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Using the Monte Carlo method to create probability maps for search and rescue operations at sea

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Abstract
In this article we proposed a probability map that allows for location of the position of survivors. We used a probability model of a survivor drift to create the map. The model is based on the provisions of IAMSAR containing factors like leeway and wind current. Our proposal of utilizing a probability map differs from that shown in the IAMSAR by using other probabilistic methods. We performed analysis of a drifting raft using the Monte Carlo method. The map is closer to reality, since it is asymmetrical and generated by the simulation. However, preparing probability maps might be helpful in SAR action planning.

Introduction

The effectiveness of the rescue operation is dependent on the probability of finding a survivor in the search area. It will take a few hours before the arrival of the unit of the emergency rescue or other vessel designated to start looking. If we know how much time expires between the SOS signal and the beginning of search operation, we could calculate the trajectory of a drifting object and sail to the point where we it should be located. In practice, the calculation and hydrometeorological data are inaccurate. We want to look for a place where you will find the missing object after the elapsed time, starting from the moment of giving the last position. As a result of calculation errors, we will not seek a point, but the area where the missing object can be located. If we add to this area probability density function then we obtain probability map, which will be a much better tool than simply one geographic point.

Determination of the datum point

The starting point of the search and rescue operation is called a datum point, which is drifting away in time (Kasyk & Pleskacz, 2015). Setting a datum point depends on the search unit, hydrological data and the span of time. According to IAMSAR regulations we can calculate the direction of a drift based on a scheme placed in the book IAMSAR vol. II (IMO, 2013). By knowing the maximum speed of the unit that is a crossing point of both the drifting survivor's and search crew's trajectory, we are given the starting point of the search and rescue.

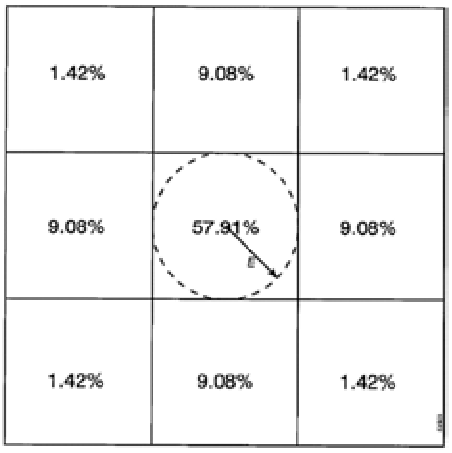

Figure 1. Probability map for a point datum (IMO, 2013)

IAMSAR also reports an error that is made while the calculations are performed. It depends on a few factors, including: determining the speed of wind and determining the influence of the wind current upon speed of wind. As the result, we are given a total probable error of the survivor's position E. Then we are able to create an entry map of probability. This is a map that uses a two dimensional normal distribution where the expected value for the datum point and standard deviation equals E for both coordinates Figure 1). The total probable error of position is used to create this value.

The concept of probability map

A map with the frequency of a given phenomenon has use in many fields. Determining the location of weather phenomena depends on many factors including the accuracy of measurements or lack of it. To determine this, probability calculus and statistic methods are used. We can use prognosis wind direction as an example. This value will be restricted to a selection of the cardinal points on a compass rose (Figure 2). If we assume that the predicted wind direction of 90° = E on the cardinal points scale, the direction is going to belong in the (78°45', 101°15') interval. Because of that, we can calculate the coordinates of the survivor after a given time. Calculating the datum point is only limited to the adoption averaged values. As an outcome, we have optimized the point to start search and rescue, which does not mean that the survivor is precisely there.

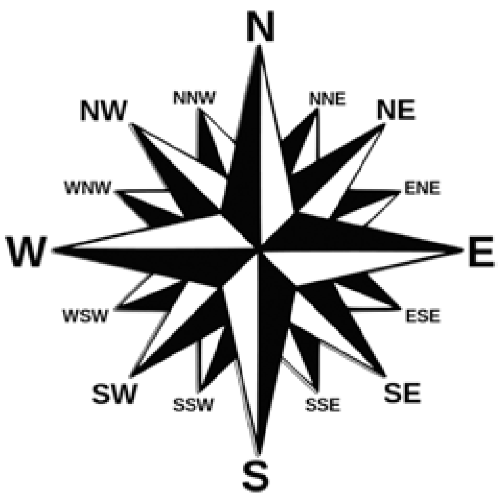

Figure 2. A 16-point compass rose (Wikipedia, 2016)

If we know the hydro metrological conditions, it is good to propose additional analysis regarding this data. In addition to calculating the datum point, we are going to look for the area where the survivor might be located. Next, this area can be divided into smaller sectors and corresponding probability values can be ascribed to them.

Model of survivor displacement

The main tool needed to create a map of probability is probability distributions. All the uncertainties such as the accuracy of measurement, relation between measurable hydrometeorological factors, and the drift of the object will be replaced with probability distributions. For the purpose of this article, we will introduce chosen factors, which will allow creation of the map of probability.

We input the factor of wind, which will affect the drift of the object in two ways. We assume that the wind blows in a specified direction α with a certain velocity V. The direction of the wind will be described using a normal distribution with an expected value α and a standard deviation with a value of half of the cardinal point 11°15'. The wind velocity will also be described using a normal distribution. This wind will generate the wind current and according to the Coriolis force, his direction will be deviated 45° right on the northern hemisphere or left of the southern hemisphere. The speed of the wind current can be calculated from the linear dependency model (Figure 3).

Due to the fact that it is a subject of the lateral drift caused by the wind, the vessel is not moving exactly with the direction of the wind. The velocity of this component of the drift can be calculated using available tables (IMO, 2013) and displayed using a normal distribution. A model of the displacement of the object can then be presented as the assembly

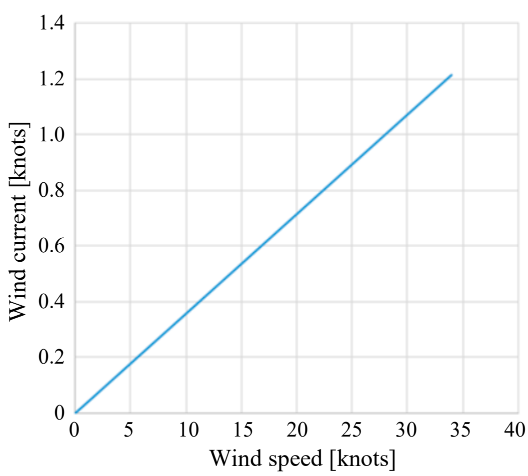

Figure 3. Local wind current graph

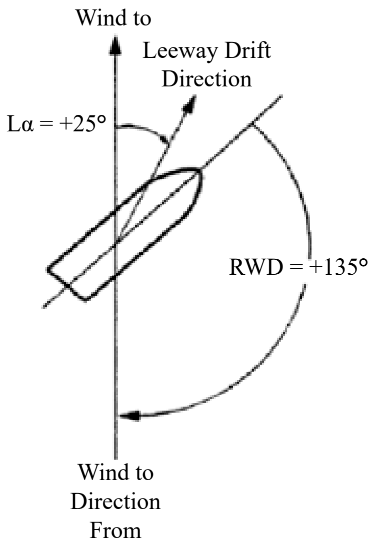

Figure 4. Relationship between Relative Wind Direction (RWD) and Leeway angle (L alpha) (Allen, 2005)

of two vectors. Thus, the vector of displacement is the sum of the wind current vector and direction of the wind vector (Figure 4).

Creating a distribution of probability using the Monte Carlo method

Let's assume that we know details of components describing the wind, which are its direction and velocity. We also know the kind of vessel being searched for, and the amount of time which has passed since the moment that the last known position of the survivor was broadcasted. We will calculate the distribution of probability of the coordinates where the survivor can be at given moment in time. To achieve that, we will apply the Monte Carlo method. Having the model of survivor's movement, we can generate the following. According to the distributions we assumed, we generate the direction of the wind and its velocity. Based on this data we can calculate the lateral and surface drift, which will provide us with a resultant direction of drift and its velocity. We move the starting position with translation by the vector with a direction compatible to the one last received, and a length equal to the product of time that has passed since the broadcast of the last known location and drift speed. All that gives us is a point where the survivor might appear, taking all the predicates into account. We repeat this activity as many times as we want. Having done all that, we created a map consisting of points that created a discrete distribution of the probability of the position of the ship. The more points we generate, the better projection we will get.

Construction of the map of probability

To create a map of probability we need to obtain a distribution of probability of the survivor's position. Thanks to the Monte Carlo method we obtain a discrete distribution, which is why the construction of a probability map will be based on counting the points on it. The first step will be to mark an area that we wish to search. It will be a rectangle covering almost 100% of the distribution of probability. We cannot assume that the probability of containment of a survivor in certain area can be 100%, because with the increase in the number of points, using the Monte Carlo method makes the area of the search grow. That's why we'll apply the three-sigma rule, in accordance with the concept of map creation from IAMSAR. On the basis of randomly selected points, we calculate the expected value and standard deviation. Then we exclude the points that are farther from the middle than the value of three standard deviations. That leaves us with a collection of points in which every single one belongs in the rectangle, in which the sides of the shape are passing through the extreme points of each of the sides. The next step involves the division of the rectangles into parts, which are smaller rectangles of equal dimensions. In each part we calculate the number of the generated points and then divide it by the total number of points. This way we obtain a probability for a survivor to be in each rectangle in a given moment of time.

Example – raft drift

Without decreasing the applicability of the general model, we assume that our survivor is located at the northern hemisphere, and as a point of reference we'll take the starting position (ONM, ONM). Every other point is equivalent with the vector of displacement of the survivor in time. The raft is not equipped with a drogue anchor. We assume that the wind is blowing in direction 0° with a velocity of 20 knots. The average velocity of wind current is $0.714w$, and its average direction is 315°. The second factor is lateral drift, and in this example the direction of the drift is deviated by 25° in relation to the wind current and has an average velocity of $1.34w$. We assume that the standard deviation of this velocity equals $0.25w$ and the time of drift is 1 hour. Then, we randomly select 1000 different sets of data compatible with the model of survivor displacement. Subsequently, we calculate points in which raft will find itself after 1 hour.

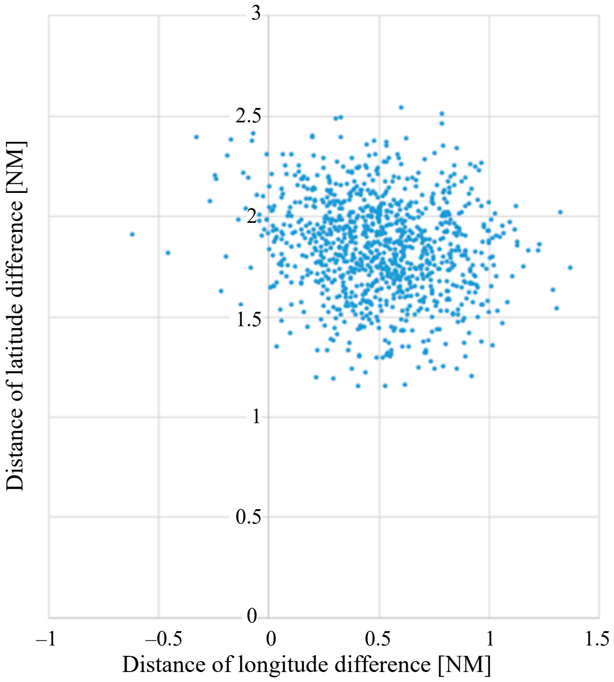

Figure 5. Changing the position of the raft after one hour drift

The Figure 5 shows a distribution of probability of a ships position in relation to the starting point. In accordance with the accepted three-sigma rule, we remove the points located on the extremes. Then we create a rectangle covering all the points save for those removed, and finally divide the rectangle into a grid of smaller rectangles 5 by 5. For every one of those we attribute the quotient of the numbers included in it and sum of all elements on the map.

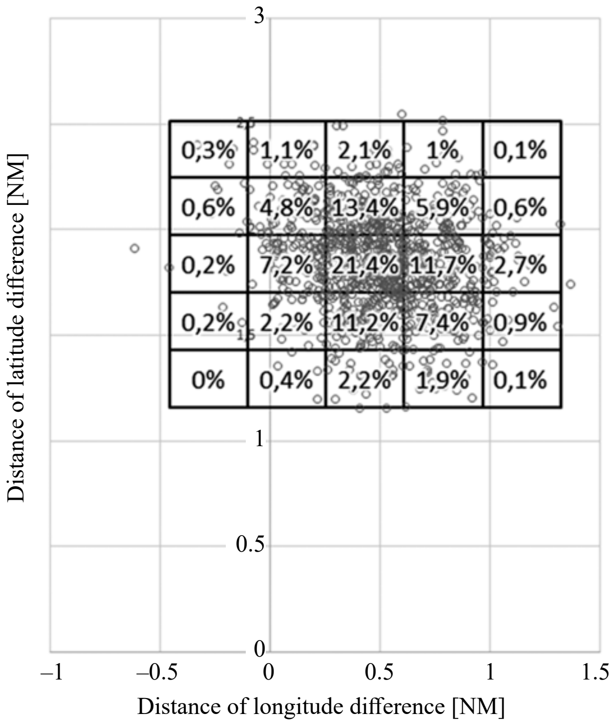

Figure 6. Probability map after one hour drift

As a result, we get a map of the probability of positions of a raft being adrift after 1 hour passes (Figure 6). The dimensions of the map and the passage of time from the starting position were chosen specifically for the requirement of presentation of the map.

Conclusions

The most important aspect of search and rescue operations is their rate capability. Success of those actions depends on many factors (Turner et al., 2007). One critical aspect is very good organization. In order to mount a rescue quickly, one must determine both the place and method of extraction, and for that one needs the proper tools to verify the plan of the SAR operation. There are certain prescriptions on how to proceed when hydrometeorological conditions are adverse, including certain major changes. One must facilitate a starting point for an action and pattern of movement for an object, which is adrift. Having a map of the probability of the potential location of the searched object in question can contribute to having a better planned rescue. That's why it is worth knowing where the probability of finding said survivor is slim to none, and where it is really high. Mounting a rescue whilst using a map of probability can significantly narrow down the area in which we won't find anything. Thus, saved time and resources can be used to search an entirely different area. The proposed map of probability must be developed in many aspects. Specifically, the model of drift included in this article encompasses the important influence of wind. In the next stages, there is a great need to perfect the model, by adding other necessary variables. Further, the shape of the map of probability should also be verified in the future.

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