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Research on three - dimensional Cooperative Formation of Sea and Air for Cruise and Rescue

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Abstract. Aiming at the problems of maritime traffic safety, a new model of jointing USV and UAV for Three-dimensional cruise and rescue is studied. Using the Information Fusion Technology, through the leader-follower formation mode, The collaborative fleet remote control. At the same time, it discusses how to carry out effective supervision on the responsible sea area under the complicated and changing sea conditions, especially the quick and efficient completion of the maritime search and rescue mission.

1 Introduction

The role of the oceans as an important player in the world's economic activities is becoming increasingly important, the maritime traffic environment is more complex, highlighting a lot of maritime traffic safety problems. Therefore, the search and rescue of maritime cruise and distress accidents has also become the focus of maritime research in order to achieve "all-weather operation, all-round coverage, emergency rapid response" for the sea traffic safety management objectives [1-3].

Unmanned Surface Vessel (USV) is a kind of maritime intelligent sports platform capable of self-safe navigation under complex sea conditions, and has the characteristics of low cost, high efficiency and no casualties. Combined with unmanned aerial vehicles (UAV) widely used, the advantages of strong mobility, USV, UAV can cooperate with each other to form a convenient control of the formation of the formation of complex sea conditions in the face of cruise and rescue missions, the formation of cruise and rescue Of the sea and air three-dimensional collaborative formation.

2 Formation diversity

2.1 Formation pattern

The determinants of formation include the nature and characteristics of the task, as well as the prevailing sea conditions and weather conditions.

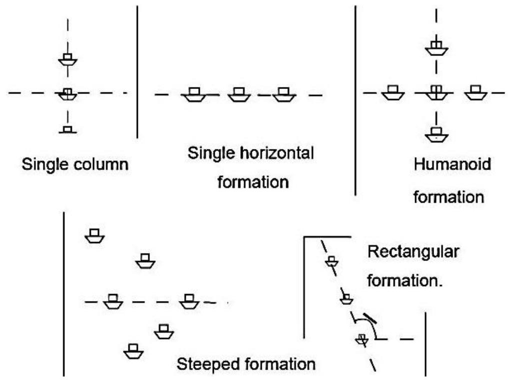

Figure 1. Formation

Table 1. Formation pattern classification

Formation pattern	Formation elements	Formation characteristics
Single column	β=180°,α=0°	Formation is simple, easy to maintain, more flexible
Single horizontal formation	β=90°,α=90°	Steering difficulties, manipulation inconvenience
Stepped formation	β≥90°	Better depth, Larger width
Rectangular formations	β=180°or 90° α=0°or 90°	Better depth, Large width
Humanoid formation	γ1=γ2	Good depth, Larger width

2.2 UAV in formation

UAV's position in the formation is flexible, applicable to any USV formation mode. UAV has the characteristics of fast flight speed, strong maneuverability, wide monitoring range and long battery life. It can reduce the emergency response time of the formation, expand the effective area of the cruise and rescue, makes the function more Three-dimensional, makes up for the shortcomings of the USV formation, provides new regulatory perspectives.

3 Cooperative control of formation

3.1 Information fusion technology

The basis of control are communications, collaborative communication to form a specific network within formations, the members can achieve resource sharing. The information fusion technology will deal with the multi-source information of each sensor, combine the information according to certain optimization criteria, thus eliminate the possible redundant and contradictory data, and complement the information, reduce the uncertainty, and finally get the same complete conclusion, for the formation of decision-making to provide a strong guarantee .Includes Data conversion, Data related, Situation database, Fusion calculation [4].

3.2 Centralized control mode

Centralized control mode [5] is to use a higher configuration, better performance of the USV as a carrier, the carrier to complete the collaborative formation of the data analysis and processing, and sent to other members to carry out the task deployment. Here the centralized control system uses the leader - followed model [6]. The L-F model is shown in Fig.2:

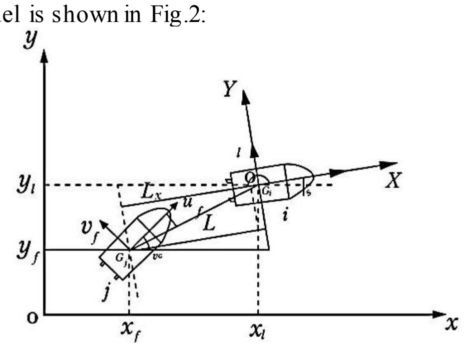

Figure 2. Leader - follower model

3.3 Remote control system

Remote control system [7-9] is divided into land-based control system and ship control system. The former mainly completes the real-time display of the status and velocity information of the USV and can send control commands to the ship-borne system. The latter can access the ship's position and velocity information, and can analyze the commands conveyed by the land-based control system and control the USV, including start up, turn, speed change, berthing, etc. In order to realize the positioning function of USV, adopts GPS positioning mode. GPS can not only determine the exact location but also calculate the speed of USVs. The land-based system uses the electronic chart system and establishes the GUI control system. The electronic chart can accurately display the real-time position of the USV. The GUI panel can send control commands to the ship borne system by setting different command buttons.

Land-based system access network , the ship-borne system access GPRS network, using the traditional Internet and GPRS wireless communication combination of the way through the TCP / IP protocol to achieve the two systems between the data communication function. USV use ultra- short wave communication for information exchange and task communication, also known as the use of 1 to 10 meters wavelength of electromagnetic waves for line-of-sight transmission. Ultra-shortwave wave shortwave wave propagation mode is highly stable, subject to seasonal and day and night changes in the small impact.

4 The maritime cruise and rescue of formation

Due to the limitations of the USV itself and its equipment and sensors, it is often difficult to complete a given task in a complex environment. But the formation of collaborative search tour can effectively overcome the restrictions, so the goal of a full range of search and observation. In short, USV, UAV collaborative formation makes the search system has better reconnaissance ability and higher fault tolerance, while reducing the waste of resources while improving the efficiency of search mission.

4.1 Formation search mode

The formation of the cooperative search mode [10] can be roughly divided into coverage mode and non-coverage mode. Coverage mode includes Extend Square mode, Parallel Line mode and Fan-shaped mode. Non-coverage mode includes Track mode.

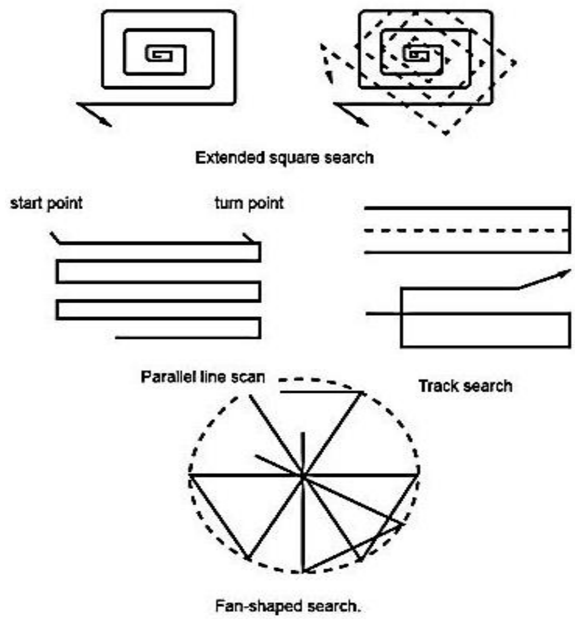

Figure 3. Formation search mode

Parallel line scan search and rescue [11] is the most common, the calculation width is "w", USV speed is "v", search area is "S". Assuming that the search area is rectangular, the target position is unknown, its probability is evenly distributed in the search area, and there is no coverage area, the search route function can be expressed as:

$$\mathrm{b}(\mathrm{t}) = \frac{wvt}{S}, (t \geq 0)$$

USVs do not find the target within time "t", and the probability of finding the target within the increment time "Δ t" is $[1 - \mathrm{b}(\mathrm{t})]wv\Delta t / S$,Whereby the probability that the USV finds the target at time "t + Δ t":

$$\mathrm{b}(t + \Delta t) = b(t) + [1 - b(t)]wv\Delta t / S$$

By the above formula :

$$b'(t) = \lim_{\Delta t \to 0} \frac{b(t + \Delta t) - b(t)}{\Delta t} = [1 - b(t)]wv / S$$

B (0) =0, $b(t) = 1 - e^{-twv/S}, (t \geq 0)$

From the nature of the b (t) function, the longer the formation search time, the slower the change in the probability of the target being found. When the search length "v" is close to "S / w", the probability of finding the target is close to "1". So for this search and rescue mode, should be selected perpendicular to the minimum span direction as USV search and rescue navigation direction, that is, the optimal path.

4.2 Search and rescue equipment combination applications

In the case of good visibility, the photoelectric tracking and monitoring equipment imaging system[12] [13] can clearly monitor the situation of the long distance sea surface with the maritime search lamp, and can effectively carry out the pollutant supervision and the night emergency rescue, Improve the success rate of finding targets (especially drowning man).

4.3 Cruise and rescue in the UAV

In the same distance, UAV's patrol radiation area is 12 times the USV [14], patrol effect is much better than the USV. Therefore, in the cruise and rescue process using UAV can effectively improve the cruise efficiency, rapid detection of regulatory waters within the latent risk factors. Through the machine, the ship can greatly enhance the flexibility of the formation of the task. UAV as the air flight platform [15], its control mode and formation function in the final analysis through its airborne system to complete the relevant equipment, include airborne digital camera, multi - spectral imager

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Table 2. UAV maritime applications

Maritime business	UAV function	Functional description
Daily cruise	Regular cruise	To inspect the waters and vessels in the area, and to supervise the traffic control areas, to curb the sewage discharge
	Used as a VHF aerial relay	As the USV ship borne VHF and land-based communication distance is short, need UAV equipped with VHF relay equipment, with the USV cruise
	With USV supervision	USV is slow at cruise, cannot be observed long-range unknown vessels, the use of ship carrying UAV can expand the scope of reconnaissance
Anti – pollution supervision	Collect evidence of pollution	Use UAV for oil spills and chemical accident emergency evidence, reach the scene of the accident will be real-time transmission to the control center
	Collect evidence of dangerous accident	UAV-USV joint investigation is required for marine hazardous sites, and UAV can expand the survey area
Emergency search and rescue	Search targeting	Borrow the UAV self-positioning system and airborne AIS to determine the location of the accident, and the information back to the control center
	Video transmission	Through the video equipment to shoot the scene of the accident, the scene of the real-time situation back to the land-based control center, easy to co-ordinate the command
	Material delivery	Through the UAV can complete the food, GPS buoys and small life-saving equipment and other materials put
	Act as a float	UAV installed on the automatic inflatable equipment, set the location identification signal, if necessary, can fall into the sea as a life-saving buoy

5 Experimental verification

5.1 Design of the ship

In order to verify the feasibility and robustness of the cooperative formation control system, the model ship experiment platform is used to verify. The experimental platform includes the leader system equipped with the leader ship, followed ship and UAV, for remote control of the computer. Results as shown:

Figure 4. Model diagram

Microcontroller is control center. It can be written into the slave computer program, the program's role is to receive the instructions of the host computer, and code analysis, to understand what kind of action issued by the user.

5.2 Algorithm design

5.2.1 Sports model

First assume that the formation of the ith USV is the leader ship, the jth USV is followed ship, the formation of two ships composed of the leader- followed[16] model, as Fig 2 shown. Modeling the leader ship, definition: "L" is the relative distance between the followed ship and the leader ship; "Ψ" is the relative angle between the followed ship and the leader ship; "G" is the center point of the USV; "Φ f "is the heading angle of the leader ship and the followed ship; Pl (x l, y l), Pf (x f, y f) are the coordinates of the position of the leader ship and the followed ship. The mathematical expression is:

$$\left\| L_y - L_{yr} \right\| \le \delta_1$$

$$\left\| \Psi - \Psi_r \right\| \le \delta_2 \qquad (1)$$

Where "δ1" and "δ2" are bounded positive numbers.

Define the tracking error of the heading angle:

$$Z\varphi = \varphi f - \varphi l \qquad (2)$$

Define the errors in the structure：

$$\begin{cases} \xi_x = L_{XR} - L_X \\ \xi_y = L_{YR} - L_Y \\ \xi_\phi = \phi_f - \phi_l \end{cases} \qquad (3)$$

The kinematic model of USVs is:

$$\begin{cases} L_X = -u_l + u_f \cos\xi_\phi - v_f \sin\xi_\phi + L_{rl} \\ L_Y = -v_l + u_f \cos\xi_\phi + v_f \sin\xi_\phi + L_{rl} \\ \xi_\phi = r_f - r_l \end{cases} \qquad (4)$$

Can be derived from the formation of the error system model:

$$\begin{cases} \xi_x = -u\cos\xi_\phi + v_r \sin\xi_\phi + \xi_y r_i + u_i - L_R \psi_R \sin\psi_R \\ \qquad -L_R r_1 \sin\psi_R \\ \xi_x = -u\sin\xi_\phi - v_r \cos\xi_\phi - \xi_y r_i + v_i + L_R \psi_R \cos\psi_R \\ \qquad +L_R r_1 \cos\psi_R \\ \xi_\phi = r_f - r_i \\ m_1 u - m_2 vr + d_1 u = \tau_1 \\ m_2 v - m_1 vr + d_2 v = 0 \\ m_3 u + (m_2 - m_1) ur + d_3 r = \tau \end{cases} \qquad (5)$$

In the actual formation voyage, the distance L between USVs (measured by laser ranging) and the relative angle "Ψ" (which can be calculated from the relative position) are calculated by comparing the actual distance "L" between the two ships angle "Ψ" according to the external environment within the allowable range of error within the allowable range can achieve the purpose of formation control, that is, to complete the formation, maintain, re-generation, formation to maintain the formation of obstacle avoidance and other tasks.

5.2.2 Bow control

During the process of ship moving horizontally, the hydrodynamic damping force is the main force, and the traverse velocity "V1"is bounded. Assuming that the interference is bounded:

$$|w_1(t)| \le w_0$$

$$|w_2(t)| \le w_0$$

$$|w_3(t)| \le w_0$$

Design the controller to make the formation of the members of the track tracking error ψ_1、μ_1、Z_1 final bounded.

The Define state variables "φ_{ie}", Using the filter to get its estimate:

$$\varphi_{ie}=\psi_{1e}+\gamma\psi_{1e} \qquad (6)$$

(6) On both sides of the derivative get:

$$m_i\varphi_{ie} = f_{i1}(x) - \tau_{ir} - w_{i\varphi} \qquad (7)$$

f (x) for the unknown dynamic function, with the network to get its theoretical estimates:

$$f\,(x) = W_i^T\sigma\,(V_i^T\xi_i) + \varepsilon_i \qquad (8)$$

To stabilize the system (7), we need to eliminate f (x), so we use the adaptive term to approximate it:

$$f\,(x) = W_i^T\sigma\,(V_i^T\xi_i) \qquad (9)$$

The controller is:

$$\tau_{ir} = (k_{i1} + h_{i1})\varphi_{ie} + W_i^T\sigma(V_i^T\xi_i) \qquad (10)$$

$$h_{ir} = k_{i4}(\left\|\xi_i W_i^T\sigma'\right\|_F^2 + \left\|\sigma' V_i^T\xi_i\right\|^2 + 1) \qquad (11)$$

Substituting control (10) into (7):

$$m_{33}\varphi_{ie} = -f(x) - (k_{i1} + h_{i1})\varphi_{ie} - w_{i\varphi} \qquad (12)$$

Into the f (x) items, finishing to get:

$$m_{33i}\varphi_{ie} = -W_{i1}^T(\sigma - \sigma' V_{i1}^T\xi_{i1}) - W_{i1}^T\sigma'(V_{i1}^T\xi_{i1}) + \varepsilon_{i1} - (k_{i1} + h_{i1})\varphi_{ie} - d_{ie} - w_{i\varphi} \qquad (13)$$

Longitudinal control and Bow control are similar.

5.3 Experimental results

According to the design idea of the formation, the L-F motion model of the bow control and longitudinal control of its experimental verification. In the remote control under the USV to follow the ideal path forward, control effect as shown:

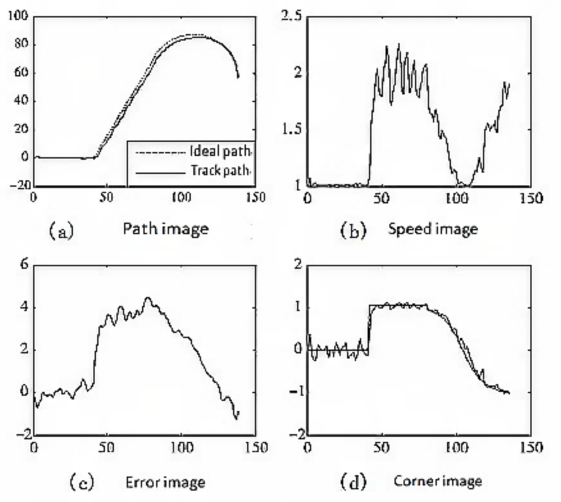

Figure 5. Control effect picture

Among them, a for the USV to track the ideal path forward curve, in considering the storm interference under the premise of USVs with good robustness, can follow the ideal path forward; Fig. b for the tracking speed chart, In the process of unmanned sailing, the stability of the input speed, has been the right to follow the ideal path forward; Fig. c is the tracking error graph, the tracking error can be stabilized within 4 unit distance, can be more accurately follow the ideal path forward; Fig. d is no progress; Fig. d is sailing steering angle, the USV straight sailing first and then turns at 60 ° steering angle, and finally moves circumferentially along the 60 ° direction.

In the L-F formation, the initial position of the three USVs is set to (0, 0), (0, 10), (0, -10), the leader ships are experimentally designed to keep the speed of the ship at any time, follower ship at any time to adjust the speed of navigation, angular speed to follow the leader ship. While setting the safety distance L = 10, in the navigation to ensure the safety of USV.

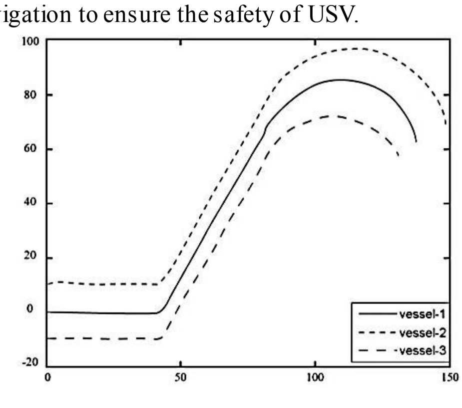

Figure 6. Rule formation effect chart

Fig.9 shows the leader-followed formation in accordance with the ideal path of the experimental results, followership to keep in a safe distance within the sailing process can basically follow the route of the leadership, the error remains within the ideal range.

Set the initial coordinates of the leader ship (0,0), the safety distance L = 5, the coordinate position of the two follower ships (-10,10) 、(-10, -10),when the initial formation is irregular. The leader ship in the storm interference to do a straight line before the movement, followed by circular motion, asked follower ships to follow the leader ship, so that the formation to maintain stability.

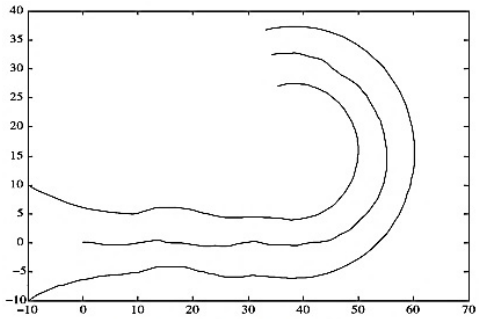

Figure 7. Irregular formation effect picture

Through the experimental results can be seen, the initial formation for the irregular state, after L-F control mode, the formation tends to be stable, the control effect is ideal.

6 Conclusion

The USV and UAV are coupled with each other to form a cooperative fleet for maritime cruise and rescue. Compared with the traditional formation mode, there is an unparalleled advantage in terms of supervision scope, search and rescue efficiency and real-time information.

The L-F model is used to control the USV and UAV cooperative formation, and the information fusion technology is applied to the cooperative information communication. The feasibility of the principle is verified by establishing the mathematical function.

Explores the various search and rescue modes in the process of maritime search and rescue, and emphasizes the role of UAV in maritime cruise.

The feasibility of the cooperative formation control is verified by the simulation test of the control platform and the shell. However, due to conditions, the UAV experimental link is relatively weak, should be further strengthened.

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