A COLREGs-Compliant Local Guidance System for Unmanned Surface Vehicles based on Hierarchical Task Network

Darlan Alves Jurak
School of Technology
Pontifical Catholic University of Rio Grande do Sul
Porto Alegre, Brazil

Abstract

This article presents an implementation of a local guidance system responsible for avoiding possible collision between unmanned surface vehicles being compliant to international marine rules of the road. The implementation is based on hierarchical planning. The development is done using a Java implementation of a domain-independent planning system based on Hierarchical Task Network (HTN).

Introduction

Direct collision between ships represents 60% of the accidents in sea and 56% of the collisions are caused by COLREGs violation (Liu et al. 2016) (Campbell, Naeem, and Irwin 2012). The International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), determine actions that must be followed by maritime pilots for preventing collisions in potential collision scenarios such as crossing, head-on and overtaking.

Unmanned Surface Vehicles (USVs) are autonomous marine vessels that can execute multiple tasks in a variety of cluttered marine environments without human supervision (Manley 2008)(Thompson and Guihen 2018). USVs are characterized by small size, high mobility and good hiding capability; they can be used in many marine applications, including oceanography, remote sensing, environmental monitoring, surveying, weapons delivery, mapping and navigation, along with providing communication support for unmanned underwater vehicles and general robotics research (Thompson and Guihen 2018)(Naeem, Irwin, and Yang 2012).

A current open challenge for USVs is the development of reliable, robust and **full capable** autonomous guidance systems. In general, guidance systems are responsible for both deliberative and reactive motion of a marine vehicle, being implemented respectively by global and local guidance systems.

So, global guidance systems are responsible for global path planning based on already known maps or nautical charts. Local guidance systems are responsible for local path planner based on real-time informations about the environment. In general, local guidance systems actuates on collision avoidance.

Based on the fact that COLREGs depends on human interpretation due to its non-objectiveness, it is a huge challenge for an USV system to be totally autonomous and capable of avoid collision. The main idea of this work is to combat the non-objectiveness of the COLREGs modeling the decision making process of an USV using hierarchical tasks. The **hypothesis** is that the decision making process based on hierarchical tasks is a good way to imitate the human decision making process to avoid collision between ships being compliant to the COLREGs.

In Hierarchical Task Network (HTN) planning, the planning system begins with an initial state-of-the-world and with the objective of creating a plan to perform a set of tasks (abstract representations of things that need to be done). HTN planning is done by problem reduction: the planner recursively decomposes tasks into sub-tasks, stopping when it reaches primitive tasks that can be performed directly by planning operators. In order to tell the planner how to decompose non-primitive tasks into sub-tasks, it needs to have a set of methods, where each method is a schema for decomposing a particular kind of task into a set of sub-tasks (provided that some set of preconditions is satisfied). For each task, there may be more than one applicable method, and thus more than one way to decompose the task into subtasks. The planner may have to try several of these alternative decompositions before finding one that is solvable at a lower level. Unlike classical planning, HTN planning is Turing-complete (Nau et al. 2003).

So, this work focus on the development of a local guidance system for USVs, responsible for reacting to detected dangerous situations as such head-on encounter between two ships, using HTN. The system must generate actions to avoid possible collisions and must be compliant to the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs).

Approach

The main idea is to simulate the behavior of a USV sailing from one location to another. During its navigation another ship will appear and the USV must avoid collision if a possible collision situation is detected. The collision avoidance action must be compliant to the COLREGs.

COLREGs Collision Situations

One possible collision situations, illustrated in Figure 1, is treated in this work: the head-on situation. According to the rule 14 of the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), for the head-on situation the USV must avoid collision changing its direction going to its right side.

Figure 1: COLREGs - Head-on

USV System

It is assumed that the USV system is composed by collision detection system, a navigation system and a guidance system. The collision detection system is capable of detect other ships that appear around the USV and recognize their direction. The navigation system is capable of determine the current position and orientation of the USV in the world. The guidance system of the USV is composed by a global and a local guidance system. The global guidance system is responsible for define actions that keep the USV in the correct configuration to accomplish its mission. In general, the missions consist in going towards a desired location.

The developed local guidance system has the main responsibility of reacting to detected possible collision situations. Therefore, the local guidance system take over the control when any possible collision is detected.

World

The simulated world is described based on a grid representation. Each cell is defined to have adjacency with its neighbors. The position of a cell is composed by the combination of its row and column index. The adjacency of the cells are defined related to the world orientation. Figure 2 shows a example of world of size 3x7, a cell marked in red located in the ”B3” position and its neighbors labeled according to the world orientation.

Danger Zone

Each cell represents a distance of 300 meters in the real world - this value is related to studies(Wang et al. 2011) that indicate that at least 300 meter of distance between two ships with a combined speed of 30 knot (55.56 km/h) is enough for a evasive actions. So, for this work it was defined that the USV must detect that an another ship going against it in a distance between 300 and 600 meters is considered a threat capable of generate collision, and must be avoided.

So, between 300 and 600 meters of distance from the USV any other ships is considered to be in the danger zone. Any distance below 300 meters is considered eminent collision and no action is defined.

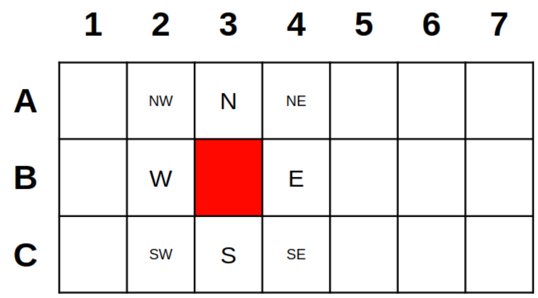

Figure 2: Grid cells and cell adjacency

Hierarchical Task Network

Based on the usage of Hierarchical Task Network planning, the local guidance system is composed by the tasks presented in 3. The main task is the ”Sail” task. From the ”Sail” task three possibilities are tested: 1 - USV has already finished its mission (arrived desired location); 2 - USV has not already finished its mission and there is no possible collision situation detected; and 3 - USV has not already finished its mission and a possible collision situation was detected.

The case where USV has already finished its mission leads to no task. The case where the USV has not already finished its mission and there is no possible collision situation detected leads to: 1 - run the collision detection system. If any possible collision is detected, the USV must let the local guidance system take control; 2 - change current position. If no possible collision is detected the navigation system must keep going toward the target localization. Otherwise, it must let the local guidance system take control; and 3 - Start Sail task again.

The case where USV has not already finished its mission and a possible collision situation was detected leads to: 1 - Identify what type of collision was detected according to the well-known situations described by the COLREGs and then apply the corresponding action; and 2 - Start ”Sail” task again.

Implementation

The implementation is done using JSHOP2. JSHOP2 is the Java implementation of SHOP2 (Simple Hierarchical Ordered Planner). SHOP2 is a domain-independent automated-planning systems. It is based on ordered task decomposition, which is a type of Hierarchical Task Network planning. So, JSHOP2 is modified version of HTN planning that involves planning for tasks in the same order that they will later be executed. The whole task-network presented on Figure 3 were implemented using JSHOP2.

HTN Problem and Domain definition

The JSHOP2 implementation of the problem consists in the definition of two main aspects: the domain and the problem itself. For example, in the problem definition it was de-

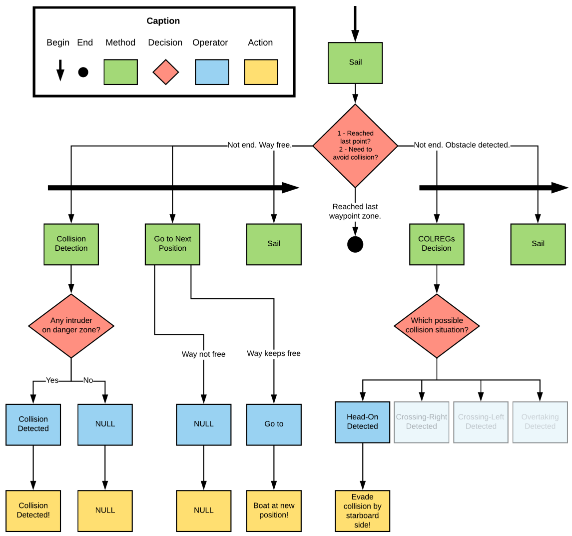

Figure 3: Task Network Diagram

scribed the grid illustrated by Figure 2 and the adjacency existing between the grid cells, which can be interpreted as fact about the problem. Besides, in the problem definition we must declare axioms that define the initial state and tasks that must be executed. In our study, for example, we want that a USV sail to a specific location.

In the domain definition was described all the tasks presented in Figure 3. Following the JSHOP2 syntax, we defined tasks as methods and operators. Methods are tasks that are decomposed in other tasks. Operators are tasks that explicit modify the current state, basically changing axioms that describe the current state. In the most common case each method must be defined as a pair of precondition and task-network. And operator must be defined as a triad of precondition, a list of axioms to be delete, and a list of axioms to be added.

USV Secondary Systems Implementation

The collision detection system was simulated by the analyses of the position of the USV and any other ship in the world and the existing adjacency between the occupied grid cells. The navigation system of the USV is simulated by the unification capability of the JSHOP2 preconditions analyzer. The global guidance system is simulated by the ”going to the next position” task, its current single action is to sending the USV forward.

Experiments

Related to the scope of this work, the experiment purpose consists in validate that the HTN description is correct implementing the task network presented in the Figure 3.

Experiment design

The experiment developed consists on simulate the head-on situation. The world is the same as described in section Approach and it is illustrated in Figure 4. Cells ”A7”, ”B7”, and ”C7” are defined as desired final location to the USV. The initial state is described with the USV at the cell ”B1” and its head orientation is east. An another ship, is located at ”B5”, stopped, and its head orientation is west. At this configuration, when the USV achieve the position ”B3” it must detect a possible collision and avoid collision going to the cell ”C4”. After collision avoidance the USV must keep sailing towards the cell ”C7”.

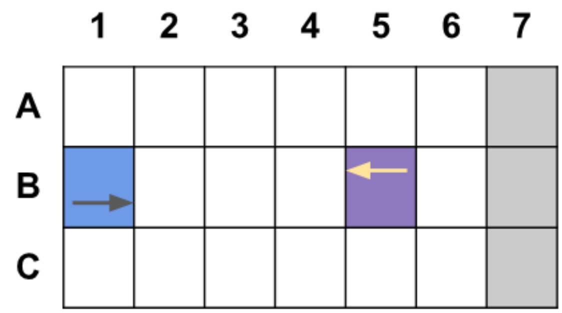

Figure 4: Experiment - Head-on

Experimental Results

The experimental results consists on the defined action by the HTN planner for the head-on situation. Figure 5 shows six 6 steps that illustrate the actions defined by the HTN planner. Figure 6 shows the JSHOP2 output that describes the HTN defined plan.

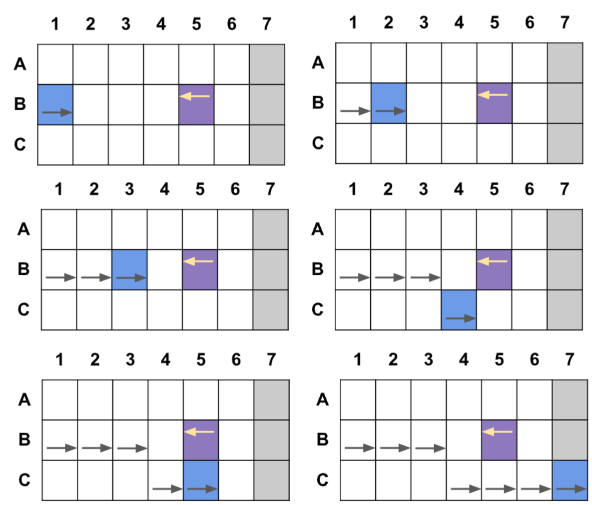

Figure 5: USV motion from initial position to desired final location, avoiding collision with another ship

Related Work

In general, for USV, planning strategies are applied to path search and the treatment of any other decision like collision avoidance, is made by changes in world representa-

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1 ]   (!goto boat1 gc_b1 gc_b2)
2 ]   (!goto boat1 gc_b2 gc_b3)
3 ]   (!collision-detected boat1)
4 ]   (!head-on-detected boat1 e)
5 ]   (!goto boat1 gc_c4 gc_c5)
6 ]   (!goto boat1 gc_c5 gc_c6)
7 ]   (!goto boat1 gc_c6 gc_c7)
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Figure 6: Plan generated

tion or in the path planning itself. Some path planning common applied techniques are genetic programming (Svec and Gupta 2011) (Gupta 2013), A* (Larson, Bruch, and Ebken 2006), Ant Colony (Wang and Cen 2016), Artificial Potential Fields (APF) (Xie et al. 2014), and Velocity Obstacle (VO) (Bertaska et al. 2015). All the cited studies are more robust in the aspect that they treat the world as a continuous space different from this work that simulates a discrete space. The only found study that uses hierarchical planning related to the USV domain, apply this planning technique for controlling a fleet in a mine countermeasure mission (Lesire et al. 2016).

Conclusion and Future Work

In this article we presented a Unmanned Surface Vehicle local guidance system responsible for reacting to possible collisions detect and define a plan to avoid this dangerous situation. The plan generated by the local guidance system is COLREGs-Compliant and it was modeled using Hierarchical Task Network and implemented using JSHOP2. The experiments shows that we achieved a correct behavior treating a head-on dangerous situation. The simulated USV avoided the collision respecting requirements defined in the rule 14 of the COLREGs. Some of the limitation of the present work are:

1. The current local guidance system presented is capable of treat only one COLREGs situation. Future work must expand it to treat at least the four most common collision situations: crossing by right, crossing by left, overtaking, and encounter between different types of ships and USVs.
2. The developed simulation is capable of control the motion of only one ship at a time. Future work could expand it to control several ships at same time.
3. The current sail task is capable of only sailing the USV ahead, according to its own orientation. Future work could expand this functionality to be capable of more complex movement in the world such as follow way-points.
4. Discrete representation of the world, based on a grid. Future work could change the world representation and the USV and other ships localization to a continuous representation.

Future work could also integrate the developed guidance system with most common robotic simulation systems as Gazebo and consider goal recognition to identify the actions of other ships.

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