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# Real-Time Extraction of Course Track Networks in Confined Waters as Decision Support for Vessel Navigation in 3-D Nautical Chart

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## *ABSTRACT*

*In an information design project at Malardalen University in Sweden a computer based 3-D nautical chart system is designed based on human factors principles of more intuitive navigation in high speeds. In this project dynamic NoGo area polygons is generated based on the draught of the individual ship and the current water level and by doing so space is divided into free and forbidden areas. Based on this an automatic wayfinding method is presented in this paper that will allow vessels to enter a goal position and have the system display a path through free water to the goal based on different parameters such as shortest route, most weather sheltered route or route most sheltered from radar detection.*

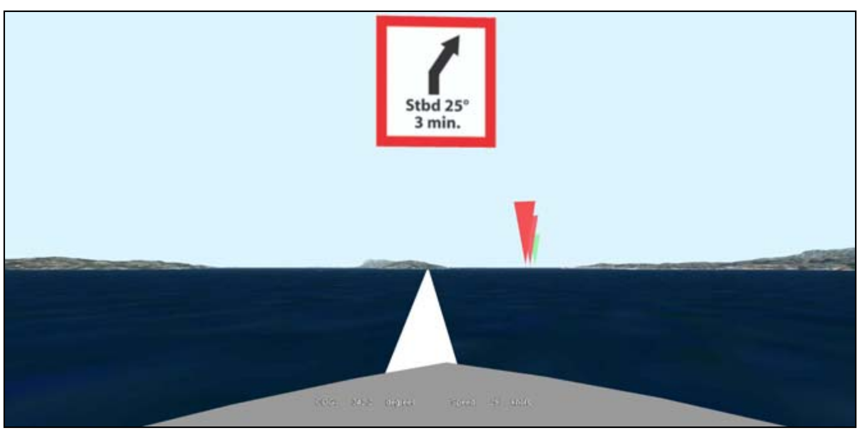


**Figure 1. The track line of an automatic route guidance system presented as a white line to follow to in the egocentric view of the 3-D chart.**

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# 1 INTRODUCTION

In presentations at the 2002 and 2004 workshops, "Massive Military Data Fusion and Visualization: Users Talk with Developers" (IST-036/RWS-005), in Halden, Norway, and "Visualisation and the Common Operational Picture" (IST-043/RWS-006 ) in Toronto, Canada, a decision support system for nautical navigation, a 3-D nautical chart, was suggested [1] [2].

The objective of the 3-D chart is to reduce the cognitive workload of the navigator by presenting map information in a more efficient way. This is done with the help of three concepts: *the Bridge Perspective*, *the No-Go Area Polygons* and *the Dual-Lane Seaways*.

*The Bridge Perspective* allows the map reader to access the map database in an egocentric 3-D view where the perspective of the map is the same as of the world surrounding the ship. Thus the troublesome mental rotations needed are removed. The dynamic *No-Go Area Polygons*, colors water too shallow for the particular vessel at the current tidal level thus dividing the water area in a free and a forbidden area. Finally *the Dual-Lane Seaways* uses red and green "carpets" to present a network of traffic separated seaways to the navigator. The suggested seaways visualises the existing navigational channel infrastructure. These are official seaways based on existing and preferred patterns of sea transportation. In a navy context they could be alternative routes plotted with other objectives in mind. Common for both is that they are defined for a maximum draft of some kind based on some specific water-level. This means that for a particular vessel (with a draft deeper or shallower than the general case) on a particular point in time (with a water level different from the specified) the possible track alternatives might differ. In deep water on the open sea this will be of minor importance as there is always a free set of possibilities. But in the confined waters of a complicated archipelago like the Scandinavian, the situation will be entirely different (see figure 2).

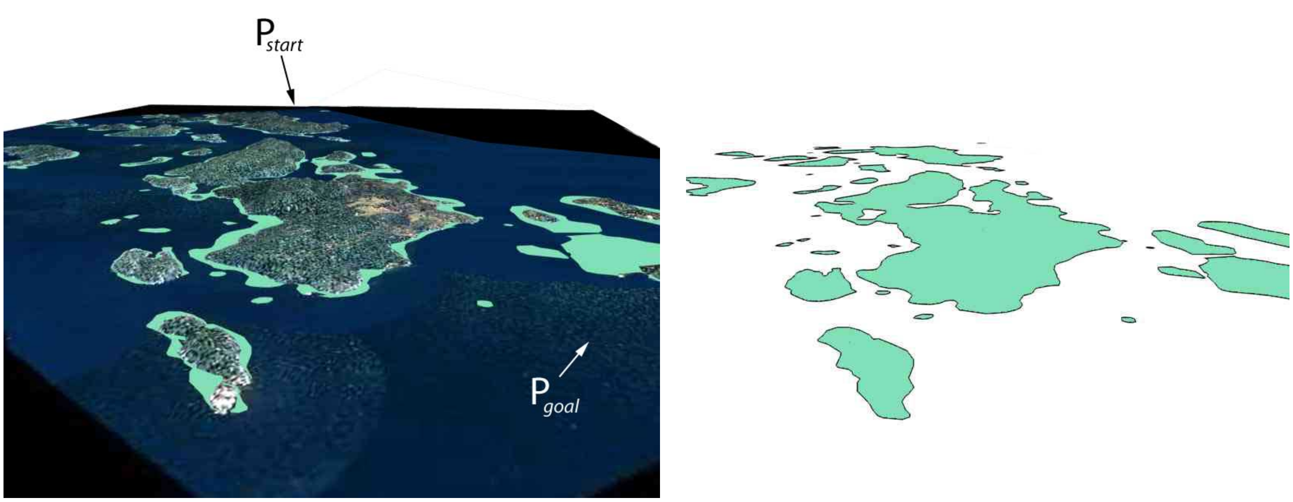


**Figure 2. A section of the Swedish archipelago. Left, a 3-D nautical chart seen from an oblique angle. The green NoGo Area Polygons are generated for a draught of 3 meters and normal water level. Right is the isolated NoGo Area Polygons which defines the so called *work space* with free and forbidden areas.**

The factor that is determining the possibility to travel in a certain area will be the depth of the water. Improving bathymetrical sensing techniques will in the future lead to better resolution of underwater databases. By using the 3-D technique described in [3] a dynamic high resolution depth curve for any depth can be produced in real time. A detailed knowledge of depth, the own ships draught and the water level will safely open new tracks in the archipelago; this will be of particular importance for units trying to avoid detection from different types of sensors or navigating autonomously.

The decision support system basted on motion planning methods from the robotics domain can help the navigator by suggesting different alternative routes to a given goal. The dynamic No-Go Area Polygon transforms a complex real world 3-D space to a simple 2-D planar *work space* with free and forbidden areas. By making a geometrical computation from the present position to a given destination point, the system can suggest different routes to the goal. The alternatives can be computed based on preferences such as shortest route, most weather protected route given wind speed and direction, most sheltered route from a stealth and radar detection point of view based on the height of surrounding islands or under water topography, etc (see figure 3).

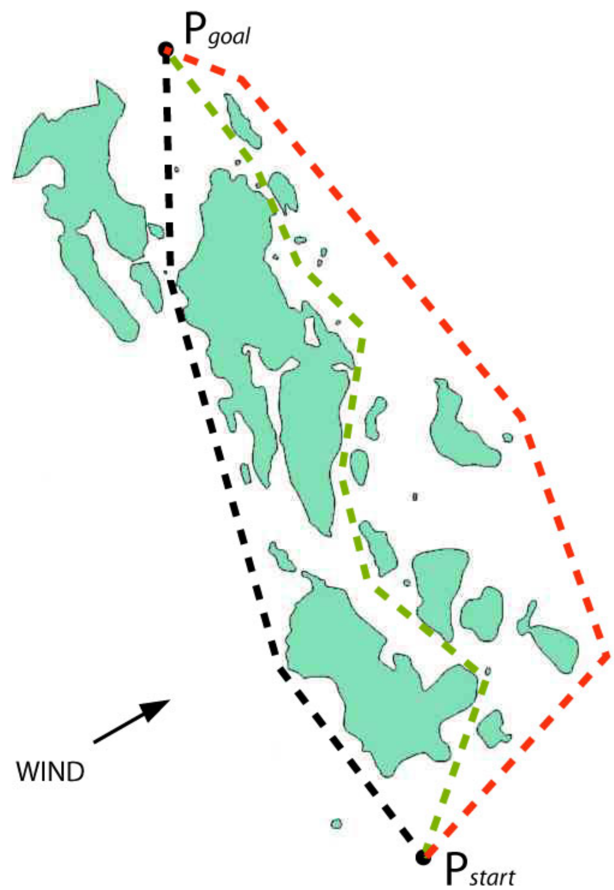


**Figure 3. The work space of figure 1 seen in a north-up orientation. Three different paths from a start to a goal position is suggested, the black path is the shortest, the red path is the fastest and the green route is the most hidden from radar detection.**

From a starting position, P(start), a boat wants automatic route guidance to a goal, P(goal). Through the GPS, the position of the boat is determined. The navigator enters a goal position by clicking in the map or by entering a name or coordinates. The route guiding system then calculates a choice of routes. For instance, in figure 3 the black route is the shortest. However due to wind exposure it may not be the most convenient or the quickest. The red rout with few turns and smooth water will probably be quicker in a high speed boat. The green route is an example of a sneak route close on to land under steep cliffs with deep water outside. This route will probably be best from a signal detection point of view.

After deciding on which track to follow the track will be presented to the navigator in the egocentric view as a white carpet in front of the vessel (see figure 1). It will be dynamically attached to the vessel and recalculated in real-time so that if an evasive maneuver is made the track will compensate for the maneuver and continue to show the way from the new position.

The next section will give a brief overview of the computation methods available in this domain.

# 2 WAYFINDING THROUGH MOTION PLANNING

The task has sometimes been called the Piano Mover's problem and can be described as follows: find a continuous collision free path taking an arbitrary rigid polyhedral object from some initial configuration through a polyhedral environment of obstacles to a desired goal configuration [4].

Over the years the problem of wayfinding for autonomous robots has received a lot of attention. Using a map over a factory space an automatic robot must itself be able to navigate through the facilities without colliding with mapped obstacles (as well as using sensors to avoid un-mapped). The problem has been solved in several different ways and I will here only briefly make an overview of three principal approaches.

## 2.1 Configuration Space Method

The *configuration space* approach uses Minkowski sums to translate the *work space* with the moving vessel into a *configuration space* with a moving point object. If we limit the problem to a translating vessel with only two degrees of freedom, (x, y), the Minkowski sums are generated by offsetting the points of the obstacle from by the points of the vessel (see figure 4). The border of the forbidden space can be visualised as the boundary traced by the reference point of the vessel as the vessel polyhedral is slid along the side of the obstacle, in this case the NoGo area polygon. (For a real vessel operating in three degrees of freedom, translation plus rotation (x,y, $\theta$), the problem will become more complex but the solution will follow the along the same lines.) The objective of this approach is to simplify the solution by computing the path for a singular point instead of a polyhedral.

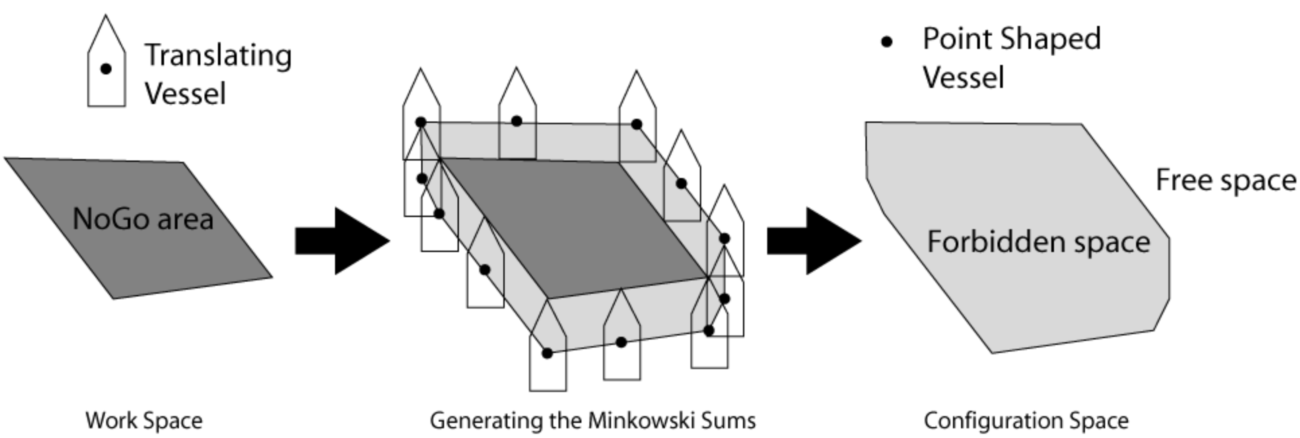


**Figure 4. By using Minkowsky sums the problem of finding a path for a polyhedral vessel in a work space of polyhedral NoGo areas can be reduced to finding a path for a point object in a configuration space of free and forbidden areas.**

The work space has now been translated into the configuration space of free and forbidden areas. The next step is to divide the free areas into a *trapezoidal map* by extending a line vertically up and down from each segment endpoint until it hits another segment or the maps bounding box. The extensions that are inside forbidden areas are then removed. As a result we have a free area divided up into trapezoidal shapes. The next step is to generate a *road map* in the free space. This is done by generating vertices in the center of each trapezoid and in the middle of each trapezoid edge segment neighboring to another trapezoid (see figure 5). The road map is now the network connecting all the vertices and along which the movement of the vessel will be computed using ordinary network analyzes methods. The algorithms for these computations can be found in any book on computational geometry, e.g. [5].

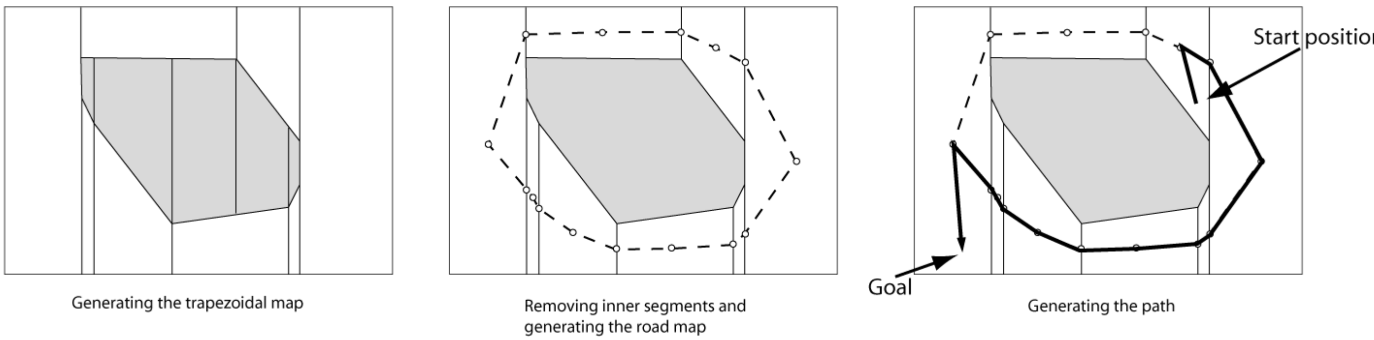


**Figure 5. A road map is generated by dividing free space into a trapezoidal map. This is then used to find a path.**

The path computed by the configuration space algorithm is collision free but the down side is that it may make large detours, which is illustrated in the beginning and end segments of the path in figure 5.

## 2.2 Potential Fields

Another approach of solving the path finding problem is using *potential fields*. By generating a potential field to each NoGo area in the construction space, whose strength diminishes with the square of the distance to the obstacle, any particle moving in this field according to the laws of Newton will never hit an obstacle [6]. By adding an inverted field with a minimum in the goal position and increasing with the square of the distance an object could find a collision free path towards the goal by just seeking a lower potential. However, there is a problem of local minima that limits its usefulness of this method in motion planning tasks.

## 2.3 Real-Time Raster Analyzes

A promising method using hardware accelerated raster technique is presented by Lengyel et al. [4]. Motion planning using this technique promises real-time performance which would allow recalculation of paths during operation, if for instance the vessel is forced to change route.

The method rasterizes configuration space into a bitmap grid. The grid size will then be dependant of the required resolution contra computation performance issues. Higher resolution will give better and tighter paths, but might take longer time to compute.

In the next step a road map is generated, but this time it is no network with a single solution. Instead each grid cell in the free space is assigned a distance value and a direction pointer to the selected goal. A rapid flood-fill technique called *expanding wavefront* solution is used. In figure 6 the distance value and the direction pointer is shown as a number and an arrow in each free grid cell. Since every cell carries a value and a direction, finding the shortest path will be simple. The problem can then be made more complex by adding additional configuration spaces for finding paths protected from signal surveillance, wind exposure etc. But basically different configuration space grids generated from the terrain based on different requirements could be weighted against each other to produce a valid path.

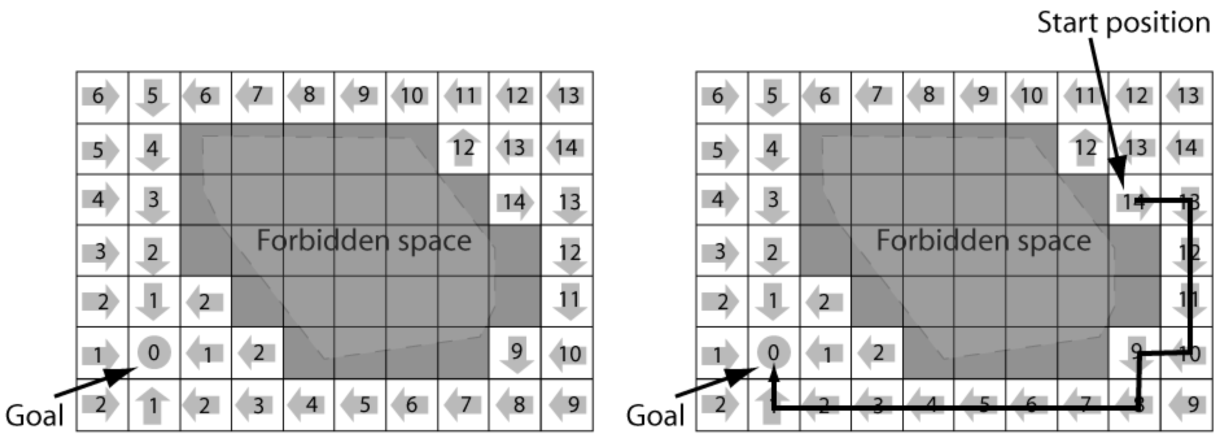


**Figure 6. Configuration space is here rasterized into a bitmap grid of required resolution. For each grid cell in free space a distance value and a direction towards the goal is generated. Path finding is the done by searching for a lower distance value along the stated direction.**

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