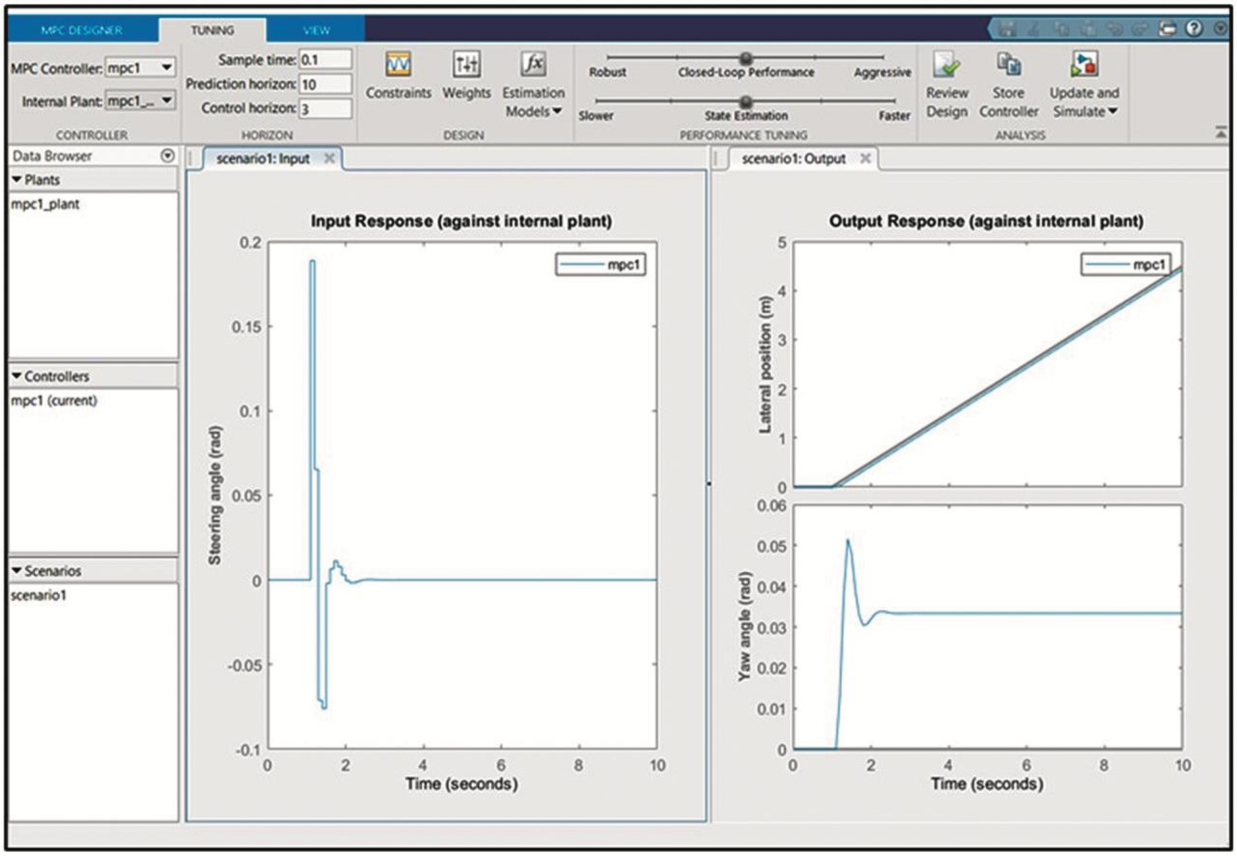

Fig. 7 — MPC input-output responses

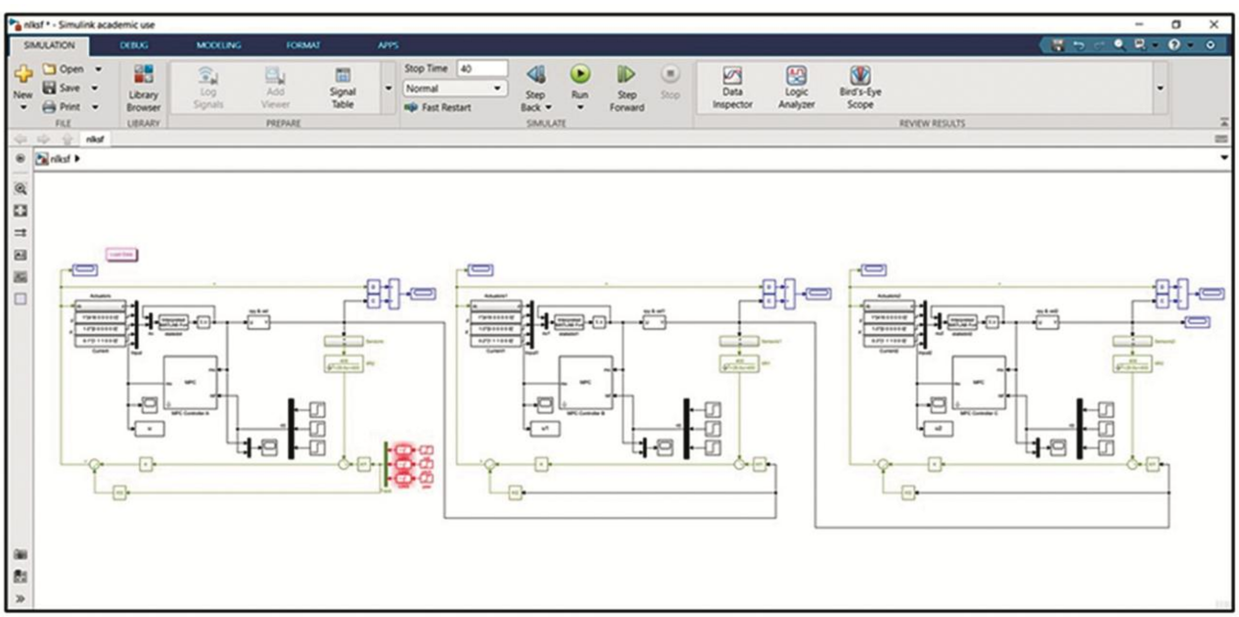

Fig. 8 — Multiagent system model

motions as a multiagent system. Finally, the responses obtained for all three agents are identical, as shown in Figure 9, even though the current applied to each agent are different, which the agent A current was 0.1, agent B was 0.2, and agent C was 0.3. This is due to the fact that, despite the differences in disturbances,

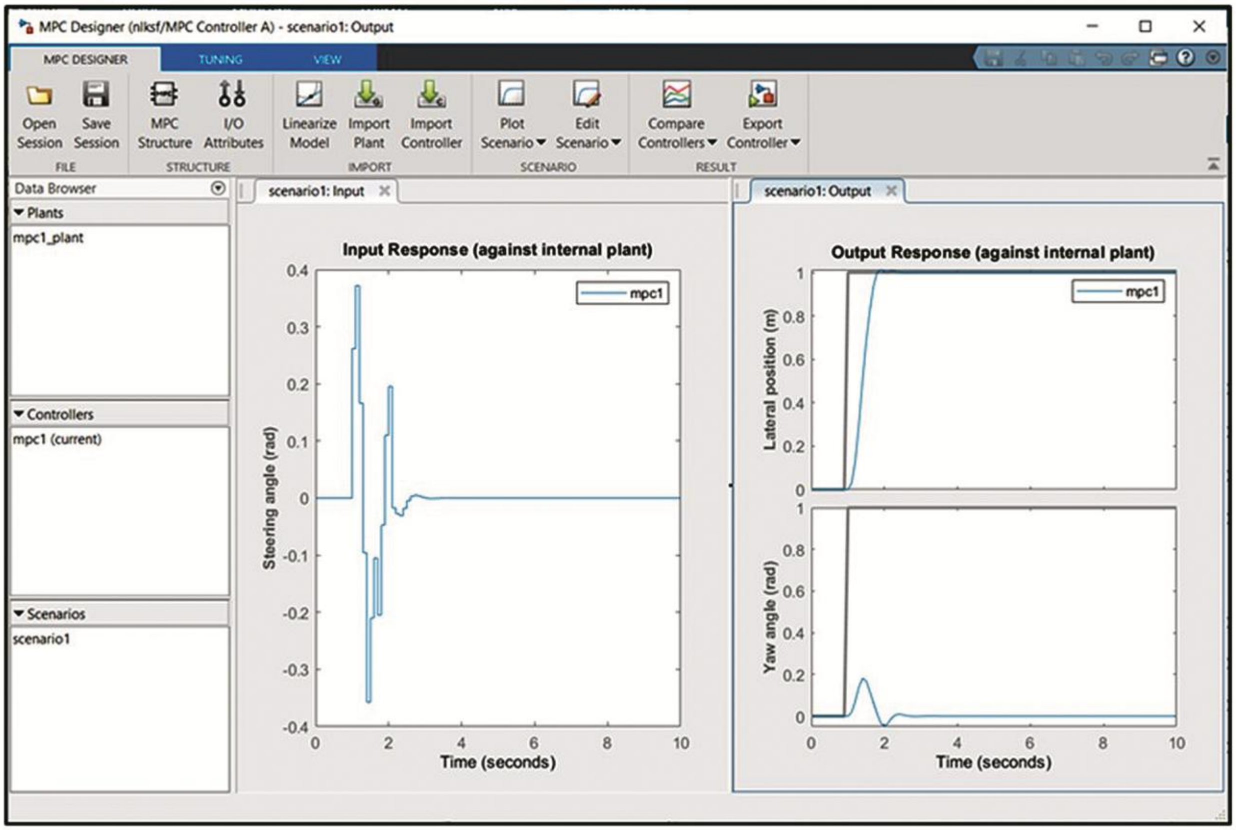

Fig. 9 — Output responses of three agents

the agents' motion still demonstrates that they are following the leader. The responses of agent A are monitored by agents B and C.

Conclusion

In conclusion, the research work's goal of designing an adaptive control system for multiagent autonomous underwater cleaning robots, simulating the adaptive controller with multiple uncertain parameters and underwater environment disturbance, and analyzing the proposed adaptive control system's performance was accomplished. The overall adaptive control system design includes the closed-loop LQR and MPC analysis and the algorithm of the project with two mathematical model that is kinematic model and dynamic model. As a result of developing the multiagent system model, it is now possible to state that a single robot cannot be successfully used for larger tasks in which it is unable to fulfil the entire objective.

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