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A REVIEW OF AUTOMATIC BERTHING SYSTEMS BASED ON ARTIFICIAL NEURAL NETWORKS FOR MARINE SHIP

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ABSTRACT

Automatic ship berthing has been known as one of most difficult problems in field of ship control. To complete the berthing automatically and safely, the control systems need to satisfy the complex feature of ship dynamic under low-speed condition of berthing. To meet this demand, artificial neural networks (ANNs) are usually applied as they have ability to imitate and perform all the actions of human brain in ship berthing process. However, when using this theory to design the automatic system for ship berthing, there are still some disadvantages which cause certain difficulties to design the control system for real-world applications of ship. In this research, a review is conducted to analyze advantages and disadvantages of automatic ship berthing systems using ANNs. In addition, some trends are also pointed out to the studies of automatic system of ship berthing in future.

Key words: Automatic ship berthing, artificial neural networks, Ship dynamic, Low speed, ANNs Controllers.

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1. INTRODUCTION

An automatic ship berthing has been known as one of most difficult problems in field of ship control. Because the ship motion in berthing is at low speed, the feature of ship dynamic is very complex, and the effectiveness to change the ship heading with the rudder is low in this process. Therefore, the maneuverability of the ship is decreased significantly. To make sure the ship berthing safely and properly, the states of the ship dynamic as, the ship position, ship heading, and velocities need to be controlled appropriately by the rudder and propeller. In practice, the berth-into-ship maneuvering process is usually performed by three steps: course changing, deceleration, and engine stopping.

The design of controller for the berthing system bases on the dynamic model of ship. However, it is very difficult to model the berthing system because the mathematical model of actuators such as the rudder and the propeller is very complex; therefore, it is not easy to synthesis the control system with conventional control theories. In such case, the intelligent control techniques such as neural network, fuzzy logic, and expert systems in artificial intelligence are commonly conducted, because they do not need the mathematical model of the control system. For such a purpose, the different controllers like fuzzy logic and expert knowledge have been investigated for ship berthing but the drawbacks and limitations are still found in these controllers. For fuzzy theory, it takes long time to find out proper membership functions and fuzzy rules, especially in unpredictable situation of external disturbance. Meanwhile, in case of expert system, every possible situation of ship motion in berthing process must be included as written the statement for main controller which makes control system become more complexity.

With the ability to learn and replicate any nonlinear process in real world, the neural network can be used as a main controller to copy all the actions of the ship master in the stages of ship berthing. Therefore, the neural networks have been widely investigated for automatic ship berthing. However, when applying this theory to design the automatic system for ship berthing, there are still some disadvantages which cause certain difficulties to design the control system for real-world applications of ship. In this research, a review is carried out to analyze advantages and disadvantages of automatic ship berthing systems using ANNs. Additionally, some trends are also pointed out to the studies of automatic system of ship berthing in future.

2. CONCEPT OF AUTOMATIC SHIP BERTHING SYSTEM AND APPROACH OF ANNS

In fact of maritime safety, the berth maneuvering of ship is complicated and done by ship captain. Because, the ship moves at low speed, the maneuvering ability of ship is strongly decreased. Therefore, the berthing process is usually divided into three steps: first, the ship’s rudder is turned to change ship heading into desired berth-approach direction; second, the ship’s speed is decreased; and finally, main engine is stopped at appropriate time so that the ship moves to the berth position with small acceleration. Due to the limitted ability of ship maneuvering in berthing, artificial neural networks are chosen to learn and replicate three steps of ship berthing process as human brain. Teaching data is created by manual berthing procedure.

On the other hand, with the simple model of ship dynamic, theories based on the stability theory of Lyapunop such as backstepping, sliding mode, etc were also suggested for designing this system. However, it is difficult to mimic the actions of human brain in performing berthing stages by these controls. Moreover, to use these controllers, we need to get desired trajectory of ship’s velocities (dynamic condition) and ship’s coordinate (geometrical condition) to follow up. But this work is difficult and not appropriate to ship berthing problem. Because the effectiveness of ship control with the rudder is insignificant at low speed, the auto-berthing controllers must have ability to alter the ship heading via the rudder and to bring the ship heading into desired direction of berth approach in first stage. Therefore, to date, artificial neural networks have been employed as most effective theory to synthesis a main controller for automatic ship berthing system. In this part, the principle of ship berthing system using ANN is shown and illustrated as in Figure 1.

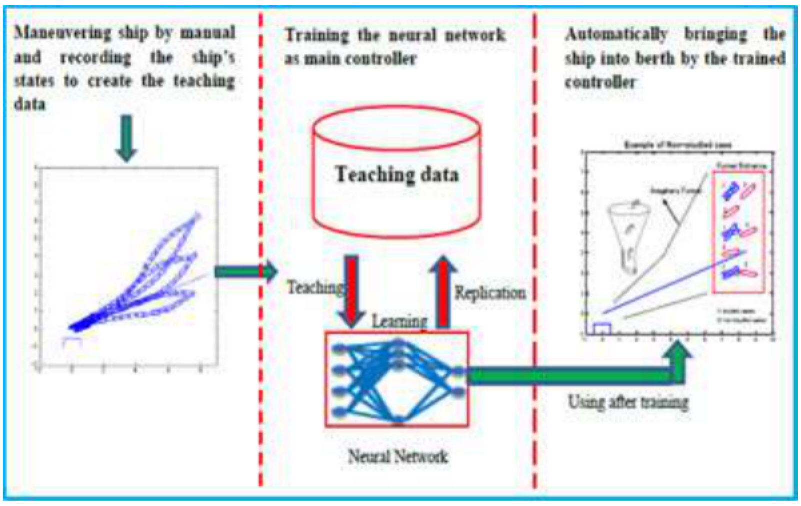

Figure 1. The principle of ship berthing system using neural networks.

First, the ship maneuvering is done by manual to create teaching data for training the neural network. The teaching data are time series of ship's sates which are recorded during the ship maneuvering process. The ship's states can be used, such as the ship coordinates, ship heading, distance and relative bearing from ship to berth, distances to imaginary line and berth, the ship velocities, the rudder angle, and propeller revolution.

Second, the time series called as teaching data are used to train the neural networks. The training process completes until the network's outputs follow up the desired outputs with minimum errors. After training the neural networks, the trained neural networks are used as main controller for ship berthing system.

Finally, in automation stage, when the ship has her states to be similar to those in teaching data, the trained neural network controller will bring the ship into the berth automatically.

3. THE ANALYSIS OF AUTOMATIC SHIP BERTHING SYSTEMS USING ANNS

With the advantages mentioned above, neural networks are used as the controller but in the dynamic system. The pioneering research, which uses neural networks as the main controller for ship berthing, was reported by Yamato et al. (1990) [5]. In this work, the inputs of neural networks included the ship coordinates, ship heading, ship velocities, and beam distances. The advantage of this approach is the proposed system which works as human brain when doing the steps in berthing process. However, this research did not consider to external disturbance. Although this approach obtained new results on designing of ship berthing system, the author Yamato (1992) [6] tried to replace the neural network controller by an expert system. However, the theory of expert system for berthing system is difficult to apply because a large amount of expert knowledge needs to be required for different circumstances.

Later, to overcome the drawback in research [5] on designing the open-loop system, Zhang et al. (1997)[14] proposed a multivariable controller for ship berthing with inputs that were feedback to the ship state, desired states, and the control signal at previous steps and with parameters that could be adapted by an online training process. In addition, external disturbances were also described with the mathematical models of wind and shallow water. However, to carry out this idea, a route planning block is required to create waypoints, and thus, this problem is track-keeping control not ship berthing control. In fact, the ship is very difficult to follow the planned route with the rudder under low speed.

As continuity of the works of Yamato, Im and Hasegawa (2001) [9] introduced a parallel controller with two sub-networks in a hidden layer. In this research, results obtained from proposed controller were compared with those given by central controller. These results showed that the performance of parallel controller is better than a central one. Moreover, disturbances, such as wind and current were also included in this research.

To improve the robustness of neural controller under wind, Im and Hasegawa (2002) [10] proposed two rules based motion identifier to overcome the disturbance. The inputs of motion identifier consisted of six nodes such as rudder angle, rate of rudder angle, integrator of rudder angle, propeller revolution, rate of propeller revolution, and integrator of propeller revolution. The outputs were estimated variables of lateral speed and angular velocity of ship at next time steps. The first rule algorithm was used to overcome lateral disturbance by comparing the difference of estimated lateral speed and real one while the task of the second algorithm is to solve yaw disturbance by comparing the difference of estimated angular velocity and real value.

Subsequently, Im (2007) [11] suggested a selective neural controller for ship berthing. The ship departs from any point around the berthing area. With each situation of initial starting position, there was an appropriate controller. For whole starting points, the selective mode of controller was applied to select the suitable controller for a certain situation. However, this study did not describe external disturbance for berthing process.

Meanwhile, Nguyen (2007) [7] followed the works of Zhang et al. (1997) [14] by using predetermined berthing route for berthing. In this study, two neural controllers using an adaptive interaction method to control the ship heading and ship speed respectively.

Recently, beside the rudder and the propeller of ship, the auxiliary devices, such as the side thruster and tugboat have been considered as new actuators for ship berthing. By incorporating these devices, Tran and Im (2012) [13] proposed the neural network with two additional nodes in the outputs of network where the bow thruster and stern tugboat were added simultaneously. The ship was automatically maneuvered to the first goal area by regulating the rudder angle and propeller, as in previous studies; then, the ship was controlled into the final goal zone by the actions of bow thruster and stern tugboat.

Later on, Ahmed and Hasegawa (2013) [1] considered a virtual window to create consistent teaching data for training the network, and the neural controller was then verified for ship berthing with no disturbance cases. In the case of gusty winds, the PD controller was applied to keep the ship on an imaginary line after the course changing process was carried out by the NN controller. The advantage of this research is create the consistent teaching data with virtual window, and gusty was described.

By continuing their work, Ahmed and Hasegawa (2014) [2] suggested a combined controller for final approaching to berth. In this investigation, the ship was automatically maneuvered to first zone as previously, but in the final zone, PD controller was applied to control side thrusters according to crabbing motion. Beside that, an experiment of automatic ship berthing was also performed by Ahmed and Hasegawa (2014) [3].

In different research of Ahmed and Hasegawa (2015) [4], after training the proposed controller, several known and unknown conditions were investigated to judge the effectiveness of the controller using Monte Carlo simulations. The trained controller was then implemented for the free running experiment system to judge the network's real time response for Esso Osaka 3-m model ship. The network's behaviour during such experiments is also considered for effect of initial conditions as well as wind disturbances.

To apply the neural controller for berthing in different ports without retraining process, Im and Nguyen (2018) [12] proposed a neural controller based a head-up coordinate system. The advantage of this research is a new controller which is trained once in original port and used for different ports without retraining process.

In order to improve the applicable ability of this controller for unmanned ship, the other neural controller in Nguyen, et al. (2018) [8] was introduced by using neural network and distance measurement system. By this controller, the inputs for controller included the distance variables measured by distance measurement system. The concept of ship berthing system and the structure of neural network are shown as Figure 2.

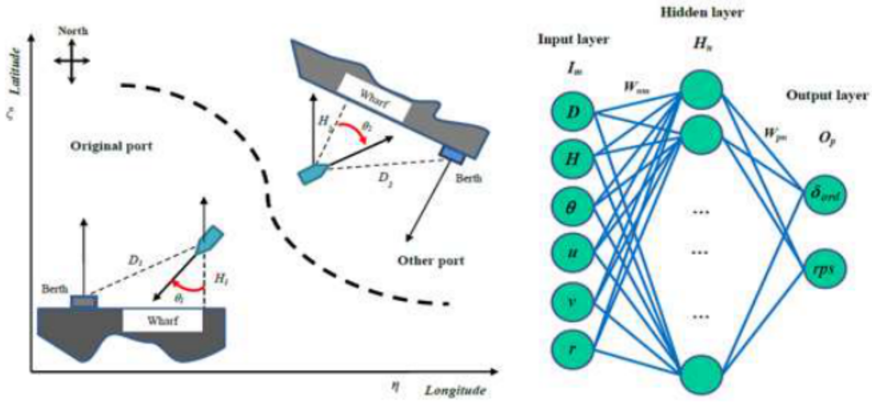

Figure 2. The concept of ship berthing system and the structure of neural network in research of Nguyen, et al. (2018) [8]

Recently, an adaptive neural control Zhang et al. (2019) [15] was reported to solve the problems of unknown model parameters and time-varying disturbance by using RBF neural network which was learned online to approximate unknown values of dynamic model. In addition, some techniques in control engineering were employed to decrease the computation load for the controller. However, this research is only suitable to control the berthing of small surface vehicles, it is absolutely not appropriate to control the berthing of marine ships. The dynamic model in this research does not represent the dynamic characteristic of ship as in fact.

To show the highlight features of neural network controllers in above mentioned investigations, several aspects are pointed out as follows:

3.1. Applicable ability

To date, there is only research of Ahmed and Hasegawa (2014) [3] which was investigated in an experiment. However, as analyzed by previous parts, this controller can just be used for a unique port. To enhance the applicable ability of controller for other ports, it is needed to apply the inputs of controller considered by Im and Nguyen (2018) [12]. But, the difficulty of this controller is how to obtain the relative bearing angle from the ship to berth. It is more feasible to produce the real berthing system by using distance measurement system.

3.2. Consideration of environmental disturbance

It is important to consider the environment disturbances such as wind, current, and wave for berthing process of ship. However, the studies such as Im (2007) [11], Tran and Im (2012) [13], Im and Nguyen (2018) [12], and Nguyen, et al. (2018) [8] did not included external disturbances. It is easy to understand that these investigations just focused on the way to the unresolved problems instead of considering the solved problem as wind and current effect.

3.3. The method of training the controller and stability of control system

The investigations of Zhang et al. (1997) [14], Nguyen (2007) [7], and Zhang et al. (2019) [15], the neural controllers were learned and trained online. However, these researches are same as the track-following control problems of ship rather than the automatic ship berthing problem. The others were trained by the direct learning method of teaching data which were supposed by manual berthing process.

Among the above-mentioned researches, there is the neural controller, Zhang et al. (2019) [15], described the stability of control system based Lyapunop theory. In the different research of Ahmed and Hasegawa (2015) [4], the stability was considered based on Monte Carlo simulations.

4. THE TRENDS OF AUTOMATIC SHIP BERTHING SYSTEMS USING ANNS

As shown out in previous parts of this article, the author proposes some trends to research and develop the automatic ship berthing system in future. This can be useful to researchers in finding new approaches and algorithms.

First, the neural networks need to be combined to other theory to guarantee the stability of closed-loop system of ship berthing with dynamic model of ship. In fact, the control theories have been used to obtain the stability, but they are only appropriate to robot.

Second, the conditions of port, such as: geometrical factor, traffic density, the depth of berthing area, and berth approach directions should be considered when designing the berthing controller.

Third, for real-world applications of ship berthing, new technologies to get the inputs such as distance, heading angle, relative bearing should be described more detail.

Finally, more experiments need to be carried out to adjust the difference between the numerical simulation and practice of ship berthing.

4. CONCLUSION

In this paper, a review of automatic ship berthing problem using artificial neural networks is considered. Conclusions of this research can be drawn as follows.

+ First, a detail review on contribution of these researches was presented to literature of automatic ship berthing using artificial neural networks.

+ Second, the advantages and disadvantages of each proposal were analyzed to point out the drawbacks of them.

+ Finally, several trends were also shown out for new researches in future.

With the contents of this article, the author hopes that they can help new researchers in understanding whole literature of automatic ship berthing control using artificial neural networks. In addition, it can help to find new ideas in this field.

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