COLREGS-Based Navigation of Autonomous Marine Vehicles

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Abstract – **This paper addresses the issue of autonomous control and safe navigation in an unmanned marine vehicle. Primarily it is concerned with the issue of effective collision avoidance. The first part of the paper examines known legal issues regarding autonomous marine vehicles, and the second part addresses how to provide an autonomous COLREGS capability in an autonomous marine vehicle.**

I. Introduction

This paper addresses legal considerations of introducing an unmanned robotic vehicle into navigable waters. Categorically, these vehicles include Autonomous Underwater Vehicles (AUV) and Autonomous Surface Vehicles (ASV). Throughout the rest of this document, we will refer to the general class as Autonomous Marine Vehicles (AMV) for simplicity. Inherent to the nature of autonomous craft, these vessels routinely operate with little or no human involvement. They are controlled by on-board computers utilizing "artificial intelligence" and/or remotely operated via a wireless link to a shore based controller. Presently, no precedent exists that clearly defines the legal responsibilities inherent in operating these vessels on and in navigable waters. This discussion is intended to encompass a generic application of appropriate precautions and expectations associated with the introduction of autonomously operated watercraft into navigable waters under U.S. jurisdiction.

We follow this discussion of legal issues with a discussion of a novel method, using behavior-based control and multi-objective action selection, for implementing a "safe-navigation" capability in AMV's based on the International Regulations for Preventing Collisions at Sea [23]. Based on both discussions, it could be argued that such a capability should be a pre-requisite for deploying autonomous marine vehicles, and that such a capability is within reach

II. Legal Considerations

A. Application of the Rules

For purpose of discussion within this paper, it is assumed that the operation of AMV's is considered to occur on and in waters defined as falling within and outside of the COLREGS demarcation line as proscribed by the Convention on the International Regulations for Preventing Collisions at Sea. The US Department of Transportation administers Inland and International rules relating to navigation within and outside of the COLREGS line respectively. Enforcement of these rules is carried out through the US Coast Guard. The rules and regulations affect "all vessels operating on the "high seas" and all waters connected to them that are navigable by sea-going vessels" [10, p6], and are considered to be binding to all vessels within the jurisdiction, and includes all US flagged vessels operating in International waters.

Submarines are not directly referenced throughout the rules, as there are few private (or commercially operated) submarines in existence. The rules do apply to submarines when operating on the surface in the same manner as they apply to surface vessels. In general, where strict compliance is impossible, the Coast Guard typically grants "exemption" status to vessels for "special circumstances" [23], Rule 1(e). It is entirely conceivable that the AUV will be treated in this manner.

B. Admiralty

Admiralty (U.S.C. Title 28) states that the commerce clause [21, p722] alone can provide "sufficient basis for federal admiralty power over some, but not all, matters of a Maritime nature."[2] *Boats And Boating* (American Jurisprudence) informs us that 'the powers of Congress to regulate navigation is based not only upon the commerce clause of the Constitution, but also independently and even more extensively upon the constitutional provision granted in admiralty and maritime jurisdiction to the federal courts, [21], This power to regulate navigation embraces control of the public navigable waters of the United States, extends to all ships navigating thereon, regardless of type, motive, power, or character of their business, and authorizes appropriate legislation regulating their national character and privileges, their form, size, equipment and inspection, their use and navigation, and the officers and seamen employed in their navigation'[3].

[2] US Constitution Article 1 § 8, c 13.
[3] Shipping 1st edition § 8.

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C. Navigation

Navigation is the maneuvering of a vessel on (or in)[4] the water from one location to another in much the same way one operates a car on the roadways. This involves some knowledge of signs, rules of the road, associated maps and the ability to manipulate the controls so as to mobilize the vehicle. Generally, the COLREGS Navigation Rules were written so as to provide guidelines which ensured consistent operating methods intended to avoid collision between vessels.

From the Navigation and Navigable Waters section of the Code of Federal Regulations, we are able to ascertain the full extent of the rules dictating navigation. 'Navigation for pleasure and recreation is as important in the eyes of the law as navigation for a commercial purpose[5]. From CFR 33 section 97.27-10 "Reckless or negligent operation is prohibited by law. " Subsection 13(a) of the act of April 25 1940 (46 USC 526l) reads as follows; 'No person shall operate any motorboat or any vessel in a reckless manner so as to endanger the life limb, or property of any person. To "operate" means to navigate or otherwise use a motorboat or a vessel' (in [25, p 124]), which is a reiteration of the concept of navigation above.

Strict interpretation of these rules implies that every vessel must maintain a lookout at all times. The appropriate rule, in [24] Section 1602, Rule 5, states: "Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision."

Federal statutes, 46 CFR §157, [25] also dictate the number of persons required aboard various vessels. Specifically, "'self propelled, un-inspected passenger vessels shall be operated by an individual licensed by the Secretary to operate that type of vessel." No specific reference exists regarding regulations relative to "unmanned" vessels. Specific safety requirements include "day shapes" and lights which allow other vessels to observe this vessel and navigate accordingly. Specific rules also dictate the behavior which is required of vessels as they come into sight of one another and are approaching a collision course, or overtaking one another. These rules compel the vessels to use sound signals and respond to same in order to allow safe maneuvering. In [24], Section 1602, Rule #1, "Whenever the government concerned shall have determined that a vessel of special construction or purpose cannot comply fully with the provisions of any of these rules with respect to ... lights or shapes ... sound signals, appliances, without interfering with the special function of the vessel, such a vessel shall comply with such other provisions ... as her government shall have determined to be (the) closest possible compliance with these rules in respect to that vessel." It is conceivable that the AMV might slip under a loophole within section (e) above, due to her purpose (typically scientific research) and her construction (autonomous control).

So that all mariners may operate safely when in proximity to one another, a hierarchy of "respect" has been established. Through this order, a vessel can immediately recognize their responsibility to "give way" to another vessel or not. In order from most privileged to least, the list goes; not under command (NUC), restricted in ability to maneuver (RESTRICTED), constrained by draft (CONSTRAINED), engaged in fishing (FISHING), sailing and underway (SAILING), power-driven and underway (POWER), and seaplane underway (SEAPLANE). It would be to the AMV's advantage, therefore, to be classified as a "vessel not under command" at all times. In some sense this seems truly appropriate, because there is no human operator maintaining a lookout, and navigating in the traditional sense. This is not really a practical approach, however, as this classification is generally thought to describe a vessel that is only temporarily without command, either because of machinery malfunction, broken mooring line, or some other unforeseen event. It is somewhat more conceivable that the AMV could be considered a vessel restricted in her ability to maneuver.

It is important to express the significance of the approved definitions relating to some of the terms in the COLREGS. "Underway" means "not attached to the ground, it does not mean moving through the water. 'Making way' means moving through the water [10]. The distinction is significant when considering the responsibility of the vessel in regards to avoidance of collision, and in terms of the necessary day shapes and lights used to identify the vessel's classification.

As a practical matter, it is conceivable that the AMV is really no more than an "obstruction" when operating on the surface, but due to the fact that the vehicle is equipped with propulsive equipment, it appears that these vehicles are obliged to perform according to the COLREGS as discussed above. It would be prudent to make every effort to provide adequate fore-warning to other mariners of the intention to operate the AMV in specific waters. This notification would best be carried out through the Coast Guard's 'Notice to Mariners', so that adequate distribution through standard channels may be made. The Coast Guard requests a minimum of one week's lead time, and would appreciate a month's notice if possible before broadcasting bulletins they receive from mariners. Clearly, these stipulations would not always be reasonable to fulfill during AMV operations.

D. Collision

Let us turn our attention now to the potential consequences of a "tort" which may arise due to the

[4] Guidry v. Durkin, C.A.9 (Cal) 1987, 834 F 2d 1465. (maritime nexus test "on or in" navigable waters)

[5] Grand Rapids v. Powers 89 MICH. 94, 50 NW 661; Mentor Harbor Yachting Club v. Mentor Lagoons, Inc. 170 Ohio St. 193, 10 Ohio Ops 2d 131, 163 NE 2d 1373.

operation of our vessel in navigable waters. As mentioned previously, the navigation rules clearly state that operation of a vessel is to be performed in a responsible and seaworthy manner, so as to avoid collisions, dangerous situations and harm to persons or property. In consideration of the size of the typical AMV currently, it seems very unlikely that damage will be generated by this vessel at the expense of another vessel, but the potential exists, and therefore must be addressed.

Under the section entitled "torts", in *Admiralty,* a short synopsis describes relevant circumstances. 'For purposes of admiralty jurisdiction, two boats regardless of their intended use, purpose, size and activity are engaged in "traditional maritime activity" when a collision between them occurs on navigable waters, since, regardless of size, purpose or activity, boats are governed by the same "rules of the road" as the largest seagoing vessels when those boats are traversing navigable waters.'[6]

An interesting case depicts a situation which could conceivably occur with the AMV due to the "special characteristics" of this vehicle. In this particular legal case, a U.S. navy vessel was navigating in Australian waters at night, and collided with a private vessel. The circumstances were that the navy ship was navigating in a condition known as "blackout" as this occurred during wartime. When a ship is "blacked out", no lights are displayed on deck, no navigation lights are displayed, and any lights visible to the outside are dim and red in color so as to completely shroud the ship from view at night. In this case, the ship was navigating in a harbor under these conditions when it collided with another vessel. The ship maintained that it had the right of way, based on the 'starboard' rule, but the court did not agree. In this case, liability was 'placed upon the "blacked out vessel"'[7] because they had the ability to see other ships without being seen, and therefore had the last clear chance to avoid collision. This is an important point because it relates back to safe operation of a vessel so as to avoid collision and harm to other vessels.

E. Liability and Negligence

The *Public Vessels Act* states that 'collision liability is based on fault, thus negligence must be shown before liability is imposed.' [8] [9] 'Negligent action must be shown ... "unseaworthiness" is considered negligent... and if a vessel is incapable of avoiding collision, then the vessel is deemed "unseaworthy", and therefore negligent.'[10] This last statement would then compel one to believe that it is necessary that the AMV must be "seaworthy" in order avoid accusations during potential legal confrontations.

In the event then, that a situation did arise where negligence was claimed due to the existence of this "unseaworthy" condition, where would the ultimate responsibility lie? Two sources of relevant consideration were discovered which begin to answer this question. The first case involves a corporate owned vessel which collided with an undersea pipeline due to the incompetence of the crew aboard the vessel. In this case, it was ruled that the damages would not be incurred by the corporation which owned the vessel. This decision was reached during appeal of the case, and the basis was that the owners were not aware of the actions being taken by the crew, and were therefore not directly responsible. [11] [12] In a second case, negligence of a master and crew resulted in damages to a dredge being towed astern. Although the negligent parties were deemed to be incompetent, they were not held liable for the damages. This case stated that 'although the vessel must be manned by a competent crew, insufficiency that has no causal connection to damages at issue is not significant.' [13] These cases are included here because they are potentially representative of the vast difference in the likely outcome of any suit which might arise from the introduction of AMV's into navigable waters.

F. Legal Issues Summary

While it has been difficult to conclusively determine the legal ramifications associated with operating autonomous vehicles on and in navigable waters, certain definitive conclusions can be drawn from these discussions.

First, despite the AMV’s unique nature as an “atypical” craft, it very likely qualifies as a “vessel” and is therefore subject to all the laws of Admiralty and its jurisdiction, enforced in the US by the Coast Guard. This implies the conveyance of risk associated with liability as defined in “tort” law that may arise through normal operations which involve damage to persons or property. Legal liability may be conveyed to the owner, the operator and the underwriter. Conclusive determination may not be established until a case of precedence is set in a formal US Court.

Second, the AMV will be responsible for observing all of the standard “rules of the road” as spelled out in the US CFR (COLREGS). Furthermore, as the CFR dictates the necessity for an “able” lookout, the AMV is

[6] Richardson v. Foremost Insurance Co. C.A. La 1981, 641 F 2d 314, rehearing denied 646 F 2d 566, affirmed 102 S.Ct. 2654, 457 US 668, 73 L Ed 2d 300, rehearing denied 103 S.Ct. 198, 459 US 899, 74 L Ed 2d 60.

[7] U.S. v. The Australia Star, 2 Cir., 172 F 2d 472, 475.

[8] Public Vessels Act, § 1 et seq.

[9] 46 U.S.C.A. 781 et seq. Bernert Towboat Co. v. USS Chandler (DDG 996), 666 F. Supp 1454. June 29, 1987 Cir. #86-547-RCB, U.S. District Court, D. Oregon.

[10] 46 U.S.C.A. § 781.

[11] 46 U.S.C.A. § 183 (a).

[12] Union Oil Co. of California v. M/V Point Dover, 756 F.2d. 1223.

[13] D.C. La 1985, Associated Dredging Co. Inc. v. Continental Marine Towing Co. Inc. 617 F. Supp 961.

inherently burdened with a responsibility to avoid collision. In addition, as this is a motorized craft, it is likely to still be seen as the "give way" vessel in many (and perhaps most) circumstances. Additional requirements include the use of lights, day shapes and other methods as spelled out in COLREGS. In any case, the AMV is required to operate responsibly, and more to the point "not in a reckless manner so as to endanger other vessels, people, objects, etc."

Lastly, there may be some possibility of seeking "research vessel" status for certain AMV configurations. This would relax certain lighting and visual aid requirements, but would not relax the requirements for observing the rules of safe operation. Due to the unique nature of the AMV, there may be justification in claiming "special status" with regards to the specific operational requirements, as spelled out in the CFR.

In summary, we see that autonomous vehicles will likely be burdened with the responsibility to observe the COLREGS rules of the road while operating in and on navigable waters of the United States and unless it becomes clearly determined through judicial process, autonomous vehicles will be obliged to take all reasonable steps to observe the requirements for lights, day shapes and "lookout" as defined in the Code of Federal Regulations.

III. AUTONOMOUS COLREGS NAVIGATION

A. *The Challenges of Controlling Autonomous Marine Vehicles*

The problem of controlling an autonomous marine vehicle is magnified in the presence of other nearby moving vehicles. This is true even when the other vehicles are cooperative and have known positions, trajectories and intentions. The challenge reaches another level when one or more of the vehicles are uncooperative, or outright adversarial, with uncertain position, trajectory, or intentions. The following are four aspects of motion planning in the marine environment that reflect the difficulty of this problem

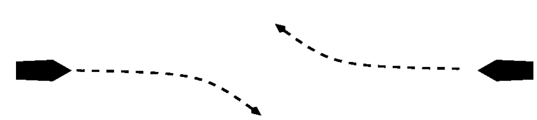
(1) *Collision avoidance is not enough*. A near-miss situation can have negative consequences that may lead to a lack of trust in the control capabilities of an autonomous marine vehicle (the same would be true of a human prone to near-misses).
(2) *Collision avoidance must follow convention*. The responsibility of collision avoidance between two vehicles typically is shared between the controller (human or otherwise) of each vehicle. A significant aspect of this shared responsibility is the expectation of what the other party is likely (or obligated) to do.
(3) *Missions coordinated with collision avoidance*. When possible, control needs to reflect a balance between collision avoidance and the mission being executed by the vehicle.
(4) *Static maps are insufficient*. When obstacles are stationary, they can be represented in a static map of free space. This is not possible when the objects are moving through space and time. Furthermore, the number of distinct states needed to describe the controlled vehicle may grow exponentially with the number of moving obstacles.

B. *The COLREGS Were Written for Humans*

Mastering the COLREGS is an essential part of many types of formal training to become prepared to safely navigate a vessel. The general structure associates prescribed actions to certain situations. The wording is laid out to be as precise as possible in describing what constitutes being in a certain situation, and what constitutes meeting one's obligation in said situation.

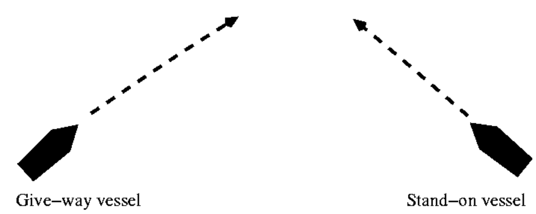
Despite its thoroughness, it depends on a human's ability to use common sense to not only determine if a situation currently applies, but also to exploit flexibility in the actions prescribed in a rule. This is particularly important if more than one rule applies simultaneously (perhaps due to the presence of more than one other vessel to avoid), or in the case where adhering to the rule conflicts or competes with the objectives tied to the overall vehicle mission.

We provide a few of the more common rules below, and discuss the points that rely on human common sense that may be exploited by humans in practice.

Rule 14 "Head-on Situation" International	
(a)	When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other
(b)	Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she could see the masthead lights of the other in a line or nearly in a line and/or both sidelights and by day she observes the corresponding aspect of the other vessel.
(c)	When a vessel is in any doubt as to whether such a situation exists she shall assume that it does exist and act accordingly.
	

Rule 14, simply stated, means "pass on the right", not unlike the convention followed when walking down the hallway, or driving on roads in North America. There is flexibility of two forms in this rule. First is the flexibility of determining when the rule applies, due in part from determining if the two vessels are on a reciprocal course, and in part by the distance between the two vessels. The second form of flexibility is in the form of the action needed to be taken to satisfy the rule. The rule states that course to the starboard is required, but does not specify the angle or ultimate clearance distance required between the two vessels. Clauses 14(b) and 14(c) address the issue of determining if the rule applies to the current situation, but both depend on language that is open to interpretation. It is this flexibility that humans can exploit when they need to by assessing the overall situation and relying on common sense and experience.

Rule 15 "Crossing Situation" International
When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.



Rule 15 addresses the situation when two vessels are at risk of collision by crossing each other's path from the side. It assigns a distinct role to each vessel – one being the "give-way" vessel, and the other being the "stand-on" vessel. (Note that it is possible to be in a situation that could be interpreted as either a crossing or head-on situation).

The primary responsibility of the give-way vessel is to take action to avoid crossing ahead of the stand-on vessel. But note that one could make the case that, if the give-way vessel crosses well enough ahead of the stand-on vessel, then perhaps the risk of collision could be deemed to have never existed. This is one type of flexibility potentially available to the give-way vessel. Rule 16 below clearly allows for further flexibility:

Rule 16 "Action by Give-way Vessel" International
Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear.

Rule 16, unlike rule 14, does not prescribe a particular turn to achieve collision avoidance. In fact, it may just simply reduce speed to let the stand-on vessel pass safely in front. The action that is ultimately chosen, by a human or otherwise, may largely depend on what else the vessel may simultaneously be trying to accomplish in its mission, or may depend on other nearby vessel that require simultaneously collision avoidance considerations.

For the give-way vessel, the choice of a collision avoidance maneuver is greatly simplified if the stand-on vessel holds it course and speed. Rule 17 places just this responsibility with the stand-on vessel. Clause 17(a)(i) is fairly unambiguous. Clauses 17(a)(ii) and 17(b) however provide flexibility if the apparent actions of the give-way vessel are deemed insufficient to avoid a collision. Clause 17(c) indicates that if action must be taken by the stand-on vessel, a maneuver to port should be avoided. The important phrase in this clause is "if the circumstances of the case admit".

Rule 17 "Action by Stand-on Vessel" International	
(a)	(i) Where one of two vessels is to keep out of the way, the other shall keep her course and speed. (ii) The latter vessel may, however, take action to avoid collision by her maneuver alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules.
(b)	When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision.
(c)	A power-driven vessel which takes action in a crossing situation in accordance with subparagraph (a)(ii) of this Rule to avoid collision with another power-driven vessel shall, if the circumstances of the case admit, not alter course to port for a vessel on her own port side.
(d)	This Rule does not relieve the give-way vessel of her obligation to keep out of the way.

Each of the four above rules contains language that is sufficiently precise, but in practice, contains flexibility that can be exploited by the human decision maker. The flexibility is present in both the determination of whether a COLREGS situation exists, as well as in the actions required by the decision maker.

C. The COLREGS in Autonomous Control

The key to providing effective COLREGS capability is to capture both the precision and flexibility of the rules. By *effective*, we mean that the situations where multiple rules are in effect, or situations where rules are in competition with mission objectives, are handled properly and gracefully when there is room for compromise.

The implementation, in short, uses a behavior-based control architecture, with a novel method of multi-objective optimization, interval programming (IvP) to coordinate behaviors. The origin of behavior-based systems is commonly attributed to Brooks' "subsumption architecture" in [5]. Since then, it has been used in a large variety of applications including: indoor robots, e.g., [1, 2, 7, 9, 13, 14, 17, 19, 20], land vehicles, e.g., [16], planetary rovers, e.g., [12, 18], and marine vehicles, e.g., [3, 4, 6, 8, 15].

Action selection, as indicated in Fig. 1, is the process of choosing a single action for execution, given the outputs of the behaviors. The "action space" is the set of all possible distinct actions, e.g., all speed, heading and depth combinations for a marine vehicle.

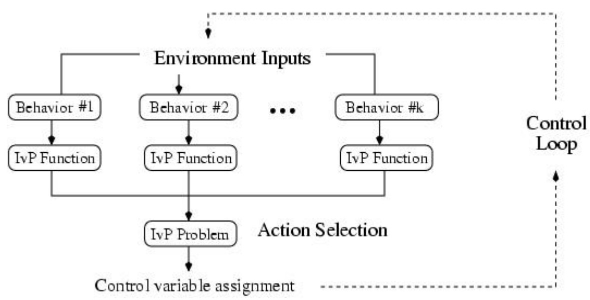


Fig 1: The Behavior-based architecture using IvP Multi-objective action selection.

Each of the COLREGS rules is captured in a distinct behavior that may or may not be influencing the overall control of the vehicle at any given moment. Its influence depends on whether the rule associated with the behavior applies to the current situation. The output of each behavior is an objective function that rates all possible actions with respect to the corresponding COLREGS rule. The details of solving multi-objective optimization problems in the interval programming model can be found in [3].

D. Current State of the COLREGS Project

The strategy for developing COLREGS navigation is to build and test each rule in simulation, and then test these rules on a set of actual autonomous surface craft. The mission driving the vehicle in our test cases is a simple transiting task. The vehicle is given a destination in terms of latitude-longitude, as shown in Fig. 2.

Fig. 2: A head-on situation.

The vehicle is given a commercially available bathymetry map which, in effect, defines its free space and occluded space. A shortest-path algorithm is run once to determine the shortest distance to the destination from all points in the operational area. The transiting behavior generates an objective function at each iteration of the control loop that rates potential latitude-longitude positions, relative to ownship, higher if they represent a shorter detour from the shortest path to the destination. An example of this function is shown in Fig. 3, where black represents more preferable decision.

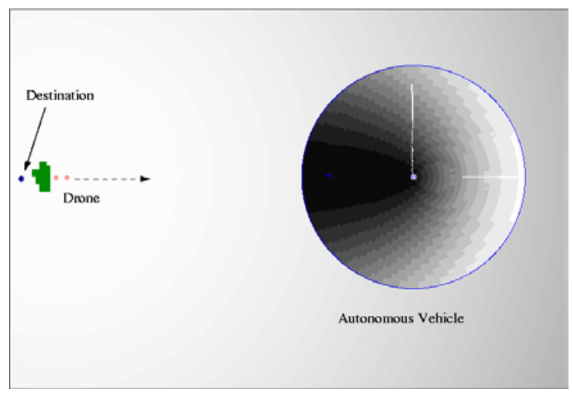


Fig. 3: The shortest-path objective function

The COLREGS behaviors each generate their own objective functions depending on the situation and the rule being modeled. The COLREGS behaviors rate possible vehicle actions in a decision space defined by the decision variables *course*, *speed*, and *intended-time*. Note that this is different than the lat-lon decision space over which the transiting behavior defines its objective functions.

In simulation, the controlled vehicle knows its own position perfectly, as well as the position and trajectory of all other moving vessels. In the in-water experiments, the vehicle knows its own position from GPS, and each vehicle broadcasts its GPS position to each other. Tracking through passive or active sensors is outside the current project scope. The objective function generated by the Rule-14, i.e., head-on situation behavior is shown in Fig. 4.

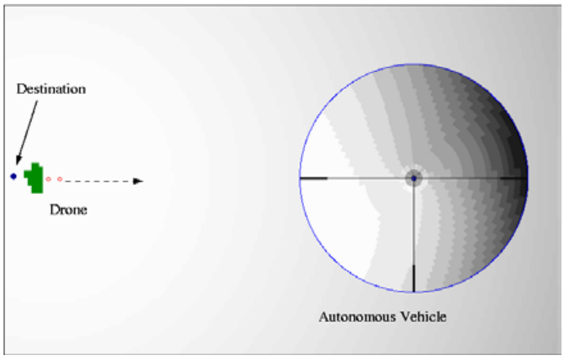


Fig. 4: The Rule-14 objective function

In this figure, black again represents more preferable decisions. Note that this objective function cares not about any progress to the destination. It simply rates maneuvers to the starboard side more favorably. From this behavior's perspective, the best action would be to turn away from the other vessel, but preferably to the starboard side. It assumes the other vessel will stay on a linear track, but will immediately begin to generate different-shaped objective functions should the other vessel change its course.

The overall path of the vehicle is shown in Fig. 5. The shorter intervals between points indicate a reduced speed.

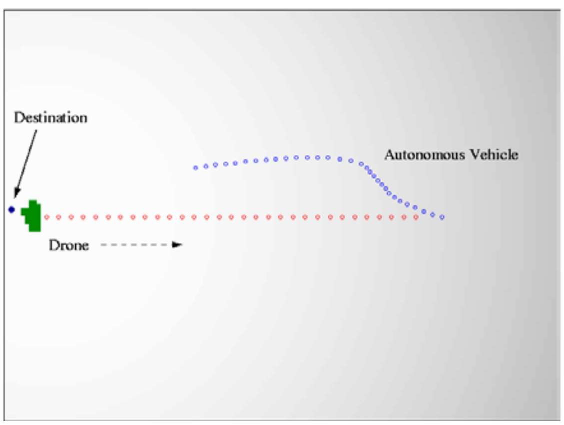


Fig. 5: The overall vehicle path

Since this objective function is defined over *course*, *speed*, and *intended-time*, only a slice is being shown in the figure, for a fixed speed. The outer portion of the function represents a greater intended-time on leg. Note that course changes which run counter to Rule 14, are deemed allowable if made for only a brief duration, and the other vessel is still far enough away. This flexibility, which is not exercised in this test scenario, is precisely the kind of flexibility that is critical in handling situations where multiple vessels are present.

E. Summary and Ongoing Work

The COLREGS are a stable and sufficiently precise set of rules for safe collision-avoidance navigation by a human. Autonomous vehicles will also likely be burdened with the responsibility to observe COLREGS rules of the road while operating in and on navigable waters. This work addresses how to capture those rules in an autonomous control system in a manner that is consistent not only with a human's strict interpretation, but also a human's common sense exploitation of the rule flexibility when appropriate and necessary.

The COLREGS behaviors are being developed in simulation and tested on a set of 4 10-foot autonomous kayaks, shown in Fig. 6.


Fig. 6: Autonomous kayak test platform

All vehicles have a single on-board computer that processes all sensor information and all navigation algorithms. It has access to a GPS system, compass, and various other system monitoring devices. The main computer on each vehicle runs Linux, and the Mission Oriented Operating Suite, MOOS, [11]. MOOS is an umbrella term for a set of libraries and applications designed to facilitate research in the mobile robotic domain. All libraries and applications are written in GNU C++.

Acknowledgment

This work is being conducted jointly between NAVSEA, Division Newport Rhode Island, and Massachusetts Institute of Technology, the Department of Ocean Engineering and the Computer Science and Artificial Intelligence Laboratory (CSAIL). It is funded, in part, by the National Oceanic and Atmospheric Administration (NOAA), and the In-house Laboratory Independent Research (ILIR) program at NAVSEA Newport.

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