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IMPLEMENTATION OF CPA (CLOSEST POINT OF APPROACH) ALGORITHM IN MULTIDIMENSIONAL RISK ANALYZING MODULE OF MarSSIES (MARITIME SAFETY & SECURITY INFORMATION EXCHANGE SYSTEM)

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1. ABSTRACT

CPA algorithm calculates closest distance which can be reached by two moving objects. This calculation is widely used in collision avoidance applications. MarSSIES risk analyzing module join CPA calculations with other vessel or maritime related factors, like IMO category of carried goods or traffic level, in order to find out possibility of danger situation and notify system operator.

2. GENERAL

MarSSIES (Maritime Safety & Security Information Exchange System) is platform distributing information between operational services cooperating in range of vessel traffic safety and security. Distribution is held between Maritime Operations Centre of the Polish Navy, National Navigation Warning Services Coordinator from Hydrographic Office of the Polish Navy and Control Centre of Polish Border Guard. System collecting data from AIS system (vessel tracking, AtoN, base stations), hydro-meteo sensors, radar system. MarSSIES serves as interface to SafeSeaNet system and access to other maritime related datebases. Recently the collision risk analyzing module has been developed as a part of the MarSSIES.

This module is designed as a VTS operators support tool based on AIS data and CPA algorithm.

3. CPA ALGORITHM

CPA (**C**losest **P**oint of **A**pproach) algorithm allows to calculate distance and time when two moving objects rich their nearest positions. CPA algorithm assumes that vector and speed of moving objects is known and constant. If speed or vector is changed, CPA time and distance should be calculated again. Presented below linear algebra formulas are implemented in MarSSIES CPA calculations. Negative value of "time to CPA (6)" means that ships are sailing away.

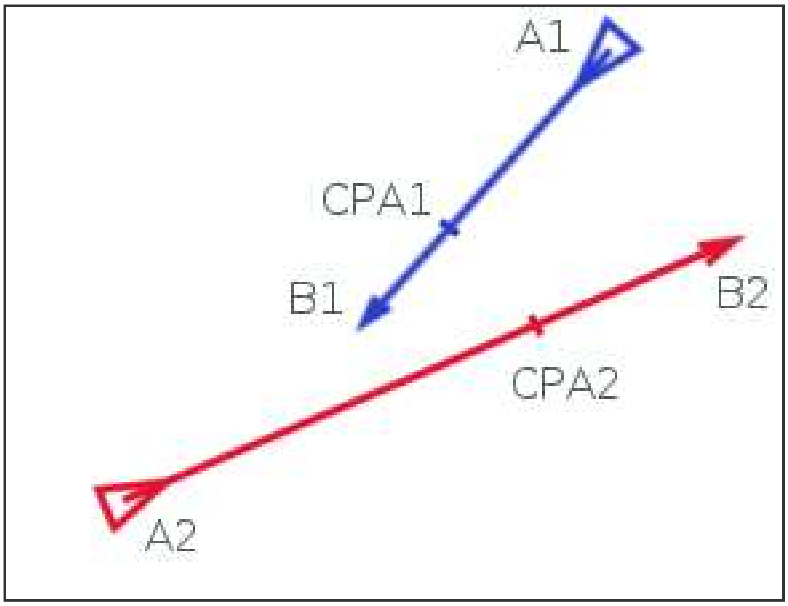

Fig. 1: Closest Point of Approach of two moving objects

CPA_t – Time to CPA
CPA_d – Distance at CPA

$$\overrightarrow{AB}_1=[x_{B1}-x_{A1}, y_{B1}-y_{A1}] \tag{1}$$
$$\overrightarrow{AB}_2=[x_{B2}-x_{A2}, y_{B2}-y_{A2}] \tag{2}$$
$$\overrightarrow{AB}_{dv}=\overrightarrow{AB}_1-\overrightarrow{AB}_2 \tag{3}$$
$$dv=(\overrightarrow{AB}_{dv}\cdot\overrightarrow{AB}_{dv}) \tag{4}$$
$$\overrightarrow{AB}_{dp}=A_1-A_2 \tag{5}$$
$$CPA_t=-\frac{\overrightarrow{AB}_{dp}\cdot\overrightarrow{AB}_{dv}}{dv} \tag{6}$$
$$CPA_1=A_1+CPA_t*\overrightarrow{AB}_1 \tag{7}$$
$$CPA_2=A_2+CPA_t*\overrightarrow{AB}_2 \tag{8}$$
$$CPA_d=\sqrt{CPA_1-CPA_2\cdot CPA_1-CPA_2} \tag{9}$$

4. RISK EVALUATION CALCULATION

Collision risk level factors are derived from AIS data like position, speed, course, IMO category of carring goods. Most significant parameters are “time to CPA (6)”, “distance at CPA (9)” and speed of vessels. Factors derived from CPA calculation are expressed in their critical value level according to overseen area or user preferences. This factors have their default values but also can be changed by user. This made the evaluation flexible and scalable.

Other significant factor is relative vector speed of vessels raised to second power. This is derived from kinetic energy formula. It should be complete by mass factor in the future, but there is no currently available data. This factor efficiently decrease evaluated risk level in case of slowly moving ships and increase risk level when both of them or at least one is moving fast.

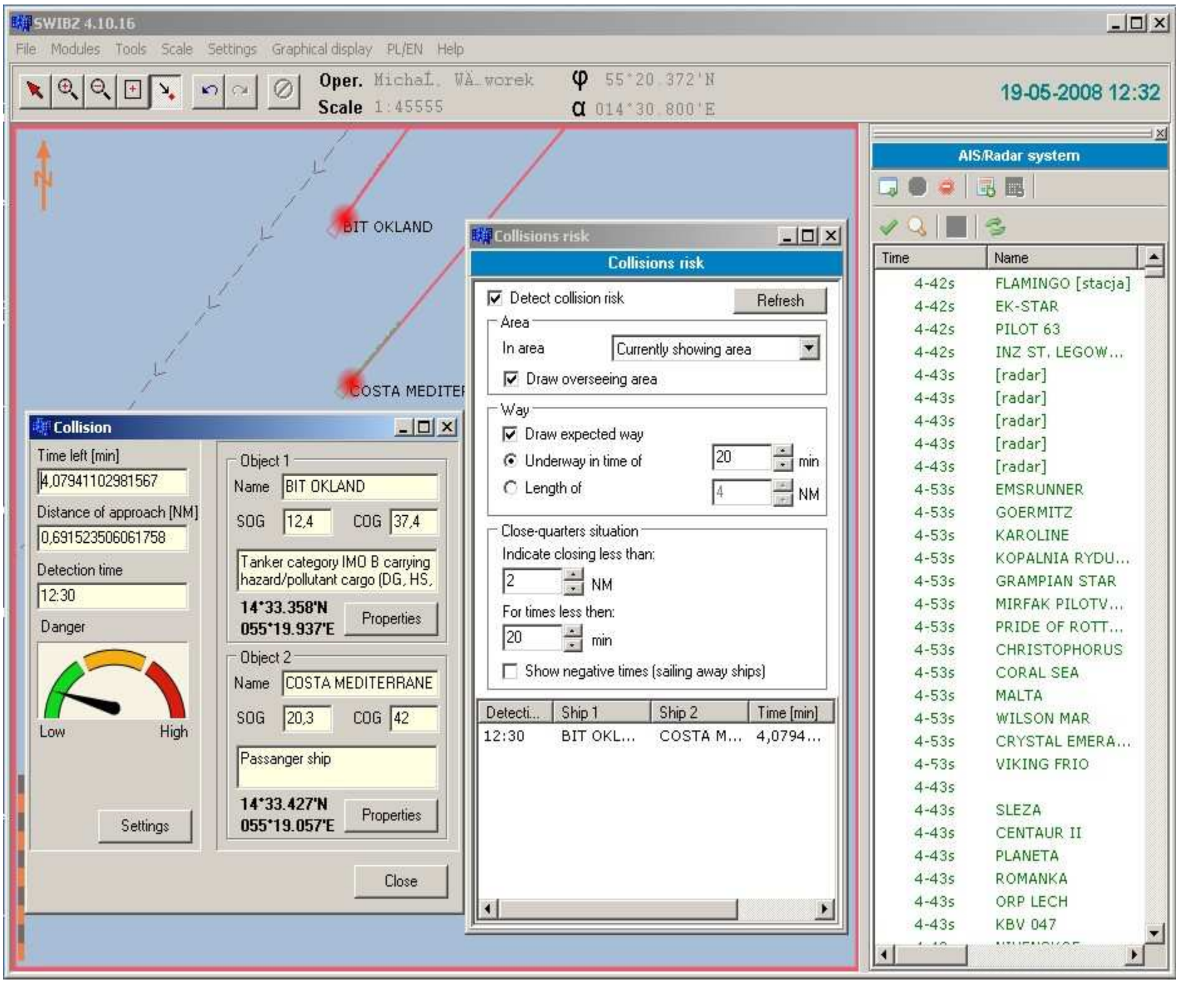

Fig. 2: Collision risk module of MarSSIES client application

Less significant factors used in collision risk level evaluation are IMO category of carried goods, traffic density, and closing trend. The first factor is directly derived from AIS stream. If one or two vessels are carrying danger goods, harmful substances or marine pollutants risk level is increased accordingly. Traffic density depends on navigational status of vessels within a radius of two nautical mile from each vessels. High traffic level increase evaluated collision risk level. Closing trend depends on changes of “distance at CPA” in time. When “distance at CPA” of two monitoring vessels is decreasing the closing trend factor is increasing and risk level increase as a result. Significant increase of “distance at CPA” trigger rapid decrease of closing trend factor.

The risk evaluation is implemented in multidimensional risk analyzing module of MarSSIES client application as it shown on Fig 2. Using this module operator of MarSSIES can precisely define water region which should be overseeing with parameters like maximum “distance at CPA” and maximum “time to CPA”. By setting critical levels for “distance at CPA” and “time to CPA” operator can calibrate risk evaluation results for overseeing water conditions. Risk level is presented gradually on graphic chart from low risk to high risk.

5. PRACTICAL IMPLEMENTATION OF RISK EVALUATION FACTORS

There are six factors used in based on AIS risk evaluation implementation:

- time factor - time when two vessels reach their nearest positions
- distance factor - distance between two vessels when they are on their nearest positions
- speed factor - relative vector speed of vessels
- danger cargo factor - existence of danger cargo on bord
- traffic factor - traffic density
- closing trend factor - trend of change of CPA distance of two monitoring vessels

Three base factors of risk evaluation are based on "time to CPA", "distance at CPA" and speed of vessels. By default, unit of "time to CPA" is 0,25h and "distance at CPA" is 0,1NM. This mean that 15 minutes and 0,1NM are critical values for collision risk evaluation. Any smaller value of "time to CPA" increase result of risk collision evaluation. The critical level of "time to CPA" and "distance at CPA" is set by operator and should depend on overseeing area conditions. Time factor is calculated by one divided by "time to CPA". Distance factor is calculated by one divided by "distance at CPA" raised to second power. Distance factor is most critical so it is derived by promotion to second power.

Speed factor is calculated from AIS data of monitoring objects. This is relative vector speed in knots raised to second power.

Danger cargo factor has two possible value. If one or both of vessels carring danger goods this factor increase evaluated risk level. This factor is based on IMO category of carried goods from AIS data.

Traffic factor introduces traffic density parameter into the risk evaluation formula. This calculation takes navigational status of close ships into consideration. Each ship increase factor value depending on its navigational status. Array of navigational status values according to traffic factor starts with low values of "moored" and "at anchor" and ends with high value of "not under command" status. Only ships within a radius of two nautical mile from both or one overseeing ships are taken into consideration.

Closing trend factor is recalculated every time when "distance at CPA" is changed. When CPA_d decrease closing trend factor increase as a result. Default value of closing trend factor is 1. Pseudocode presented below shows how closing trend factor is calculated.

```
if (CPAd >= new_CPAd) closingTrend *= 0.08;
else if (new_CPAd - CPAd > CPAd / 7.5) closingTrend /= 1.7;
if (closingTrend < 1) closingTrend = 1;
```

Formula and pseudocode of collision risk level C calculation:

$$C = \log\left(\left(\frac{1}{CPA_d}\right)^2 * \frac{1}{CPA_t} * \sqrt{(\overrightarrow{AB_1} - \overrightarrow{AB_2}) \cdot (\overrightarrow{AB_1} - \overrightarrow{AB_2})}\right) \quad (10)$$

```
if (vessel_1 -> DangerCargo) C += C * 0.2;

if (vessel_2 -> DangerCargo) C += C * 0.2;
```

$$C = C^{closing\ trend} + traffic\ \ factor \quad (11)$$

6. CONCLUSIONS

Collision risk analyzing module of MarSSIES is based on CPA calculation and other available maritime related factors. This module not only returns time and distance at which vessels are going to pass, but also estimated collision risk level. In this evaluation, factors like speed of vessel, cargo type, traffic density together with CPA time and distance are applied in order to find out possibility of danger situation. The collision risk evaluation can be used in monitoring of different kind of water areas, because algorithm parameters can be modified by operator. Along with future development of MarSSIES, the collision risk evaluation can be diversified with new available factors like vessels mass, visibility and other data received from external databases.