# EVALUATION METHODOLOGY ON TRAJECTORY OF INBOUND SINGLE SHIP USING SIMILARITY MEASUREMENT BETWEEN PLANAR CLOUDS

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## SUMMARY

In order to evaluate the ship trajectory more reasonable based on the quantitative information. This paper presents a new approach to evaluate the inward-port single ship trajectory quantitatively based on ship-handling simulator. First, a ship tracking points generating algorithm is proposed to generate sufficient tracking points in order to address the issue that the sample information is not enough on the ship simulator. Second, three reference tracking belts are established based on the sample data and cloud drop contribution degrees for the scenario that the collected samples information are enough. Finally, a quantitative score evaluation method that combines the qualitative information and the quantitative information is proposed, the similarity measurement results verify that the MES algorithm is more reasonable, the evaluation results of inward-port single ship trajectory illustrative that the proposed method is effective when applied to quantitative evaluation problems.

## NOMENCLATURE

| | |
|---|---|
| IMO | International Maritime Organization |
| STCW | International Convention on standards of Training, Certification and Watch keeping for Seafarers |
| SVM | Support Vector Machine |
| BP | Back Propagation |
| CS | Cloud Similar |
| VTS | Vessel Traffic System |
| IBCSC | Interval Based Cloud Similarity Comparison |
| MMCM | Maximum and Minimum based Cloud Model |
| LICM | Likeness comparing method based on cloud model |
| ECM | Expectation based cloud model |
| MCM | Maximum boundary based Cloud Model |
| ES | Expectation Surface |
| MBS | Maximum Boundary Surface |
| MES | Modified Expectation Surface |
| $Ex$ | Expectation: the distribution of droplet expectations in the domain |
| $En$ | Entropy: the uncertainty of qualitative concept determined by the concept of randomness and fuzziness. |
| $He$ | Hyper Entropy: the uncertainty of Entropy, namely the entropy of entropy |

## 1. INTRODUCTION

At present, ships developed to be large-sized, intelligent and specialized, then the more advanced requirements of comprehensive quality crews are needed, such as the ship manoeuvring ability and the bridge resource management ability, thus the IMO promulgated the Manila amendment of the STCW convention to strengthen the skill training of the crew (Jin & Yin, 2010), especially, to strengthen the ship navigator manoeuvring ability training. However, in the training practice, the problem is "how to reasonably evaluate the ship navigator manoeuvring ability when the ship is navigating in the fairway", In order to deal with this problem, the traditional evaluating method only consider the expert experience or the personal subjective experience, the reasonable evaluating method should consider both the subjective information and objective information, and the ship trajectory provides important quantitative objective information when the single ship is navigating an inward-port fairway (Chen, Ren, & Yi, 2011) (Roberge, Tarbouchi & Labonte, 2013) and if enough sample ship trajectories are collected which are navigated by the different experts or captains, then, these samples contain both objective information and subjective information, because of the partial related subjective information comes from these samples. The evaluation of ship trajectory is an effective way to deal with the evaluation of the ship navigator's manoeuvring ability.

In the navigational research field, some researchers pay attention to the research of route plan or route optimization, such as: compare the ship trajectory of not-under command vessel navigating nearby the bridge water area by using SVM (Wang, 2010), learn the optimal route by using genetic algorithm (Yang, 2012) (Zhang, Zhang, & Zheng, 2015) (Zhang & Zhang, 2015). Some researchers focus on the prediction of ship route, such as: analysis of the ship trajectory and prediction of Vessel Traffic System based on the improved adaptive trajectory estimation algorithm and BP neural network prediction algorithm (Xu, 2012). Very seldom research on the evaluation of ship trajectory can be found.

From the analysis of algorithm point of view, the existing references and algorithm always focuses on route planning algorithm and parameter learning. First, determine the objective function, the constraint conditions, and then, learn parameters by the corresponding machine learning algorithm. From the route evaluation and using information a point of view, the existing research results always focus on the route planning, dead reckoning and route prediction, however, the route planning reference standard are highly subjective, model selection is often set in advance, and the best evaluation selection is chosen from a variety of programs based on the expert experience or subjective information.

In order to make the ship trajectory evaluation more objective, an effective way to evaluate the ship trajectory is based on using and learning the existing sample information. However, in navigation practice, it is difficult to evaluate the ship trajectory due to the large number of ships, sailing on the same waters in different times, the navigation path are overlap and cross, evaluation objects are complicated, and the evaluation of the inward-port single ship trajectory is the most simple and typical state. Therefore, the study of the evaluation of the inward-port single ship trajectory is the basis of the evaluation of other navigation conditions.

## 2. PROBLEM FORMULATION AND PRELIMINARIES

### 2.1 PROBLEM FORMULATION

For the inward-port single ship trajectory, the position point of the ship trajectory is determined by the longitude and latitude in the electronic chart based on the ship simulator, it is difficult to collect the certainty degree of position in the sample information. Therefore, the suitable backward cloud algorithm is the algorithm of backward cloud without certainty degree.

When evaluating the inward-port single ship trajectory, it is necessary to establish the reference tracking belt with different requirements owning to the ship tracking points that may navigate outside of the fairway, and it is can be obviously concluded that the more excellent sample information the more reasonable results. However, in practice, there is always not thousands of sample information, because the one inward-port navigation procedure always last more than an hour and the experiment are not always acceptable. So the inward-port single ship tracking points generating algorithm is needed.

In order to generate the inward-port single ship tracking points cloud chart, first, set the same ship condition, the same environment condition, then, invite the excellent captains or pilots to test the inward-port navigation, after finishing the navigation, check whether the ship trajectory has obviously problem or not, such as collided with the other objects, ship aground. If there are problems, reset the exercise and try again, if there is no problem, save it as a sample ship trajectory, all these exercises are based on ship simulator. Collect the samples, setup the sample information database. If there are enough samples in the database according to the evaluation requirement, then directly generate the inward-port single ship tracking points cloud chart. If there are no enough samples, then use the inward-port single ship tracking points generating algorithm to generate enough ship tracking points. Finally, generate the inward-port single ship tracking points cloud chart.

### 2.2 PREMILINARIES

The cloud model (Li and Du, 2005) that was first proposed by Li *et al*. The related definitions are as follows:

Cloud drop: suppose $U$ is a quantitative domain with exact numerical value, $C$ is a qualitative concept on $U$ ,if qualitative value $x \in U$ ,and $x$ is a stochastic realization of the qualitative concept $C$ , $\mu(x) \in [0,1]$ is the certainty degree of $x$ belonging to $C$ , which is a random number with stable tendency $\mu : U \to [0,1]; \forall x \in U;\ x \to \mu(x)$

The distribution of $x$ can be defined as a cloud, and each $x$ is a cloud drop.

The cloud model describes the quantitative characteristics of qualitative concept by using the three digital features: Expectation, Entropy, and Hyper Entropy.

The cloud model algorithms mainly divide into two kinds of algorithm: the forward cloud generator and the backward cloud generator, and the normal distribution is one of the commonly used distribution in the navigational research field, thus, the two typical cloud algorithms are the forward normal cloud generator and the backward normal cloud generator.

Some researchers propose another forward normal cloud generator (Zhang, Li and Li, 2007) to revise the parameter $He$ , for example, in the solution process of $He$ , the thickness variation of the cloud satisfies two the half-normal distributions:

$$f_1(x) = He\exp(-\frac{(x-Ex_1)^2}{2(En_1{}^2)}), f_2(x) = He\exp(-\frac{(x_i-Ex_2)^2}{2(En_2{}^2)})$$

Where $En_1 = (3-(\ln 8)^{1/2})En/4,\ Ex_1 = 0,\ Ex_2 = 0,$ $En_2 = (\ln 8)^{1/2} En/4$ .

According to the sample information whether the uncertainty of the information or not, divide the backward normal cloud generator into two categories, One is the algorithm of backward cloud with certainty degree, and the other is the algorithm of backward cloud without certainty degree.

For the algorithm of backward cloud with certainty degree research, Yu Shaowei proposes an algorithm of backward cloud based on normal distribution interval number (Yu and Shi, 2011). Li Deyi proposes an algorithm of backward cloud based on mean method (Li, Wang, and Li, 2016). Wang Hui proposes an algorithm of backward cloud based on improved curve fitting (Wang, Qin, Liu, *et al,* 2014). Luo Ziqiang proposes an algorithm of backward cloud based on curve fitting (Luo. and Zhang, 2007), and so on.

Few researches discuss the algorithm of backward cloud without certainty degree: Liu Changyu first proposes the algorithm of backward cloud without certainty degree (Liu, Feng, Dai, *et al,* 2004). Hu Shenping proposes the cloud model based on the Monte Carlo Algorithm (Hu, Huang and Zhang, 2012).

The algorithm of backward cloud without certainty degree is as follows:

Set Sample information ( $N$ cloud drops ( $x_i$ )).as input,

Set $Ex$ , $En$ , $He$ as output, first, calculate the sample mean, absolute centre distance of first order sample, sample variance

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \ , \frac{1}{N}\sum_{i=1}^{N}|x_i - \bar{x}| \ , S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2$$

Then calculate estimated expected value, estimated entropy, and estimated Hyper Entropy

$$E\hat{x} = \bar{x} \ , E\hat{n} = \sqrt{\frac{\pi}{2}} \times \frac{1}{N}\sum_{i=1}^{N}|x_i - E\hat{x}| \ , H\hat{e} = \sqrt{S^2 - E\hat{n}^2}$$

## 3. EVALUATION METHODOLOGY

### 3.1 THE SHIP TEACKING POINTS GENERATING ALGORITHM

The ship tracking points generating algorithm is as follows: first, set $S$ samples, each sample select $P$ position points as input, set $N$ ship tracking points position and its degree as output. One select the same time interval points with the same numbers of points from each sample ship tracking line, that is, each sample tracking line has $P$ position points, select each sample $S_i$ the position of the same time $S_iT_j$ , thus, the set of $T_j$ tracking position points is $A_{T_j}$ :

$$A_{T_j} = \{drop(\varphi_{S_1T_j}, \lambda_{S_1T_j}), drop(\varphi_{S_2T_j}, \lambda_{S_2T_j})..., j = 1, 2...P\}$$ ,

according to $A_{T_j}$ , calculate $E\hat{x}_{T_j}$ , $E\hat{y}_{T_j}$

$$E\hat{x}_{T_j} = \overline{\varphi_{T_j}} = \frac{1}{S}\sum_{i=1}^{S}\varphi_{S_iT_j} \ , E\hat{y}_{T_j} = \overline{\lambda_{T_j}} = \frac{1}{S}\sum_{i=1}^{S}\lambda_{S_iT_j}$$ Calculate $Enx_{T_j}$ and $Eny_{T_j}$

$$Enx_{T_j} = \sqrt{\frac{\pi}{2}}\frac{1}{S}\sum_{i=1}^{S}\left|\varphi_{S_iT_j} - \overline{\varphi_{T_j}}\right|, Eny_{T_j} = \sqrt{\frac{\pi}{2}}\frac{1}{S}\sum_{i=1}^{S}\left|\lambda_{S_iT_j} - \overline{\lambda_{T_j}}\right|$$

, calculate $S\hat{x}_{T_j}$ and $S\hat{y}_{T_j}$

$$(S\hat{x}_{T_j})^2 = \frac{1}{S-1}\sum_{i=1}^{S-1}(\varphi_{S_iT_j} - \overline{\varphi_{T_j}})^2 \ , (S\hat{y}_{T_j})^2 = \frac{1}{S-1}\sum_{i=1}^{S-1}(\lambda_{S_iT_j} - \overline{\lambda_{T_j}})^2$$

, next, calculate $He\hat{x}_{T_j}$ and $Hey_{T_j}$

$$Hex_{T_j} = \sqrt{(S\hat{x})^2 - (Enx)^2}, Hey_{T_j} = \sqrt{(S\hat{y})^2 - (Eny)^2}$$

Then, generate two dimensional normal random number $(Enx_{T_j}^{'}, Eny_{T_j}^{'})$ based on the expectation of $(Enx_{T_j}, Eny_{T_j})$ , and the standard deviation of $(Hex_{T_j}, Hey_{T_j})$ .and generate two dimensional normal random number $drop(\varphi_{Nk}, \lambda_{Nk})$ based on the expectation of $(Ex_{T_j}, Ey_{T_j})$ , and the standard deviation of $(Enx_{T_j}^{'}, Eny_{T_j}^{'})$ ., next, calculate $\mu_{Nk}$ : the degree of $drop(\varphi_{Nk}, \lambda_{Nk})$

$$\mu_{Nk} = e^{-[\frac{(\varphi_{Nk} - Ex_{T_j})^2}{2(Enx_{T_j}^{'})^2} + \frac{(\lambda_{Nk} - Ey_{T_j})^2}{2(Eny_{T_j}^{'})^2}]}$$

if $N$ is the total ship tracking position points, each select time $T_j$ generate $N/P$ tracking points, so, repeat it until you generate $N/P$ ship tracking cloud position points. Finally, repeat each sample points until you generate $N$ ship tracking cloud position points (Fang, Ren and Jin, 2016).

### 3.2 THE INWARD-PORT SINGLE SHIP REFERENCE TRACKING BELT

In ship navigating alter-course situations, the generated position points are more discrete, therefore, to determine the present navigation situation compare the present position point with the history position point cloud chart. This is a good way to set the inward-port single ship reference tracking belt with different requirements.

According to the normal cloud drops group of concept contribution (Figure.1), the cloud drops in [Ex-0.67En, Ex+0.67En] accounted for 22.33% of cloud chart, the contribution of the concept is the total contribution of 50%, known as the key element. The cloud drops in [Ex-En, Ex+En] accounted for 33.33% of cloud chart, the contribution of the concept is the total contribution of 68.26%, known as the basic element. The cloud drops in [Ex-2En, Ex+2En] accounted for 66.66% of cloud chart, the contribution of the concept is the total contribution of 95.44%, the cloud drops in [Ex-2En, Ex-En] and [Ex+En, Ex+2En] known as the peripheral element. The cloud drops in [Ex-3En, Ex+3En] accounted for 99.99% of cloud chart, the contribution of the concept is the total contribution of 99.97%, the cloud drops in [Ex-3En, Ex-2En] and [Ex+2En, Ex+3En] known as the weak peripheral element (Lu, Wang, Li, *et al*, 2003) (Yang, Yan, Zeng, 2013). Therefore, set the area of key element, the area of basic element and the area of including peripheral element as the requirement condition.

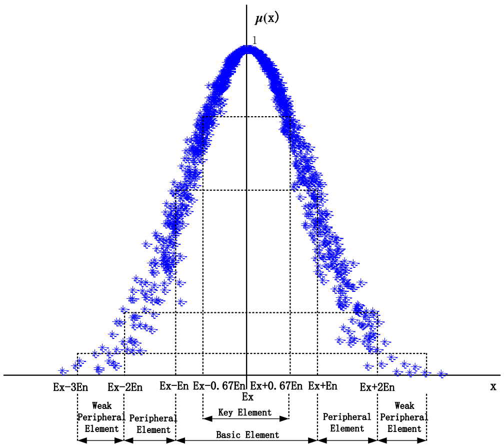


Figure 1. The normal cloud drops group of concept contribution chart

### 3.3 THE SIMILARITY MEASUREMENT ALGORITHM OF INWARD-PORT SINGLE SHIP TRAJECTORY

The existing cloud similarity measurement evaluation algorithms divide into three kinds, the first kind of algorithm is the cloud drop measurement algorithm, such as CS algorithm (Zhang, Zhao, Li, 2004), IBCSC algorithm (Cai, Fang, and Zhao, 2011), and MMCM algorithm (Jin and Tan, 2014). This kind algorithm selects the suitable cloud drops from the generated cloud, and calculates the similarity of the drop based on distance. The second kind of algorithm is a vector measurement algorithm, such as LICM algorithm (Li, 2012). This kind of algorithm uses the cosine value to calculate the similarity of two clouds by the cloud parameters. The third kind of algorithm is public space measurement algorithm, such as ECM algorithm (Li, Guo, and Qiu, 2011), MCM algorithm (Sun, 2015). This kind algorithm uses pubic space to calculate the similarity of cloud. Most of the above algorithms and references focus on the one dimension cloud, but for the two dimensions or higher dimensions, there are seldom relevant reference and supporting tests.

As for the evaluation of inward-port single ship trajectories based on the ship simulator, referring to the relevant literature, combining with the assessment of an actual situation, it is more reasonable to describe the navigating situation by using the course deviation and displacement difference in two-dimensions.

The evaluation algorithm of inward-port single ship trajectory is as follows:

Set $S$ --sample tracking line, $H$ --a tracking line to be evaluated as input,

Set $Sim(H,H')$--The cloud similarity value of $H$ and the reference tracking line $H'$ select from the $S$ sample tracking line as output.

Step 1: Select the same time interval points with the same numbers $F$ of points from each sample ship tracking line, select each sample $S_i$ the position of the same time $S_iT_j$ , thus, the set of $T_j$ tracking position points is $A_{T_j}$ ,the related course information set know as $C_{T_j}$ ,

$$A_{T_j} = \{drop(\varphi_{S_1T_j}, \lambda_{S_1T_j}), drop(\varphi_{S_2T_j}, \lambda_{S_2T_j}), \dots$$
$$, drop(\varphi_{S_iT_j}, \lambda_{S_iT_j}), i = 1,2\dots S\}$$
$$C_{T_j} = \{C_{S_1T_j}, C_{S_2T_j}, \dots, C_{S_iT_j}, i = 1,2\dots S\}$$

Step 2: according to $A_{T_j}$ , $C_{T_j}$ , calculate $E\hat{x}_{T_j}$ and $E\hat{y}_{T_j}$

$$\bar{\varphi}_{T_j} = \frac{1}{S}\sum_{i=1}^{S}\varphi_{S_iT_j}, \bar{\lambda}_{T_j} = \frac{1}{S}\sum_{i=1}^{S}\lambda_{S_iT_j}, \bar{C}_{T_j} = \frac{1}{S}\sum_{i=1}^{S}C_{S_iT_j}$$

Step 3: according to the $T_j$ moment of sample tracking point position $drop(\varphi_{HT_j}, \lambda_{HT_j})$ in $H$ , and course $C_{HT_j}$ , calculate the course deviation $\Delta C_{T_j}$ and displacement difference $\Delta D_{T_j}$ ( R is the radius of earth, about 6378137 meters). $\Delta C_{T_j} = C_{HT_j} - \bar{C}_{T_j}$

$$C = \sin(\varphi_{HT_j}\pi/180)\sin(\bar{\varphi}_{T_j}\pi/180) +$$
$$\cos(\varphi_{HT_j}\pi/180)\cos(\bar{\varphi}_{T_j}\pi/180)\cos((\lambda_{HT_j} - \bar{\lambda}_{T_j})\pi/180)$$
$$\Delta D_{T_j} = \arccos(C)\cdot R\cdot\pi/180$$

Step 4: for the course deviation dimension, calculate $Ex(\Delta C)$ , $En(\Delta C)$ , $He(\Delta C)$ , for the displacement difference dimension, calculate $Ex(\Delta D)$, $En(\Delta D)$, $He(\Delta D)$ :

$$Ex(\Delta C) = \Delta\bar{C} = \frac{1}{F}\sum_{j=1}^{F}\Delta C_{T_j}$$
$$Ex(\Delta D) = \Delta\bar{D} = \frac{1}{F}\sum_{j=1}^{F}\Delta C_{T_j}$$

$$En(\Delta C) = \sqrt{\frac{\pi}{2}}\frac{1}{F}\sum_{j=1}^{F}\left|\Delta C_{T_j} - \Delta\bar{C}\right|$$
$$En(\Delta D) = \sqrt{\frac{\pi}{2}}\frac{1}{F}\sum_{j=1}^{F}\left|\Delta D_{T_j} - \Delta\bar{D}\right|$$

 

$$(S(\Delta C))^2 = \frac{1}{\text{F-1}}\sum_{i=1}^{\text{F}-1}(\Delta C_{T_j} - \Delta\bar{C})^2$$

$$(S(\Delta D))^2 = \frac{1}{\text{F-1}}\sum_{i=1}^{\text{F}-1}(\Delta D_{T_j} - \Delta\bar{D})^2$$

$$He(\Delta C) = \sqrt{(S(\Delta C))^2 - (\text{En}(\Delta C))^2},$$

$$He(\Delta D) = \sqrt{(S(\Delta D))^2 - (\text{En}(\Delta D))^2}$$

Step 5: generate two dimensional normal random number $(En(\Delta C_t)', En(\Delta D_t)'), t = 1, 2, ..., \text{N}$ based on the expectation of $(En(\Delta C), En(\Delta D))$, and the standard deviation of $(He(\Delta C), He(\Delta D))$; generate two dimensional normal random number $\text{drop}(\Delta C_t, \Delta D_t), t = 1, 2, ..., \text{N}$ based on the expectation of $(Ex(\Delta C), Ex(\Delta D))$, and the standard deviation of $(En(\Delta C)', En(\Delta D)')$, and calculate the degree of membership $\mu_t$

$$\mu_t = \text{e}^{-[\frac{(\Delta C_t - Ex(\Delta C))^2}{2(En(\Delta C)'^2)} + \frac{(\Delta D_t - Ex(\Delta D))^2}{2(En(\Delta D)'^2)}]}$$

Step 6: for the course deviation dimension, the cloud drops in $[Ex(\Delta C)\text{-}2En(\Delta C), Ex(\Delta C)\text{+}2En(\Delta C)]$ accounted for 66.66% of cloud chart, the contribution of the concept is the total contribution of 95.44%, the distribution of cloud drops are relevant concentrate and the drop density change are relevant low, the same to the displacement difference dimension, so define the set $B = \{drop(\Delta C_t, \Delta D_t, \mu_t), t = 1, 2, ..., N\}$, when the drop both satisfy the condition $Ex(\Delta C)\text{-}2En(\Delta C) \le \Delta C_t \le Ex(\Delta C)\text{+}2En(\Delta C)$ and $Ex(\Delta D)\text{-}2En(\Delta D) \le \Delta D_t \le Ex(\Delta D)\text{+}2En(\Delta D)$, and these drops form the set K.

Step 7: in order to find the largest degree of membership in the certain area with the same interval delta distance and delta course, divide the delta distance dimension into M parts, and divide the delta course dimension into M parts, then form the M*M mesh area, and find the drop with the largest degree of membership in each small part, and all these drops form set Y.

Step 8: for the course deviation dimension, calculate $Ex_Y(\Delta C)$, $En_Y(\Delta C)$, $He_Y(\Delta C)$, for the displacement difference dimension, calculate $Ex_Y(\Delta D)$, $En_Y(\Delta D)$, $He_Y(\Delta D)$.

$$Ex(\Delta C_Y) = \Delta\bar{C}_Y = \frac{1}{\text{M}^2}\sum_{j=1}^{\text{M}^2}\Delta C_{Y\text{T}_j}$$

$$Ex(\Delta D_Y) = \Delta\bar{D}_Y = \frac{1}{\text{M}^2}\sum_{j=1}^{\text{M}^2}\Delta C_{Y\text{T}_j}$$

$$En(\Delta C_Y) = \sqrt{\frac{\pi}{2}}\frac{1}{\text{M}^2}\sum_{j=1}^{\text{M}^2}\left|\Delta C_{YT_j} - \Delta\bar{C}_Y\right|,$$

$$En(\Delta D_Y) = \sqrt{\frac{\pi}{2}}\frac{1}{\text{M}^2}\sum_{j=1}^{\text{M}^2}\left|\Delta D_{YT_j} - \Delta\bar{D}_Y\right|$$

$$(S(\Delta C_Y))^2 = \frac{1}{\text{M}^2\text{-1}}\sum_{i=1}^{\text{M}^2-1}(\Delta C_{YT_j} - \Delta\bar{C}_Y)^2$$

$$(S(\Delta D_Y))^2 = \frac{1}{\text{M}^2\text{-1}}\sum_{i=1}^{\text{M}^2-1}(\Delta D_{YT_j} - \Delta\bar{D}_Y)^2$$

$$He(\Delta C_Y) = \sqrt{(S(\Delta C_Y))^2 - (\text{En}(\Delta C_Y))^2}$$

$$He(\Delta D_Y) = \sqrt{(S(\Delta D_Y))^2 - (\text{En}(\Delta D_Y))^2}$$

Step 9: choose a typical ship tracking line as reference tracking line H', repeat step1 to step 8.

Step 10: calculate the value of $Sim(H, H')$ by different method, such as vector measurement algorithm, public space measurement algorithm and so on.

The similarity of Vector measurement formula:

$$\overrightarrow{U_H} = vector(Ex(\Delta C_{HY}), En(\Delta C_{HY}), He(\Delta C_{HY}), Ex(\Delta D_{HY}), En(\Delta D_{HY}), He(\Delta D_{HY}))$$

$$\overrightarrow{U_{H'}} = vector(Ex(\Delta C_{H'Y}), En(\Delta C_{H'Y}), He(\Delta C_{H'Y}), Ex(\Delta D_{H'Y}), En(\Delta D_{H'Y}), He(\Delta D_{H'Y}))$$

$$Sim(H, H') = \cos(\overrightarrow{U_H}, \overrightarrow{U_{H'}}) = \frac{\overrightarrow{U_H} \cdot \overrightarrow{U_{H'}}}{\left\|\overrightarrow{U_H}\right\|\left\|\overrightarrow{U_{H'}}\right\|}$$

The similarity of public space measurement formula:

$S_H$ is the cloud area based on H tracking line, $S_{H'}$ is the cloud area based on H' tracking line, $S_{public}$ is the pubic area between the H tracking line and the H' tracking line

$$Sim(H, H') = \frac{2S_{public}}{S_H + S_{H'}}$$

Therefore, the evaluation score of inward-port single ship trajectory can be calculated by three steps: first, judge whether the sample information is sufficient or not, if not enough, use the ship tracking points generating algorithm to generate enough sample information, and then construct the inward-port single ship reference tracking belt with the different requirement condition, and calculate the outside-belt score. Next, use the similarity measurement algorithm to evaluate the similarity score by comparing the reference tracking line with the target tracking line. Finally, calculate the total score of the inward-port single ship trajectory.

## 4. EXPERIMENTAL STUDIES

Generally, in order to make evaluation results more comparable, the evaluation of the inward-port single ship trajectory need lots of navigational samples in the same ship condition, the same traffic condition, and the same starting point, but it is very difficult to collect these kinds of sample information in the real port, because the environment and condition always change.

The ship simulator is formed from a collection of navigational equipment simulator, the system can simulate the expected navigational environment (Fang and Ren, 2015) (Fang and Ren, 2015b), in order to test the algorithm effectiveness, when collecting the samples information of the inward-port single ship trajectory, we set up the same ship condition, the same traffic environment, and the same starting point based on the ship simulator.

Set the oil tanker "CHANGHANGXIWANG" entering into the Dalian port as an example, set NE wind 1kn, E current 0.5kn, the starting point is latitude $38^{\circ}55.812'$ longitude $121^{\circ}47.028'$. Select about an hour period of navigation ship trajectory, for each tracking line select 127 position points with the same time interval, in this case, invite 32 different experienced captains and 20 different experienced pilots to test the navigation, collect 50 valid exercises ship tracking lines for the sample information database. According to the ship tracking points generating algorithm, the input information $S$ is 50, and $P$ is 127. These 127 sample point at the same time generates 100, 1000 and 10000 tracking points are shown in Figure.2, and the overall situation of inward-port single ship tracking point's generation cloud chart is shown in Figure.3.

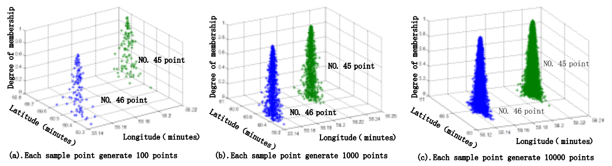


Figure.2. The cloud chart of a single sample point generate tracking points

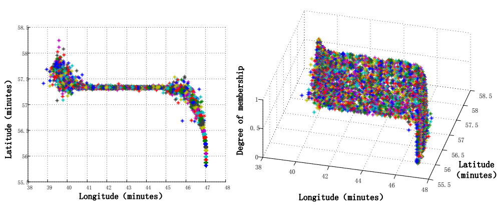


Figure.3. the overall situation of inward-port single ship tracking points generation cloud chart

According to the results of Figure.3 and the cloud drop contribution of Figure.1, set the area of key element, the area of basic element and the area of including peripheral element as the requirement condition when determining the inward-port single ship reference tracking belt. As Figure.4 shows, the key element area tracking belt, the basic element area tracking belt and the including peripheral element tracking belt.

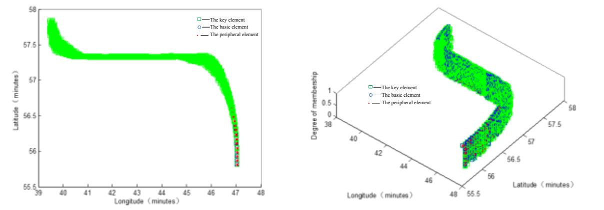

Figure 4. the inward-port single ship reference track belt chart

Based on Figure 3 information, according to the evaluation algorithm of inward-port single ship trajectory, set input information S=49, the tracking line to be evaluated, after step 1-step 6, then set K is as the circle drop points in Figure.5 shows, then continue to step 7, form the set Y is as the selected maximum points in Figure 5 shows, after step 8 calculate the six parameters of the two-dimension cloud, and it is easy to draw the mathematic equation surface based on the six parameters of the two-dimension cloud. Figure 6 shows that the ES, MBS and MES on set Y cloud drops, $z_{ES}$ is the degree of membership based on ES, $z_{MES}$ is the degree of membership based on MES, $z_{MBS}$ is the degree of membership based on MBS.

$$z_{ES} = e^{-\left[\frac{(x-Ex(\Delta C_Y))^2}{2(En(\Delta C_Y)'^2)}+\frac{(y-Ex(\Delta D_Y))^2}{2(En(\Delta D_Y)'^2)}\right]}$$

$$z_{MES} = e^{-\left[\frac{(x-Ex(\Delta C_Y))^2}{2(He(\Delta C_Y)^2+En(\Delta C_Y)'^2)}+\frac{(y-Ex(\Delta D_Y))^2}{2(He(\Delta D_Y)^2+En(\Delta D_Y)'^2)}\right]}$$

$$z_{MBS} = e^{-\left[\frac{(x-Ex(\Delta C_Y))^2}{2(3He(\Delta C_Y)+En(\Delta C_Y)')^2}+\frac{(y-Ex(\Delta D_Y))^2}{2(3He(\Delta D_Y)+En(\Delta D_Y)')^2}\right]}$$

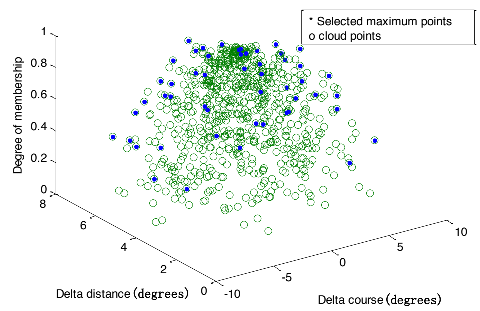


Figure.5. the set K and set Y cloud drops chart

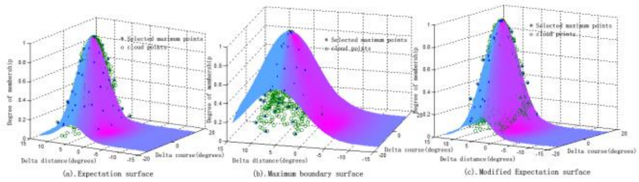

Figure.6. the ES, MBS and MES curve fitting based on set Y cloud drops

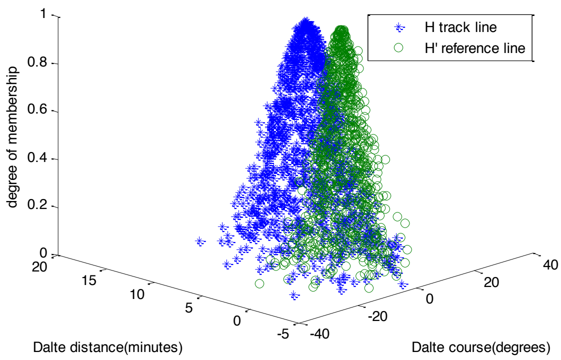


Figure.7. the relationship between the selected reference line cloud and the target track line cloud

Figure.7 shows the relationship between the selected reference line (H') cloud and the target tracking line (H) cloud. by using different mathematic equation surfaces, the similarities of the cloud are different, according to the experiment of one-dimension cloud, the modified expectation is more reasonable (Zhang, Li & Sun, *et al*. 2014) (Gong, Jiang and Liang, 2015). However, for the two-dimension cloud, it is necessary to compare these four algorithm's test results to each other (Dong, Hong, & Xu, *et al*., 2011) (Zhang and Sanderson, 2009). In this case study, select five typical track lines as target track lines to be evaluated in the S sample information, and evaluate the similarity based on the S sample information, the results are seen in Table 1.

From the similarity of the selected five target lines based on COSINE, ES, MBS, MES algorithm in the Table 1, it can be concluded that :H2 has the highest similarity of H4, H3 has the highest similarity of H5, H1 has the lowest similarity of H2 and has the higher similarity of H5. Although the value differences are different, the tendency conclusion is the same. It also can be concluded that the MES algorithm is better than the ES and the MBS algorithm when compared H2 to H5, because the similarity value difference between the ES and MBS algorithm is small, and the difference of similarity value is larger by using the MES algorithm.

Table 1 the similarity of selected five target lines based on COSINE, ES, MBS, MES algorithm

| | | H1 | H2 | H3 | H4 | H5 |
|---|---|---|---|---|---|---|
| COSINE | H1 | 1 | 0.7142 | 0.8328 | 0.7438 | 0.8715 |
| | H2 | 0.7142 | 1 | 0.7546 | **0.9104** | 0.7919 |
| | H3 | 0.8328 | 0.7546 | 1 | 0.8316 | **0.9126** |
| | H4 | 0.7438 | 0.9104 | 0.8316 | 1 | 0.8236 |
| | H5 | 0.8715 | 0.7919 | 0.9126 | 0.8236 | 1 |
| ES | H1 | 1 | 0.6857 | 0.7896 | 0.6904 | 0.8578 |
| | H2 | 0.6857 | 1 | 0.7027 | **0.8432** | 0.8225 |
| | H3 | 0.7896 | 0.7027 | 1 | 0.7946 | **0.8410** |
| | H4 | 0.6904 | 0.8432 | 0.7946 | 1 | 0.7858 |
| | H5 | 0.8578 | 0.8225 | 0.8410 | 0.7858 | 1 |
| MBS | H1 | 1 | 0.6214 | 0.8012 | 0.7102 | 0.8136 |
| | H2 | 0.6214 | 1 | 0.7324 | **0.8360** | 0.7908 |
| | H3 | 0.8012 | 0.7324 | 1 | 0.8127 | **0.8349** |
| | H4 | 0.7102 | 0.8360 | 0.8127 | 1 | 0.7735 |
| | H5 | 0.8136 | 0.7908 | 0.8349 | 0.7735 | 1 |
| MES | H1 | 1 | 0.7263 | 0.8231 | 0.7325 | 0.8869 |
| | H2 | 0.7263 | 1 | 0.7641 | **0.9018** | 0.8035 |
| | H3 | 0.8231 | 0.7641 | 1 | 0.8019 | **0.9028** |
| | H4 | 0.7325 | 0.9018 | 0.8019 | 1 | 0.8002 |
| | H5 | 0.8869 | 0.8035 | 0.9028 | 0.8002 | 1 |

Therefore, when evaluating the inward-port single ship tracks quantitatively, first, it is necessary to set the track line belts with different requirements, for example, in Figure.6, suppose: the total score is 100, if the evaluator needs a strict rule during the navigation, and there are 127 sample points in the track line, when the ship track point navigating outside the green track belt, it should be minus 1 score, when the ship track point navigating outside the blue track belt, it should be minus 0.5 score. Secondly, by using the evaluation algorithm of inward-port single ship track, and comparing them, and make sure the score-calculating reference track line is under the numbers of experts' supervision, for example, in table1, suppose the H5 is the score-calculating reference track line, use the similarity with the other track line, it is easy to calculate the score of the others track line by multiplying the similarity, and the total score is the similarity score minus the outside-belt score. The quantitative score results of the other track line are obtained by using the MES algorithm is shown in Table 2.

Table 2 the quantitative score results by using the MES algorithm

| | H1 | H2 | H3 | H4 | H5 |
|---|---|---|---|---|---|
| The similarity score | +88.7 | +80.4 | +90.3 | +80.0 | +100 |
| The outside-belt score | -4.5 | -5.0 | -2.5 | -6.5 | -1.5 |
| The total score | +84.2 | +75.4 | +87.8 | +73.5 | +98.5 |

In addition, if the experts group think the score of H5 is another score not 100, then the others score will change according to the score of H5. Therefore, this method combines effectively the qualitative information with quantitative information based on the ship handling simulator.

## 5. CONCLUSIONS

This paper has outlined a feasible approach in which historical and sample information were used to evaluate the inward-port single ship tracking line based on the ship-handling simulator. Once an adequate sample trajectory information by excellent captains or pilots were obtained, a reasonable inward-port single ship reference tracking belt will be formed, then the evaluation score should be more reasonable, however, if there are not adequate sample trajectory information, the inward-port single ship tracking points generating algorithm can be used. When evaluating the inward-port single ship tracking line, by using the evaluation algorithm of inward-port single ship trajectory, calculate the similarity of different measurement algorithm (COSINE, ES, MBS, MES), and choose the more suitable algorithm result, set the score-calculating reference tracking line under the numbers of expert's supervise, calculate the outside-tracking score, then the total quantitative score of each tracking line can be obtained. Therefore, this similarity of cloud model algorithm combines effectively the sample information and the expert's experience.

It can be concluded that if sufficient information is available, the evaluation results will be more reasonable, so future work will involve collecting more sample information, and integrating the evaluation algorithm with the expert's human-computer interaction based on the navigational simulation system.

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