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Motion Control of an Autonomous Surface Vessel for Enhanced Situational Awareness

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Abstract**—**This paper focuses on the critical components of the situational awareness (SA), the controls of position and orientation of an autonomous surface vessel (ASV). Moving of vessel into desired area in particular sea is a challenging but important task for ASVs to achieve high level of autonomy under adverse conditions. With the SA strategy, the approach motion by neural control of an initial stage of an ASV trajectory using neural network predictive controller and the circular motion by control of yaw moment in the final stage of trajectory were proposed. This control system has been demonstrated and evaluated by simulation of maritime maneuvers using software package Simulink. From the simulation results it can be seen that the fast SA of similar ASVs with economy in energy can be asserted during the maritime missions in search-and-rescue operations.

Keywords**—**Autonomous surface vessels, neurocontrollers, situational awareness.

I. Introduction

SITUATION awareness has been formally defined as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [1]. As the term implies, situation awareness refers to awareness of the situation. Grammatically, situational awareness (SA) refers to awareness that only happens sometimes in certain situations.

SA has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems, including emergency response and military command and control operations [2].

The term SA have become commonplace for the doctrine and tactics, and techniques in the U.S. Army [3]. SA is defined as "the ability to maintain a constant, clear mental picture of relevant information and the tactical situation including friendly and threat situations as well as terrain". SA allows leaders to avoid surprise, make rapid decisions, and choose when and where to conduct engagements, and achieve decisive out comes.

SA with using of autonomous surface vessels (ASVs) expands and enhances the possibilities of fleet operations, greatly reduces the logistics and command/control burden to the fleet, and enables ASVs to serve as tactical multipliers for missions that are currently manned and for missions unacceptable for manned operations [4].

The use of tactical ASVs provides a means to accomplish a wide variety of combat missions without risk to human life and without loss of expensive platforms. Many ASVs are small and modular, allowing for rapid deployment in remote areas or deployment by larger vessels, and its command and control systems are user-friendly, compact and have low cost.

Possible ASV missions include:

- Intelligence surveillance and reconnaissance
- Port and border security
- Special operations support
- Autonomous search and rescue
- Communications relay (space, air, ground, sea surface, underwater)
- Maritime protection
- Track and trail
- Force protection
- Mine detection and neutralization

In [5], a two stage multirate control procedure using two ADAptive LInear NEuron Neural Networks (ADALINE NNs) with one neuron for desired depth levels was presented. The proposed control strategy has been verified by simulation of diving maneuvers of an autonomous underwater vehicle (AUV) "r2D4" model using software package Simulink and demonstrated good performance for fast SA in real-time search-and-rescue operations.

This paper concentrates on issues related to the area of [5], but demonstrates another field for application of these ideas, i.e., research technique using modeling and simulation control system with two parts of trajectory on the basis of equations of motion of chosen model of ASV for fast SA.

The ASV provides the commander with a number of capabilities including:

- Enhanced SA.
- Target acquisition.
- Enhanced management capabilities (assessment of area defense capability over large sectors and visualization of close and distant blockades).

Some conditions for conducting sea surface reconnaissance with ASVs are as follows.

- Time is limited or information is required quickly.
- Threat conditions are known.
- Sea bottom relief restricts approach by large surface ships.

In [6], the tracking control problem of an under actuated surface vessel is considered. New asymptotical tracking controller and exponential tracking controller are proposed

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with the aid of the cascaded structure of the error dynamics, and the back stepping technique. From the simulation, the two proposed control laws all make the tracking error converge to zero. Since the first control law does not guarantee an exponential convergence rate of the tracking error of the closed-loop system, the tracking performance may be not good as one desires. The second control law guarantees the tracking error exponentially converge to zero.

In this paper our research results in the study of position and orientation controls of an ASV which make such SA task scenario as “go-search-find” possible are presented.

The contribution of the paper is twofold: to develop new schemes appropriate for SA enhancement by control of an ASV trajectory in real-time search-and-rescue operations, and to present the results of maritime maneuvers for chosen model of the ASV for fast SA in simulation form using the MATLAB/Simulink environment.

II. ASV Model

Consider the model of an under actuated surface vessel. The vessel has two propellers which are the force in surge and the control torque in yaw. The kinematics of this system can be written as [6]

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix}, \quad (1)$$

where (x, y) denotes the coordinate of the center of mass of the surface vessel in the earth-fixed frame, ψ is the orientation of the vessel, and u, v, r are the velocities in surge, sway and yaw, respectively.

Assume that

- the environment forces due to wind, currents and waves can be neglected in the model
- the inertia, added mass and damping matrices are diagonal.

The dynamic model for control yields the general form of equations for the ASV [6]

$$\dot{u} = \frac{m_{22}}{m_{11}} vr - \frac{d_{11}}{m_{11}} u + \frac{1}{m_{11}} t_1 \quad (2)$$

$$\dot{v} = -\frac{m_{11}}{m_{22}} ur - \frac{d_{22}}{m_{22}} v \quad (3)$$

$$\dot{r} = \frac{m_{11} - m_{22}}{m_{33}} uv - \frac{d_{33}}{m_{33}} r + \frac{1}{m_{33}} t_2 \quad (4)$$

where $m_{ii} > 0, i = 1,2,3$ are given by the vessel inertia and the added mass effects, $d_{ii} > 0, i = 1,2,3$ are given by the hydrodynamic damping; m_{ii} and d_{ii} are assumed to be constant; t_1 and t_2 are the surge control force and the yaw control moment, respectively.

The parameters m_{11} through m_{33} and parameters d_{11} through d_{33} in (2)-(4) are given by:

$$m_{11} = 200kg,\ m_{22} = 250\text{kg},\ m_{33} = 80kg;$$

$$d_{11} = 70kg/s,\ d_{22} = 100\text{kg/s},\ d_{33} = 50kg/s.$$

Then, we have

$$x(\tau) = \int_0^\tau \dot{x}(t)dt,\ y(\tau) = \int_0^\tau \dot{y}(t)dt, \psi(\tau) = \int_0^\tau \dot{\psi}(t)dt, \quad (5)$$

where $x(0) = 0, y(0) = 0, \psi(0) = 0.$

From (1)-(5) we can see that the vector of position and orientation $(x, y, \psi)^T$ for given model of the ASV can be computed.

III. Simulation Results

Consider the control of the ASV model for the case of trajectory with initial and final parts.

In [7], the model predictive control method is proposed. This controller uses a neural network (NN) model to predict future plant responses to potential control signals. An optimization algorithm then computes the control signals that optimize future plant performance. The NN Predictive Controller tuning can be accomplished quickly and accurately using internal windows for this block.

The NN Predictive Controller is used to control the initial part of trajectory as approach motion with constant surge control force $t_1 = 50N$.

The constant surge control force $t_1 = 50N$ and the constant yaw control moment $t_2 = 2Nm$ are used to control the final part of trajectory as circular motion.

Simulation results for the offered block scheme (see Fig. 1) for various desired heading angles are shown in Figs. 2-9.

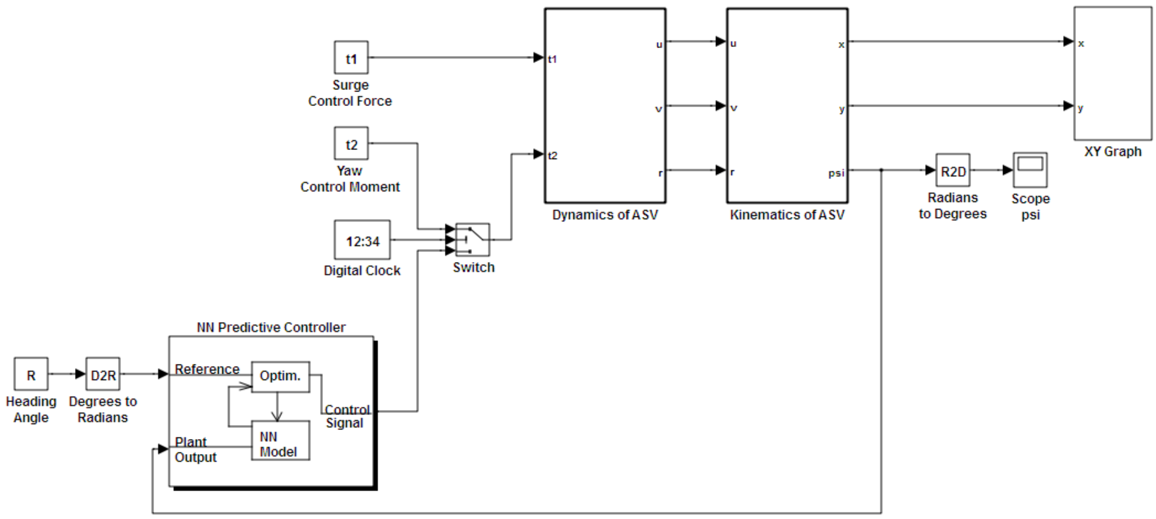

Fig. 1 Block diagram of control system

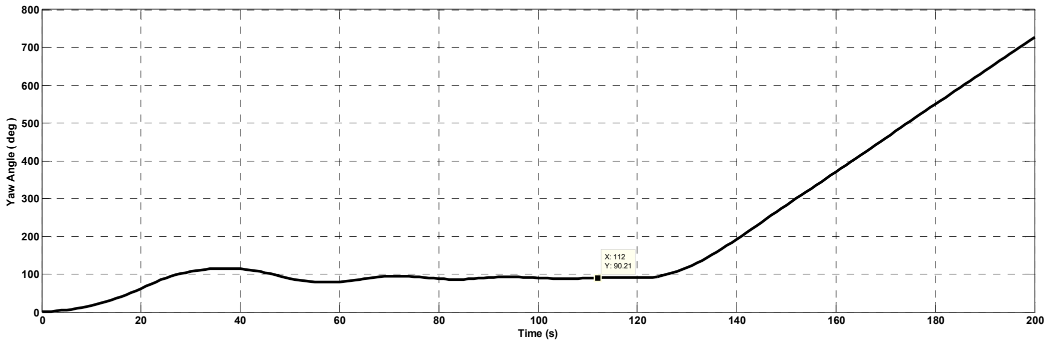

Fig. 2 Yaw angle of ASV for desired 90-degree heading angle

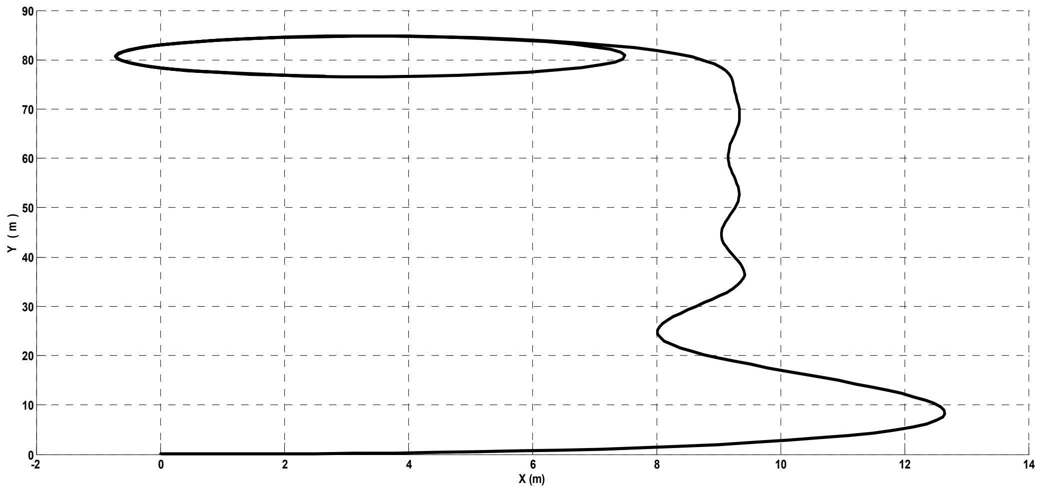

Fig. 3 ASV trajectory for desired 90-degree heading angle

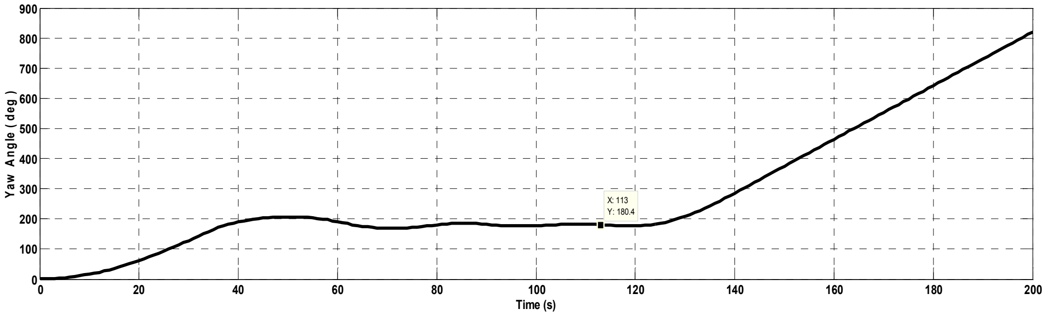

Fig. 4 Yaw angle of ASV for desired 180-degree heading angle

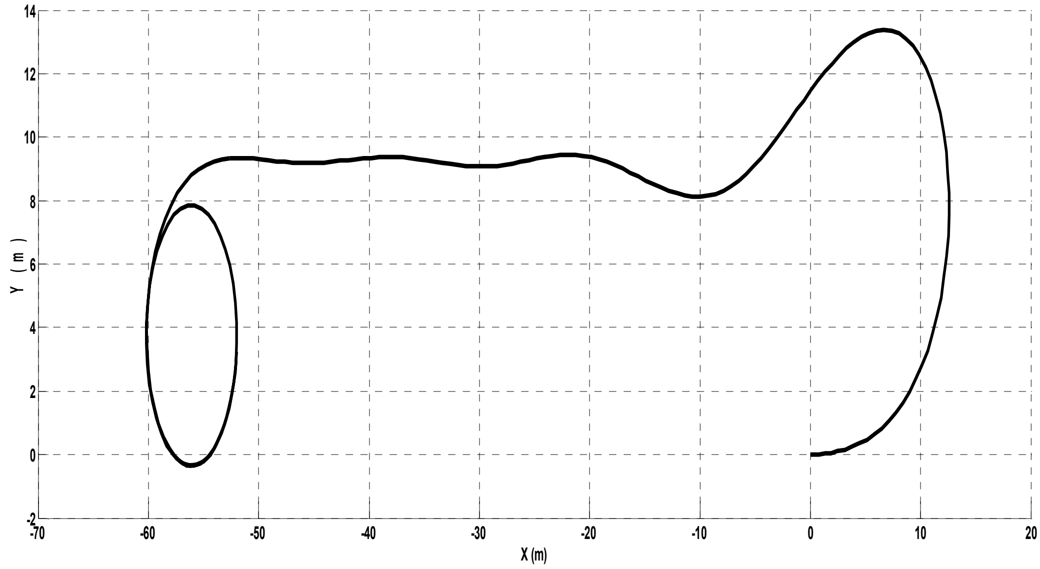

Fig. 5 ASV trajectory for desired 180-degree heading angle

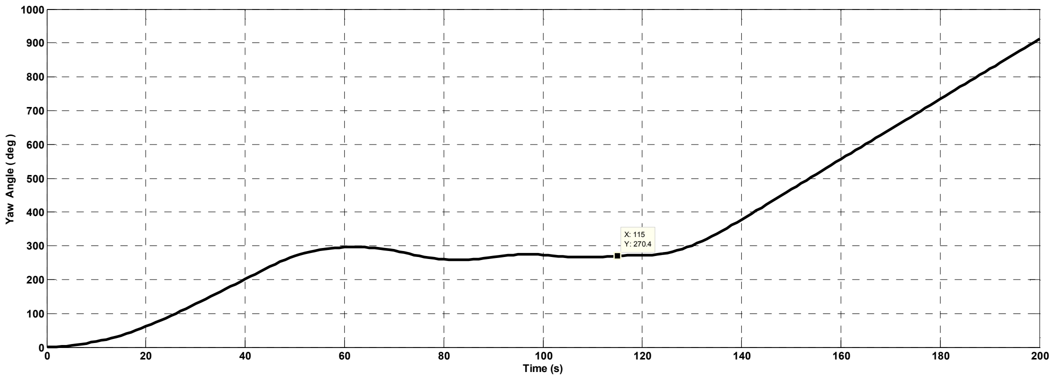

Fig. 6 Yaw angle of ASV for desired 270-degree heading angle

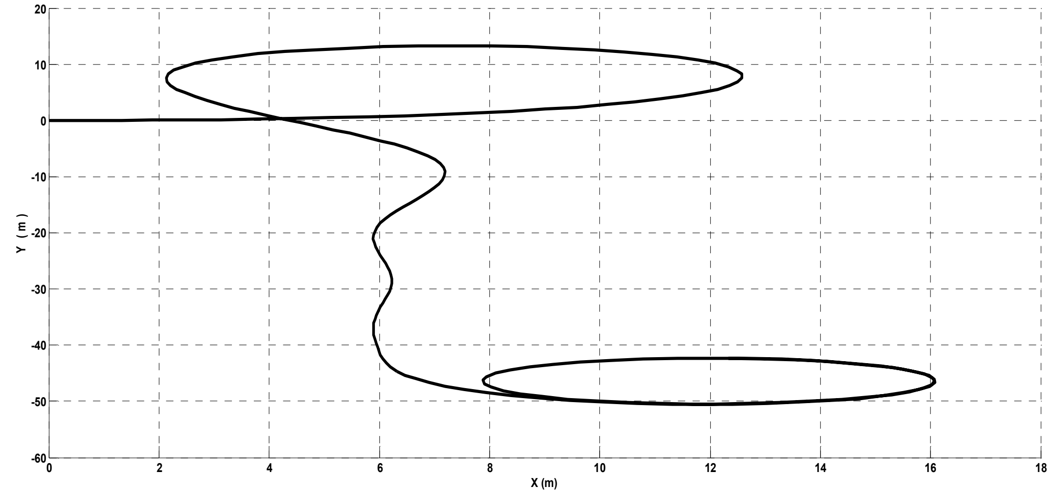

Fig. 7 ASV trajectory for desired 270-degree heading angle

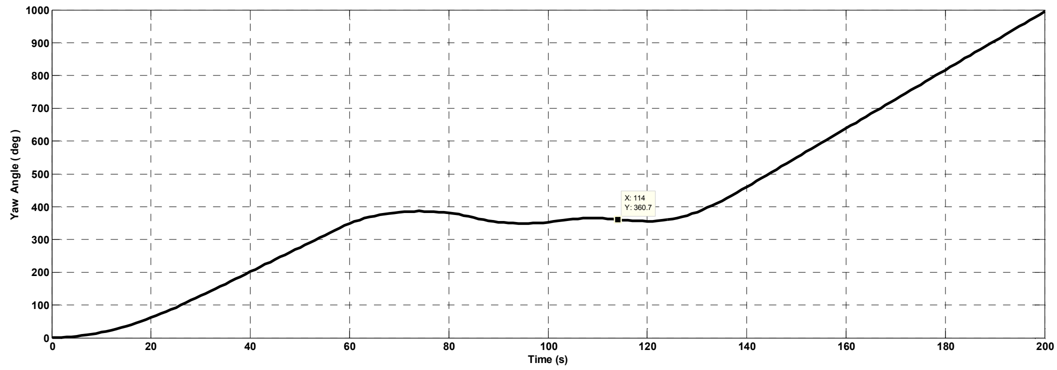

Fig. 8 Yaw angle of ASV for desired 360-degree heading angle

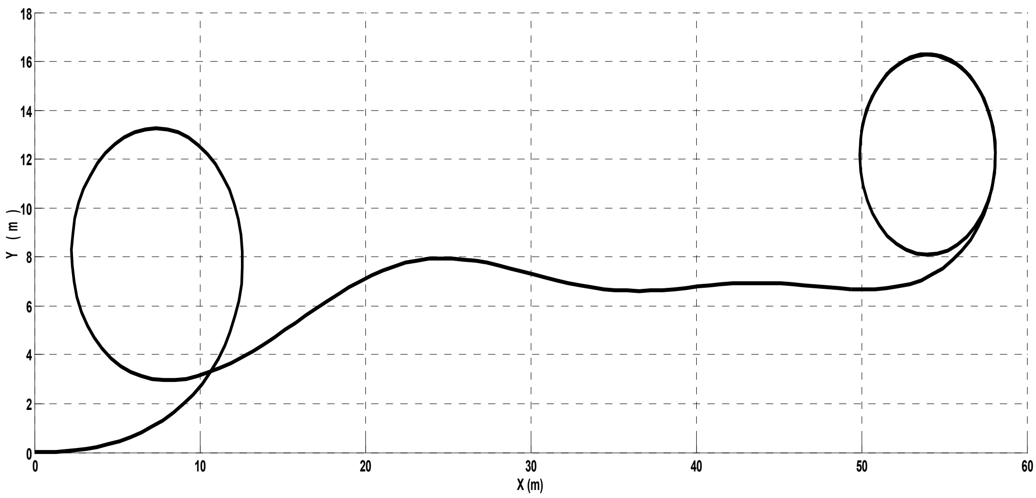

Fig. 9 ASV trajectory for desired 360-degree heading angle

These results support the theoretical predictions well and demonstrate that this research technique would work in real-time maritime conditions.

IV. Conclusions

The need for accurate positioning of ASV class autonomous vehicles has increased morbidly for critical situations in real-time search-and-rescue operations for fast SA.

A new research technique is presented in this paper for enhanced SA in possible ASV missions. The effectiveness of this technique has been verified in field of maritime simulation tests for chosen model of ASV using software package Simulink.

From the applications viewpoint, we believe that this control furnishes a powerful approach for enhancing SA in applications to ASV class autonomous vehicles in real-time search-and-rescue operations.

Although many of the details inevitably relate with this particular ASV model, there is sufficient generality for this research technique to be applied to similar ASV models.

Future work will involve further validation of the performance of the proposed research technique and exploring other relevant and interesting ASV missions.

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