Apr 20th, 12:00 AM - 12:00 AM

Statistical Approach to Quantifying Interceptability of Interaction Scenarios for Testing Autonomous Surface Vessels

Benjamin E. Hargis
Old Dominion University

Yiannis E. Papelis
Old Dominion University

Statistical Approach to Quantifying Interceptability of Interaction Scenarios for Testing Autonomous Surface Vessels

Hargis, B and Papelis, Y

Old Dominion University
bharg010@odu.edu

ABSTRACT
This paper presents a probabilistic approach to quantifying interceptability of an interaction scenario designed to test collision avoidance of autonomous navigation algorithms. Interceptability is one of many measures to determine the complexity or difficulty of an interaction scenario. This approach uses a combined probability model of capability and intent to create a predicted position probability map for the system under test. Then, intercept-ability is quantified by determining the overlap between the system under test probability map and the intruder's capability model. The approach is general; however, a demonstration is provided using kinematic capability models and an odometry-based intent model.

Keywords: Evaluation Metrics, Avoid-ability, Simulation

INTRODUCTION
Simulation-based testing of autonomous navigation algorithms is conducted to help provide information to evaluators regarding important qualities, i.e., safety. The algorithms are presented with scenarios in a simulation environment and their performance is quantified by a myriad of metrics to include "avoid-ability". This metric quantifies the ability of a system under test (SUT) to avoid an undesirable situation such as a collision with an intruding vessel. While this measurement is useful, it does not necessarily quantify how difficult avoidance is in the scenario. The paper proposes a method for quantifying an intruding vessel's ability to intercept a SUT in a given encounter.

Scenarios designed to test avoidance capabilities typically designate position, heading, and velocity parameters of the intruding vessel, Stankiewicz, et.al (2019). In Hargis and Papelis (2022), a method was proposed for implementing scenarios deterministically which also designates a window of simulation time within which the encounter is presented. With these design parameters in mind, this method proposes the use of motion capabilities of both the SUT and intruder as well as the estimated intent of the SUT to quantify the intruder's ability to intercept the SUT within a specific time horizon.

METHOD
This method can be accomplished in four stages. First, create a model of the reachable space with respect to the SUT and intruder within the desired time horizon. Second, assign probabilities to the SUT reachable area. Next, create a probabilistic model of the SUTs position intent at the time horizon. Finally, combine and normalize the two SUT models and sum the total probabilities contained within the intruder's reachable space (Fig.1 Right). This results in an interceptability quantification on a scale from 0 to 1.

The reachable area model implemented here uses the kinematic constraints, maximum speed (V_{max}) and maximum yaw rate (ω_{max}), to define the reachable areas (Fig. 1 Left). It can be shown that for a given time horizon (t_h), the left and right straight-line boundaries are defined by an angle δ in equation 1. It can also be shown that the length of these boundaries which also defines the leading curved-edge of the area can be defined by the distance d in equation 2. The resulting bounded region is referred to as the kinematic evelope. This implementation assumes a uniform probability model for the SUT kinematic evelope (Fig.1 Center-Left). The SUT intent model uses the current velocity and yaw rates along with an odometric error model modified from Siegwart et al. (2011) to propogate normally distributed rate uncertainties through time. The result is a probability map (Fig. 1 Center-Right) which represents the probability that the SUT will occupy a specific location at the time horizon.

$$\delta = \pm \frac{\omega_{max} t_h}{2} \qquad [1]$$

$$d = 2 \frac{V_{max}}{\omega_{max}} \sin(\delta) \qquad [2]$$

RESULTS AND DISCUSSION

To demonstrate the method, a contrived scenario consisting of a 90° cross-over interaction is used. The kinematic limations are set to resemble frigate sized vessels, $V_{max} = 15\ m/s$ and $\omega_{max} = 0.03\ rad/s$. The time horizon was arbitrarily selected to be 30 seconds. The inital position of the SUT using cartesian coordinates in meters is [0,0] with a heading of 0 degrees using right handed coordinate frames. Its initial yaw rate and velocity are $0.0\ rad/s$ and $5.0\ m/s$, respectively. The variances of the SUT's velocity and heading are 1.0 m/s and 0.01 rad, The intruder position is [200, -150] with a heading of 90°. The method was implemented using MATLAB 2022b and the resulting interceptablity quantification was calculated as approximately 0.96.

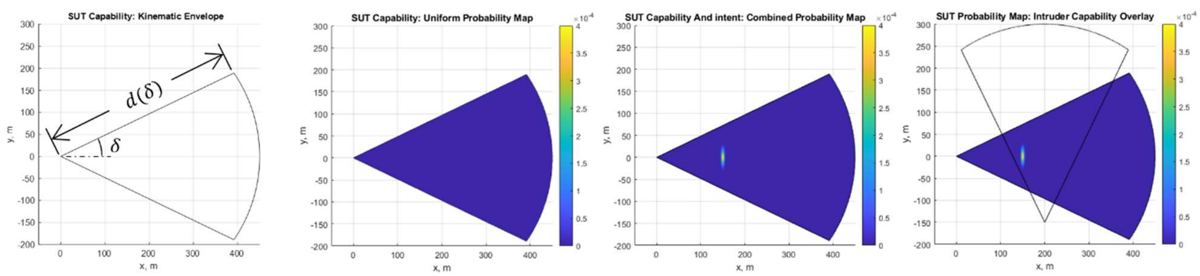

Figure 1. Method Process and Results.

CONCLUSION

This paper presents a probability method for quantifying interceptability. The results of the provided example demonstrate a successful implementation of the method. Despite being demonstrated with relatively simplistic models, the structure of the method is general and could accommodate more sophisticated probabilistic models. The stated kinematic capability model is subject to optimistic assumptions i.e., no external forces. This metric could be used to further inform the performance of SUTs in scenarios by reporting both the SUTs ability to avoid a collision and the Intruders ability to intercept the SUT in the scenario. If an SUT can successfully avoid collision in a scenario with a high interceptability, a clearer picture of the underlying algorithms performance can be had.

REFERENCES

Hargis, B.E., Papelis, Y.E. 2022. Simulation-based approach to synthesizing maritime interaction scenarios for testing autonomy. Interservice/Industry Training, Simulation, and Education Conference 2022.

Siegwart, R., Nourbakhsh, I.R. and Scaramuzza, D. 2011. Introduction to autonomous mobile robots. 270-275. Cambridge, MA: MIT Press.

Stankiewicz, P.G. and Mullins, G. E. 2019. Improving evaluation methodology for autonomous surface vessel COLREGS compliance. OCEANS 2019. 1–7