Archives of
Transport System
Telematics
Volume 8
Issue 2
May 2015

Proposal of the prediction algorithm of the object's position in restricted area

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ABSTRACT
In this paper an algorithm of finding the optimal path of an object in restricted area, focusing on the position prediction, is presented. Moving in the restricted area requires not only the knowledge of this area, but also the current and future position of other objects present in it. These informations let to minimalize the possible collision risk. It's significant not only due to the safety, but also to the economic factors. This approach is the further development of the investigations in the area of finding the optimal path in restricted area, carried out at the Maritime University of Szczecin. The authors propose the algorithm for the use in the decision support systems in maritime navigation, but it could be also applied in the other areas of transport.

Keywords: prediction, restricted area, navigation, transport, shortest path, optimal route

1. Introduction

Prediction of the object's movement is a very important factor in traffic management [1]. It allows us to estimate the possible course / direction of other moving vehicles e.g. vessels in maritime navigation. Let's consider the simple example. The calculation of the position of our object in the given moment of time is done well, only if we assume that there is no other moving object crossing or moving very close to our course. Then there is a need to do some predictions because the situation changes dynamically in time and some possible paths can be no longer allowed. This fact lets to make the transport process much safer and faster. Generally in maritime transport VTS systems are used but it could be supported also by other tools. Besides there is a need to consider the case of smaller vessels (yachts, boats etc.) which can move outside the area covered by VTS. In this paper a proposal of an algorithm in restricted areas is given. It consists of few steps:

- determination of the position of own ship (object) on the map,
- processing the map data to obtain a mesh of trapezoids which allows to determinate the restricted and allowed areas,
- determination of the basic graph of all possible paths in given area,
- calculation of the optimal route basing on the current position of own ship (object),
- if other moving objects are detected the local modification of the graph becomes necessary. In this case the prediction of the object's movement has to be done.

2. Optimal route

What is the optimal route or trajectory? The shortest one? Not always. The optimal route of any moving object in transport can't be considered only in the geometric sense. There is a need to take into account other limitations such coastlines, other moving objects etc. It has to be remembered that the most important factor in transport is always the safety. The most common algorithms used in the optimal route problem are Dijkstra algorithm or A* approach. They are described and tested e.g. in [2].

Let's consider now the area at the Figure 1.

As it can be seen this is a typical restricted area with five islands. In the opposite to wide open areas, here is practically no possibility that the optimal route would be a straight line, especially when the objects are moving e.g. between the islands.

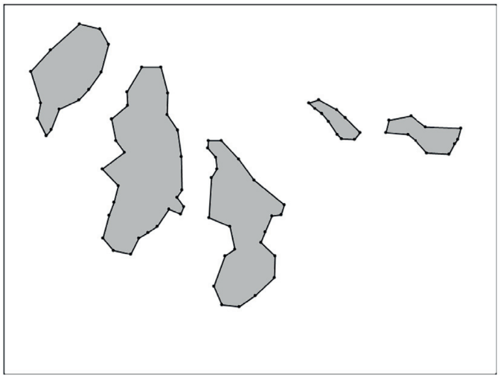

Fig. 1. The area considered [own study]

3. Prediction

The prediction of the movement of own ship is quite easy. Because the model of our object is known we can use e.g. regulators (like LQR [1]), regression models etc. So, the estimation of the future position is not a significant problem. This one increases when other moving objects have to be considered. The main factor that makes it difficult is that we don't know the model parameters of these objects, so the prediction would be less reliable. But it is necessary to do it to avoid some collision situations which can be caused by poorly estimated prediction of the future situation.

In this paper we apply some linear regression model to predict the future position of other moving objects, so the navigator could estimate their positions and prevent dangerous situations like collisions etc.

Let's consider some example navigation situations:

3.1. Situation A

We have two moving objects in the given restricted area. S1 is moving from the north towards it's waypoint. The second S2 is moving in the opposite direction. So it has to be determined if these other objects are on collision course. We assume that the speed of both objects is constant. In this case we see that the lines representing the course of each object are going to cross, probably somewhere outside of this figure. This fact leads to the conclusion that when the S2 comes to the cross point, the S1 would be near it's waypoint. So we can't describe this situation as a collision risk. If we know the current position and speed we can predict the location of each object only in simple mathematic calculations. Moreover in this case we can omit even these calculations because the experienced navigator can clearly assess the situation basing only on this figure.

But if we want to do some predictions we have to determine the regression line (RL1) of the object S2 (S1 is our own object so we don't have to do any predictions). Assuming that few former positions of S2 are given (with some deviations of course) we can do some simple calculations. The equation of RL1 will be then (LSQ method):

$$\hat{y} = bx + a \quad (1)$$

where:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (2)$$

$$a = \bar{y} - b\bar{x} \quad (3)$$

x_i – the x coordinates,
y_i – the y coordinates,
$\bar{x}$ – the arithmetic mean of x coordinates,
$\bar{y}$ – the arithmetic mean of y coordinates,
n - the total number of points

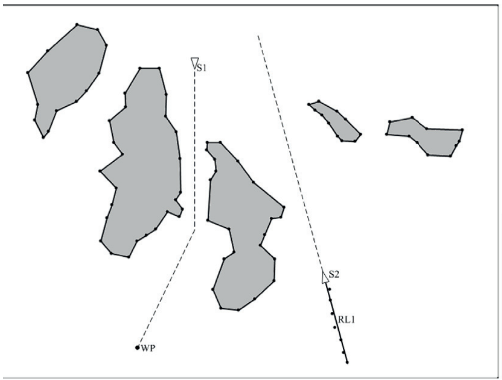

Fig. 2. Situation A [own study]

In this situation there is no need to determine other regression lines. If the direction and speed of object S2 are constant it can be assumed that the a and b coefficients of the regression line are not going to change significantly. The regression line RL1 is a model of the movement of the object S2.

3.2. Situation B

This case has some familiar features with the situation A described above. Basing only on observation we can assume that there is no collision risk. But what about the prediction of the object S2 movement? It can be seen that the course of S2 is changing in time. So determination of only one regression line is not the best idea. The reasoning is very simple. One regression line can't be the model of the S2 movement because it is not reliable. Of course we can determine this line and sometimes the average error between it and real position points wouldn't be significant. It has to be known that position is calculated only basing on few points from the past. Not all. This phenomenon is clearly visible e.g. in artificial intelligence when the over-learning of artificial networks is observed. This situation can't be solved by adding some new points because all the measurements were made in past. But we can build some smaller local models and then observe the differences between each regression line (RL1, RL2, RL3, …), so we can predict not only the future position of the object S2 but also we are able to detect that the course is changing. The last regression line (RLn) becomes the current model of the object's movement.

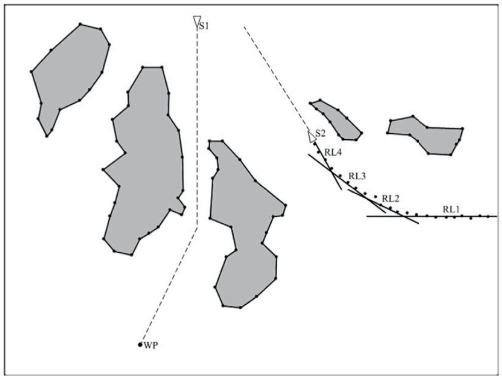

Fig. 3. Situation B [own study]

There is one more question which is important in this situation. How many points are necessary to determinate each local regression line? As we know we need at least two points, but taking only this amount of data can lead to some useless relief calculations. In this paper we propose the observation of the Pearson's correlation coefficient *r* which is given by:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (4)$$

where:
xi – the x coordinates,
yi – the y coordinates,
$\bar{x}$ – the arithmetic mean of x coordinates,
$\bar{y}$ – the arithmetic mean of y coordinates,
n - the total number of points

The Pearson's correlation coefficient is useful if we want to determinate if the dependency between two variables is linear. The value of r is always in the interval of <-1,1>. If r = 1 or r = -1 or it's value is near these numbers, we can assume that this dependency is linear or can be described by linear model with a low average error.

So let's conduct some simple experiment. We have 10 points and want to obtain a regression line. We start from third three points and observe the correlation coefficient. Then we add one point and observe how the correlation coefficient changes. The results of this simple experiment are given in the table below.

Table 1. The change of Pearson's correlation coefficient [own study]

No.	X	Y	r	Comment
1	0.00	0.00	-	We have only one point
2	1.00	1.00	1	We have straight line conducted through two points
3	1.90	2.05	0.999	below 1 but very close to it
4	2.80	3.14	0.999	below 1 but very close to it
5	3.20	3.86	0.997	below 1 but very close to it
6	4.10	5.04	0.997	below 1 but very close to it
7	4.20	7.22	0.954	decreases significantly – possible maneuvre
8	4.40	9.56	0.911	as above
9	4.60	12.34	0.881	as above
10	4.80	19.44	0.806	as above

The data from the Table 1 indicates that adding the seventh point decreased significantly the correlation coefficient. Further points made it more visible. So it leads to the conclusion that object probably changed it's course. It can be seen also at the figure below.

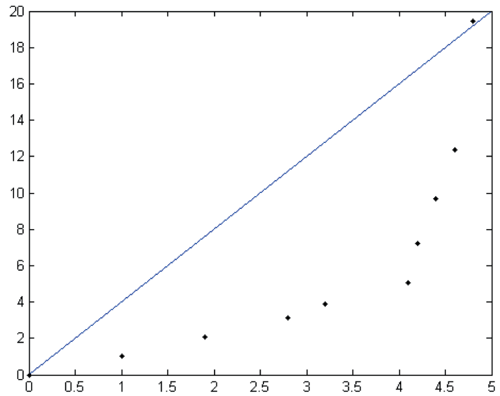

Fig. 4. Detection of the maneuvre [own study]

So if we observe the behavior of the correlation coefficient we can decide when to build the next regression line. The prediction of the future position of S2 should be equal to this indicated by the last regression line (RL4 in the situation B). In this case the first regression line (RL1) could consist of first seven points.

3.3. Situation C

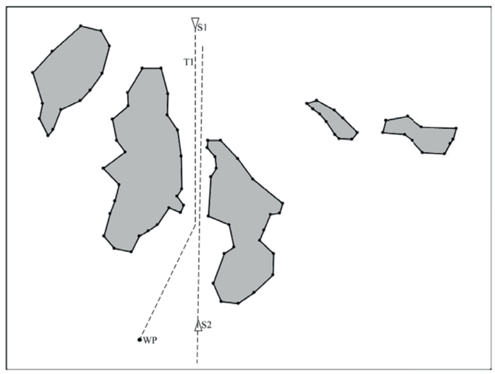

Fig. 5. Situation C [own study]

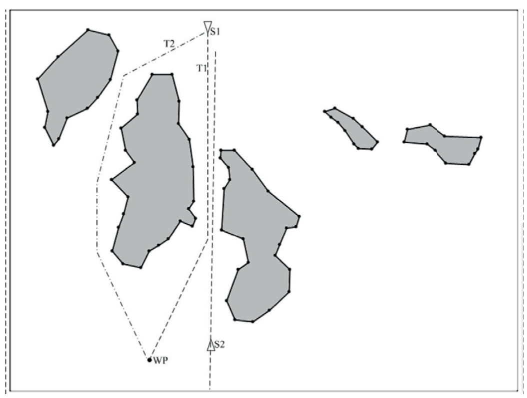

Fig. 6. Situation C – a solution [own study]

This situation is very interesting. We have two objects with practically the same trajectory but opposite directions. It can be seen that there is a fragment with very narrow passage that it's impossible to cross by two objects at the same time. Let's assume that our prediction gave us an information that the collision risk is too high.

There is a couple of solutions. In this paper we propose to find some other alternative routes. As it can be seen if the object S1 chooses the trajectory T1, the collision risk is high. But if it changes its course and chooses T2 trajectory – there won't be any collision risk. This information can be also obtained by prediction.

3.4. Situation D

This situation is similar to the described above but we have an additional object S3. The presence of S3 causes that S1 has to change its alternative course. If it chooses the trajectory from situation C there will be a collision with S3. It can't maintain the T1 trajectory due to the presence of S2, but there exists an alternative solution.

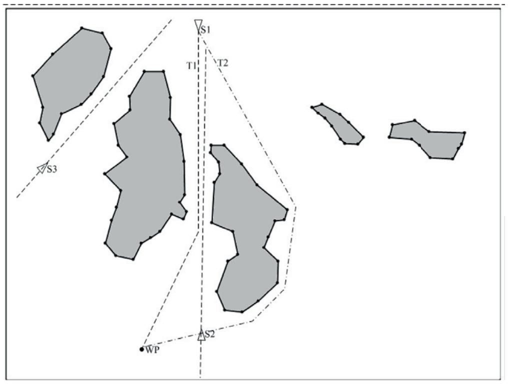

Fig. 7. Situation D [own study]

4. Conclusion

As the conclusion it can be seen that the simple prediction of the movement of objects can be done, using only the linear regression and Pearson's correlation coefficient. When the object changes its course the better way is to create some local models (regression lines) and then observe a correlation coefficient to detect possible maneuvers. Anyway, it is necessary to consider the fact that Pearson's correlation coefficient is sensitive to the data available. It is often used as a significance index and sometimes researchers make some mistakes because this is not a typical tool to detect dependencies between the input and output variables.

If the determination of collision risk is done, there are several ways to maintain the better / safer solution to minimalize the possibility of an accident.

The prediction described in this paper can be a part of the algorithm of shortest path selection which was described e.g. in [3], [4] or [5]. Anyway, there is a need to do some more research in this area and the results seems to be very promising. This type of work could be very helpful for navigators and would become a part of support decision system in navigation (not only maritime).

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