

The Machine Learning Method of PIDVCA

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ABSTRACT: Building a dynamic collision knowledge base of self-learning is one of the core contents of implementing "personified intelligence" in Personifying Intelligent Decision-making for Vessel Collision Avoidance (short for PIDVCA). In the paper, the machine learning method of PIDVCA combined with offline artificial learning and online machine learning is proposed. The static collision avoidance knowledge is acquired through offline artificial learning, and the isomeric knowledge representation integration method with process knowledge as the carrier is established, and the Dynamic collision avoidance knowledge is acquired through online machine learning guided by inference engine. A large number of simulation results show that the dynamic collision avoidance knowledge base constructed by machine learning can achieve the effect of anthropomorphic intelligent collision avoidance. It is verified by examples that the machine learning method of PIDVCA can realize target perception, target cognition and finally obtain an effective collision avoidance decision-making.

1 INTRODUCTION

In order to solve the problem of collision and aground accidents caused by human factors, it is a feasible scheme to develop the assistant decision-making system of ship collision avoidance to reduce the effects of man-made factors as much as possible. In view of the collision avoidance problem, which can not be reappeared, the intelligent collision avoidance decision-making system should have advanced humanoid intelligence, that is, surpassing the human ability to solve complex collision avoidance problems. The assistant decision-making system of collision avoidance should be able to provide both safe and economical (scientific and reasonable) decision scheme, and it must follow the rules, seafarers' common practice and good seaman ship, and have the ability of quantitative analysis and calculation at the same time. Therefore, the machine must have the

ability of on-line automatic learning based on the original knowledge, so that the system has the ability of automatic perception, cognition, analysis and reasoning, and can make wise choices in complex and even dangerous environments. Make a successful decision-making and implementation plan to ensure the safety of ships to avoid risks. Nowadays, the deep learning method based on big data needs a large number of learning samples. However, due to the non-reappearance and high uncertainty of the marine encounter situation and the restriction of the "International Regulations for Preventing Collisions at Sea" (Hereinafter referred to as COLREGS), it is difficult to effectively solve the problem of collision avoidance decision-making of ships at sea. Other machine learning methods, such as intensive learning[1~2] and so on, at present, still in the exploration stage, no examples of application have been found.

After more than 20 years of research, the R & D team of Jimei University combined artificial intelligence ideal with knowledge in the field of navigation and solved the expression of existing knowledge of collision avoidance based on artificial off-line learning. Based on the perceptual system, the dynamic and static data of the own ship and the target ship are obtained, and the on-line machine automatic learning is carried out with a series of modes and algorithms of the Personifying Intelligent Decision-making for Vessel Collision Avoidance (short for PIDVCA) in the static knowledge library. Realize machine automatic perception, cognition, analysis and decision-making. A lot of Simulation results show that PIDVCA machine learning method achieves the desired results.

2 BRIEF INTRODUCTION OF PIDVCA PRINCIPLE

2.1 The goal and connotation of PIDVCA

In the final analysis, the goal of studying "PIDVCA" is to solve the automation problem of "intelligent collision avoidance decision making for ships". Specifically, it is to apply the "COLREGS" and knowledge in the field of ship collision avoidance. With the help of the environment acquired by the sensors and the qualitative analysis of the experts' experience knowledge, the deck officer practical experience knowledge and artificial intelligence technology are used to carry out the automatic reasoning, quantitative calculation and evaluation, with the help of the environment obtained by the field sensors. Realize the automatic generation and optimization of PIDVCA scheme.

The connotation of "PIDVCA" is to realize the automatic intersecting relationship between the ship and the ship according to the object mark (target ship and obstructed object). Imitating the analysis and judgment of the surrounding environment and dangerous situation and the thinking of the collision avoidance decision made by the experienced deck officer (collision prevention expert), the collision avoidance decision, which is both safe and economical, can be brought forward by the collision avoidance expert automatically. If necessary, a simple coordinated collision avoidance process between two ships can be simulated; When the decision is accepted and implemented by the deck officer, the ship can be automatically informed of the ship's intention.

2.2 PIDVCA realization principle

As shown in figure 1, the functions of each component of PIDVCA program model are as follows:

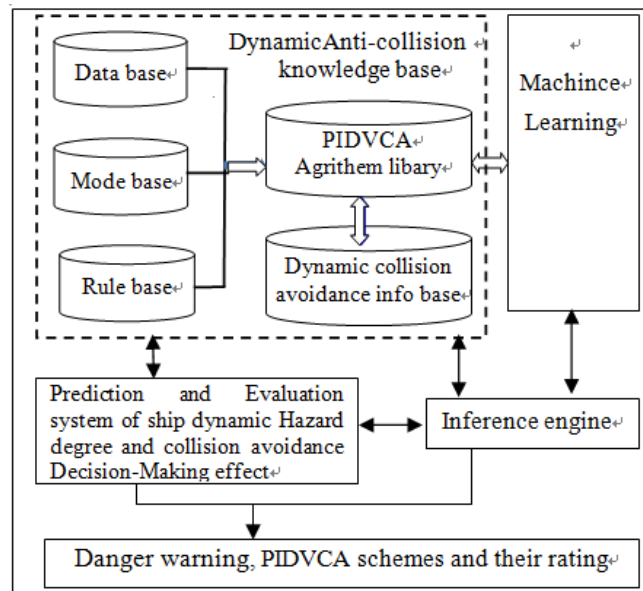


Figure 1. PIDVCA program model

- 1 The prediction of ship dynamic risk and the effect of collision avoidance decision is an evaluation system for the decision behavior of collision avoidance. It not only relies on the basic model of dynamic collision avoidance knowledge base and related algorithms, but also uses online learning to generate dynamic risk threshold in real time as the criterion of machine perception, cognition and decision-making process.
- 2 Dynamic collision avoidance knowledge base consists of database, model base, rule base, PIDVCA algorithm base and dynamic collision avoidance information base. The database is used to represent the factual knowledge required in the collision avoidance decision-making process, including from marine radar, AIS, gyro compass, log, GPS, ECDIS, Navigation data, meteorological and hydro-logical information, provided by navigation equipment such as visibility meters (referred to as sensors), basic parameters of the ship and static data of electronic charts.
- 3 The model base provides all kinds of collision avoidance models needed for the quantification of the concept and decision-making; The rule base provides the knowledge of the situation division, the rules of action and the assignment of the duty to avoid collision in the form of production rules, as well as the casual knowledge of the good seaman ship and common practices; The PIDVCA algorithm library integrates the knowledge of database, rule base and model base in the form of meta-knowledge, and provides a series of PIDVCA algorithms for machine perception, cognition and decision making. The dynamic collision avoidance information base is used to store and interact the intermediate dynamic collision avoidance information generated by the automatic learning process of machine in the form of array or variable..
- 4 Inference engine and algorithm Library as an Organic whole, and the algorithm flow forms the automatic reasoning mechanism of reasoning

machine heuristic rule, analogy (matching), case and non-monotone reasoning.

- 5 Machine learning includes knowledge discovery and approximate reinforcement learning strategy under the guidance of automatic reasoning mechanism.

To sum up, the PIDVCA principle takes the model and algorithm as the main representation form of machine learning and the basis of prediction and evaluation system of ship dynamic risk and collision avoidance decision effect, and adopts process knowledge representation as the carrier of heterogeneous knowledge representation integration method. The automatic inference mechanism is designed based on the evaluation system of ship dynamic risk degree and collision avoidance decision effect prediction and evaluation, the reasoning engine guides the on-line learning of the machine based on the original knowledge of the dynamic collision avoidance knowledge base (the database, rule base and model base) and the object information (database) obtained in the field, using the calculation and reasoning of integrated machine learning strategy, form the dynamic collision avoidance knowledge base. Through the PIDVCA program model, the heterogeneous dynamic collision avoidance knowledge and inference machine are expressed in database, rule base, PIDVCA algorithm library and dynamic collision avoidance information base. The system of machine learning and prediction and evaluation of ship dynamic risk degree and collision avoidance decision effect is integrated into an organic whole, which realizes the automatic generation, verification and optimization of target perception, cognition and PIDVCA implementation scheme.

3 KEY TECHNOLOGIES OF PIDVCA MACHINE LEARNING

The original knowledge is composed of model base, rule base, algorithm base and factual knowledge in database. The construction of PIDVCA algorithm library is the core technology of machine learning. Model base and rule base are the basis of constructing algorithm library. This chapter mainly discusses the core technology and foundation of PIDVCA machine learning.

3.1 The Goal and Mechanism of Machine Learning

The title of this paper makes it clear that the goal of machine learning is to realize the intelligent collision avoidance decision of ships, that is, to get new knowledge and new skills to solve arbitrary collision avoidance problems through on-line self-learning of machines, and the concrete learning process is the automatic perception, cognitive and anthropomorphic collision avoidance decisions of machines.

Online machine learning includes heuristic rule reasoning, analogical (matching) reasoning, case-based reasoning and non-monotone reasoning under the guidance of knowledge discovery and approximate reinforcement learning strategies.

The approximate reinforcement learning strategy is a reinforcement learning method based on dynamic decision making and objective function optimization for special problem in order to further optimize collision avoidance decisions on the basis of forming initial decision making and determining search space. To process dynamic collision avoidance knowledge in real time and obtain the optimal collision avoidance decision implementation scheme, that is, to solve the problem of environmental awareness of this own ship (can be called as an agent), how to learn, in order to determine the optimal collision avoidance decision scheme which can safely and economically avoid dangerous target ship, PIDVCA takes the minimum track deviation after the implementation of collision avoidance decision as an economic index. The objective function of dynamic decision optimization is further established based on the quantitative model of the rudder timing(T_s), the range of avoidance(AC) and the opportunity $T_r(AC)$.

$$J^*(s) = \min_{AC_k \in A} [T_{rk}(AC) \times V_0 \times \sin(AC_k)] \quad (1)$$

$$\forall s \in S, k = 0, 1, 2, \dots, N$$

where $N = \frac{(TL - T_s)}{\Delta T}$, ΔT is the search step, A is the behavior set of the ship in the search space $T \in \{T_s, TL\}$, S is the state set and is the speed of the ship. Corresponding to each search step can be obtained, according to which the corresponding ones can be solved. According to the prediction end time of all dangerous target ships, the maximum value of (1) is their maximum value, which is the corresponding optimal decision in the minimal case.

Machine online learning how to use field information and original knowledge of collision prevention experts through automatic reasoning, learning, optimization to achieve the desired goals? The key is to get the original knowledge, which they are a series models and algorithms, the analogical source of analogical matching reasoning and the case source of case-based reasoning through off-line learning. It can be seen that the original knowledge is the important technical foundation of machine on-line learning to produce new knowledge. Therefore, the machine learning of PIDVCA adopts the mechanism of combination of off-line artificial learning and on-line machine self-learning, using off-line artificial learning to realize the formalization of ship collision avoidance domain knowledge, and to solve the problem of knowledge representation of collision avoidance experts. The original knowledge of collision avoidance is formed in the model base and algorithm base, which provides the technical foundation for online machine learning.

Off-line artificial learning is mainly used to generate analogy source and case source of analogical matching reasoning and case-based reasoning learning, and a series models and algorithms to obtain heuristic information and new knowledge online, to form static collision avoidance knowledge base. A heterogeneous knowledge representation with process knowledge as the carrier is established so that the machine can acquire new knowledge and new skills of problem solving in real time based on pre-built static collision avoidance knowledge.

$$T_c[i] = \frac{\sqrt{(xp[i] - x_c)^2 + (yp[i] - y_c)^2}}{Vrn[i]} \times 60 \quad (6)$$

In formula (5), Cr and Crn are not included with the 0, 90°, 180° and 270°.

3.2.2 Experiential knowledge representation of causality in production rules

Rule is one of the important contents of the knowledge of collision avoidance experience. The method of production rule representation can conveniently express the knowledge of collision avoidance with causality. The following is an example of overtaking situation in the form of production rule set.

If: wx[i]=1∧B>112.5°∧B<247.5°
 Then: Tsea[i]=4 (4 Indicates that the target vessel I is a overtaking ship)
 If: wx[i]=1∧V0>Vt[i]∧Bo>112.5°∧Bo<247.5° Then: Tsea[i]=1 (“1” Indicates that the target vessel i is a being overtaking ship)
 If: Tsea[i]=1∨Tsea[i]=4 Then: Overtaking situation
 If: Visibility_Level=1∧Tsea[i]=1 Then: Tzt[i]=1
 If: Visibility_Level=1∧Tsea[i]=4 Then: Tzt[i]=2

B is the azimuth of the target ship relative to the ship, Bo is the orientation of the ship relative to the target ship, Tzt is the target property identifier, its value is 1 indicating that the target ship is a direct vessel, and the ship is making way for the ship, if its value is 2, the value is the opposite. Tsea is the target attribute identifier (target ship encounter attribute), whose value is 1, 2, 3, 4, 5 and 6 respectively, the target ship is overtaken, coming from the front of the right forward, from the right cross, overtaking the ship, from the port side, and from the opposite state. The “wx” stand for identifier of danger for target ship, its value equal to 1 or 0 respectively represents the target ship being danger or not. Visibility_Level is stand for identifier of visibility, its value equal to 1 or 0 respectively represents the insight of one another or restricted visibility condition.

3.2.3 Algorithm representation of Meta-Knowledge — The PIDVCA algorithm Library

The PIDVCA algorithm representation of meta-knowledge is the core technology of machine learning. It mainly solves the leading information source of heuristic rule reasoning, the analogy source of analogical matching reasoning and the case source of case-based reasoning in machine learning process.

The PIDVCA algorithm library is described by flow chart, decision tree, decision table and mathematical equation. It is used to realize the combination of the qualitative analysis based on “COLREGS” the ordinary practice and fine seamanship of seamen, and quantitative calculation processing, in order to obtain real-time dynamic collision avoidance knowledge.

It includes target rendezvous feature(TRF) recognition algorithm, potential hazard analysis algorithm, encounter situation recognition algorithm, risk degree analysis evaluation, decision scheme

quantification, scheme verification and optimization, prediction and evaluation of collision avoidance effect and a series of PIDVCA algorithms. As shown in Table 1, the TRF recognition algorithm is used as an example source to identify the TRF.

Table 1. The value of TRF recognition

TRF	C _t -C _o	C _r	velocity relation
1	0°~90°	90°~180°	V _o ≤ V _t
2	270°~360°	180°~270°	V _o ≤ V _t
3	0°~90°	90°~180°	V _o ≥ V _t
4	270°~360°	180°~270°	V _o ≥ V _t
5	180°	180°	V _o ≥ V _t
50	0°	180°	V _o > V _t
6	0°	0°	V _o ≤ V _t
60	C _o	180°	V _o = 0
7	0°~90°	0°~90°	V _o < V _t
8	270°~360°	270°~360°	V _o < V _t
10	90°~180°	90°~180°	V _o ≤ V _t
20	180°~270°	180°~270°	V _o ≤ V _t
30	90°~180°	90°~180°	V _o > V _t
40	180°~270°	180°~270°	V _o > V _t
70	90°	90°	V _o < V _t
80	270°	270°	V _o < V _t

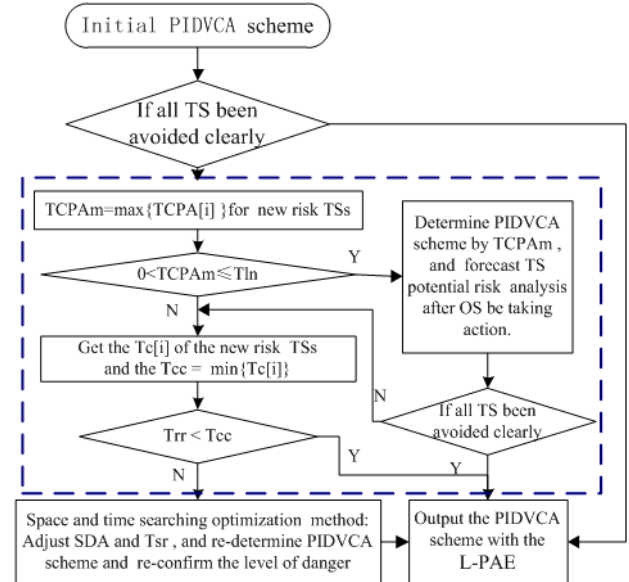


Figure 3. Flow chart of case source generic algorithm for heuristic case-based reasoning

Based on the anti-collision methods of the experienced captain and the chief mate taken in the typical examples, in the virtual box of figure 3 is the flow chart of case source generic algorithm for heuristic case-based reasoning (CBR) algorithm which simulates the deck officer's correct assessment of collision risk, avoidance opportunity, amplitude of avoidance recovery opportunity and L-PAE. The Trr, Tcc and L-PAE in fig. 3 are separately stand for the value of max{Tr[i]}, min{Tc[i]} and level of predicted anti-collision effect.

3.3 On-line machine self-learning steps

According to the information of the ship and the target ship obtained from the navigation and environment sensor, the inference engine calls the corresponding algorithm of the algorithm library in

turn, and realizes the automatic perception, cognition and anthropomorphic collision avoidance decision of the machine, through the pre-designed machine automatic reasoning mechanism, and according to the information of the ship and the target ship obtained from the navigation and environment sensors. The specific steps are as follows:

Step 1: the system adopts online heuristic rule reasoning, then calls the algorithm of solving collision avoidance parameters of the target ship (TS stands for target ship) in the PIDVCA algorithm library and the target rendezvous feature recognition algorithm in turn, and obtains the motion elements, collision parameters and the threshold value of collision risk evaluation. The rules of analogical reasoning are used to match and identify the features of target rendezvous and the perception of target dynamic information is realized.

Step 2: according to the result of targets' perception on step 1, the system calls in turn the target ship potential hazard analysis algorithm in the PIDVCA algorithm library, the encounter attribute analysis and its situation classification algorithm, and the recognition algorithm of the collision avoidance attribute of the ship. The heuristic rule matching of analogy reasoning is used to automatically judge the potential danger of the TS, if there is no potentially dangerous TS, turn step 1, otherwise identify the encounter attribute, and then determine the own ship (OS stands for own ship) to give-way vessel or stand-on vessel and its corresponding avoidance measures, and then according to the action that the OS should take, By calling the dynamic risk analysis algorithm, the initial risk evaluation and the most dangerous ship are given.

Step 3: according to the result of step 2 initial risk evaluation, the system calls the algorithm of PIDVCA scheme generation, and determines the initial PIDVCA scheme which is composed of avoidance opportunity, amplitude and forecast time.

Step 4: the system calls the potential hazard analysis algorithm for predicting TS to verify whether the initial PIDVCA scheme can clear other obstructions (dynamic TSs and static obstructions), if feasible, turn to step 6, otherwise turn to step 5;

Step 5: the system calls the PIDVCA scheme check and optimization algorithm, implements the check and of the collision avoidance decision scheme, generates the PIDVCA scheme. For the unreasonable scheme of special scene, if necessary, the approximate reinforcement learning algorithm is used to implement local optimization and turns to the sixth step.

Step 6: the evaluation and analysis of collision avoidance decision based on evaluation system of ship dynamic hazard degree and prediction of collision avoidance effect. If the effect of avoidance belongs to the state of safety or secondary, then output danger early warning and collision avoidance scheme and the scheme of avoiding collision is executed; if it is unsafe, the program of coordination of immediate danger is executed.

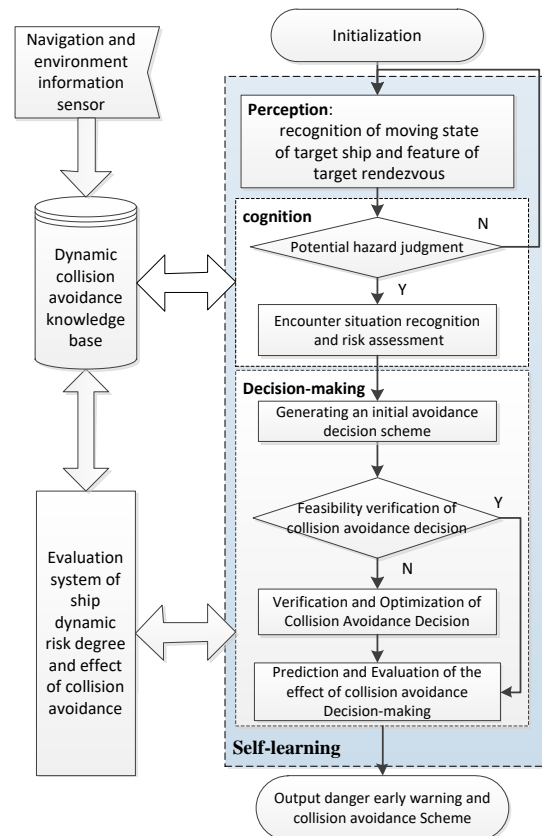


Figure 4. Machine online self-learning flow chart

4 SIMULATION VERIFICATION ANALYSIS

4.1 SIHC simulation platform

To validate the algorithm of PIDVCA, we developed a simulation platform with the name of “the ship intelligent handling control (SIHCS) platform”, which is based on the ship maneuver simulating model and electronic chart display and information system (ECDIS). The SIHCS platform is constructed by making good use of the technology of ship handling simulator. It is composed of one console computer and three own ship (OS) servers and one target ship (TS) server. The console, OS and TS servers are linked by local network. The SIHCS platform possesses all functions of ship handling simulator. The software of OS server also has an interface for users. The PIDVCA algorithm is integrate together with the Self tuning fuzzy PID autopilot algorithm into the SIHCS platform in the form of dynamic link library. Thus, the SIHCS platform is used to carry out simulating test on the process monitor for vessel automatic collision avoidance. Figure 5 is a simple simulation test platform composed of console and target ship server.

4.2 Simulation example analysis

In this paper, give a typical training example of a marine radar simulator that meets multiple ships, and the PIDVCA algorithm is integrated into the target ship server with the help of the ship intelligent control simulation test platform, such as figure 5, which is a simple test platform composed of the console and the

target ship server. When the target ship is selected as an intelligent state, it means that the target ship has the functions of automatic generation of PIDVC scheme and automatic collision avoidance. In this example, the target ship 1 is chosen as the intelligent own ship (OS), with a heading of 0.0° and a speed of 15.0 kn, and TS2, TS3 and TS4 are unintelligent TSs, as shown in figure 6 (a), the initial state of the simulation instance, as shown in Table 2. Figure (b) and (c) are the simulation results of the automatic monitoring of the process of the OS being turned and clearing the target respectively. The PIDVCA algorithm of OS is executed according to the online machine self-learning sequence:

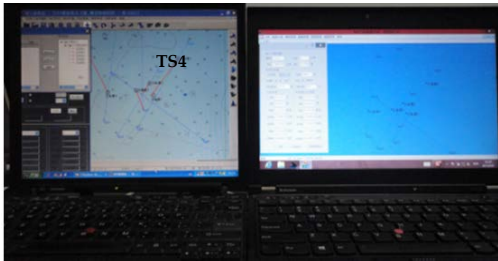


Figure 5. A simple simulation test platform

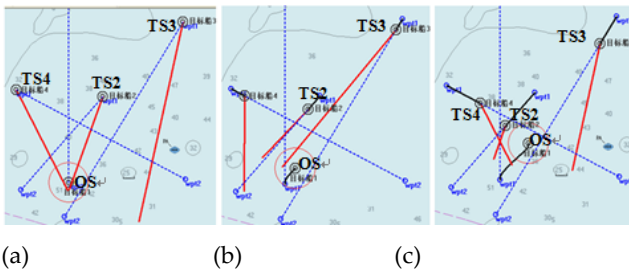


Figure 6. The automatic anti-collision process for simulating example

Table 2. Situation for OS relative to TS2, TS3 and TS4

No	B (Deg)	R (nm)	Ct (Deg)	Vt (kn)	Cr (Deg)	Vr (kn)
TS2	21.6	3.99	225.0	14.0	200.1	26.7
TS3	49.6	11.2	224.3	10.0	197.3	23.2
TS4	151.8	4.93	115.6	12.0	152.1	23.0

The relevant information is calculated according to step 1 and step 2, as shown in Table 3, as the DCPA between the OS and TS2 is 0.01nm, that is $DCPA < SDA$ (risk judgement threshold) it constitutes a potential collision hazard and is determined to be the most dangerous TS.

Table 3. Information for TS2, TS3 and TS4 relative to OS

No	TRF	Tsea	TCPA (min)	DCPA (nm)	SDA (nm)	DCPAn (nm)
TS2	20	1	8.93	0.01	1.37	-1.54
TS3	40	-	24.0	6.00	1.20	0.76
TS4	30	5	12.9	0.19	1.28	2.4

Table 4. L-PAE: Level of Predicted Anti-collision

L-PAE	Connotation
Safety Class: 0	Only changed the course by OS (Own ship) according to COLREGS or ordinary practice, satisfy with $DCPA \geq SDA$.
Secondary Safety Class : 1 Close Quarter Situation	Only changed the course by OS according to COLREGS or ordinary satisfy with $SDA_{min} < DCPA < SDA$ practice, just
Safety Class: 2 (Only for multi-vessels)	Only changed its original anti-collision course direction by OS, according to ordinary practice in multi-vessels, satisfy with $DCPA \geq SDA$
Secondary Safety Class : 3 Close Quarter Situation (Only for multi-vessels)	Only changed its original anti-collision course direction by OS, according to ordinary practice in multi-vessels just satisfy with $SDA_{min} < DCPA < SDA$
Urgent Class: 4 Immediate Danger Situation	Only changed the course by OS can't be avoided collision with $DCPA < SDA_{min}$.

Step 3. Based on the encounter relationship between OS and TS2, according to the rules applicable between the two ships, the usual practice of seafarers', the OS is required to fulfill the obligations of the responsible ship, and by calling the Crn (Crn represents target's new relative course after turning AC) model and formula (2), (3) and (4) the initial PIDVCA scheme was obtained as follows: $T_{isr}: 0$, $AC: 49^\circ$ and $T_{rr}: 9.3$ min, that is, to turn Starboard to 49° immediately, to predict that 9.3min can be resumed. Here T_{rr} is the maximum value of the OS's predicted recovery time.

Step 4 check the initial scheme. Table 3 shows that the predicted results are in the $DCPA_n (0.76nm) < SDA (1.2nm)$ of TS3. Is it possible for the OS to pose a new potential collision risk with TS3? By calling the generic algorithm from case source for heuristic case-based reasoning(as shown in the imaginary box in figure 4), first determines whether the $TCPA (24min)$ of the new dangerous target TS3 is less than the latest time (TL) of the OS turning course? Because of the correlation model calculation, it is obvious that the $TL=2.18min$, judgment result is negative; Then continue to calls (3) and (5) to calculate the predictive reversion limitation time of TS3. The T_c is 22.2min. obviously, the $T_{rr} (9.3min) < T_{cc} (22.2min)$ of OS shows that the potential collision danger between OS and T2 will disappear naturally after OS restored. As shown in figure 3, the initial decision scheme: ($T_{isr}: 0$, starboard $AC: 49^\circ$, $T_{rr}: 9.3min$) is effective. According to the result of calculation, the DCPA of OS and TS2 is more less than $SDA(1.28n.m)$ after OS recovering. it can be seen that there is no collision risk between OS and TS3. Because it is feasible to verify the result of the initial scheme, go directly to step 6. Based on the analysis of the evaluation table 4 of the effect of collision avoidance prediction, according to the implementation of the initial scheme, in the case of the TS with guaranteed direction and speed, the prediction safety level of avoidance effect is 0, That is, "safe".

5 CONCLUSION

In this paper, a learning mechanism combining offline artificial learning and online machine self-learning is proposed. Based on off-line artificial learning, the empirical knowledge of experts in the field of collision avoidance is regularized, conceptual knowledge modeling and the algorithm representation of procedural meta-knowledge are presented. The static collision avoidance knowledge base and automatic reasoning mechanism are constructed to provide the technical basis for online machine self-learning. A lot of simulation results of intelligent ship loaded with PIDVCA algorithm show that:

- 1 Under the guidance of predefined reasoning mechanism, the machine can reasoning and calculation from the field information provided by the perceptual system and the corresponding knowledge provided by the static collision avoidance knowledge base, and learn the new knowledge to solve the collision avoidance problem in any encounter scene.
- 2 The machine has the ability of perceiving TS, cognitive TS scene and making scientific and reasonable collision avoidance decision plan.
- 3 The machine has the ability to simulate people's thinking mode in solving complex collision avoidance problems and the ability to deal with them.

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