SeaSafe Simulator

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Motivation

Maritime transportation underpins the global economy by facilitating the efficient movement of goods, with over 80% of international trade conducted by sea. Despite its vital role, maritime incidents remain a critical concern, as human error is responsible for 80–85% of such events. Autonomous vessels can potentially reduce this risk by relying on sensor data and algorithms for real-time decisions. However, any autonomous system must comply with the International Regulations for Preventing Collisions at Sea (COLREG), originally designed around two-vessel interactions. We focus on 3 main scenarios of COLREG: Crossing, Overtaking and Head-on, as shown on Fig.1.

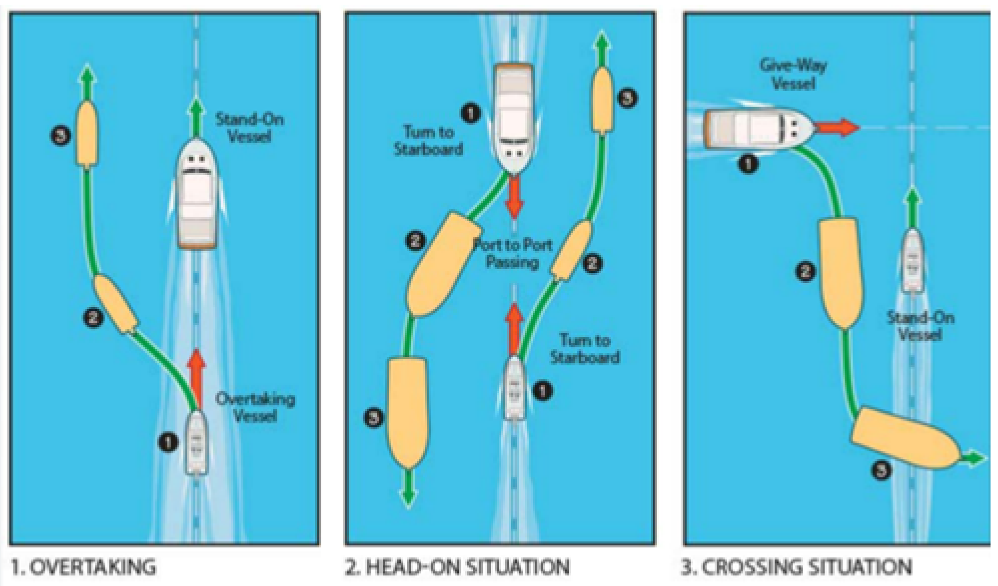

Figure 1. Crossing, Head-on and Overtaking scenarios and how COLREG handles them

This project addresses the challenge of extending COLREG compliance to multi-ship scenarios, ensuring safe navigation in dynamic maritime environments. We develop a collision avoidance algorithm that handle those scenarios. In order to test the algorithm, we developed a simulator using Python, The simulator uses discrete time steps and allows the user to test various scenarios and environments.

Methodology

Step 1: Each time step, the simulator calculates CPA/TCPA for all ship pairs, prioritizing urgent threats by earliest time or smallest distance. If no collisions exist, ships continue forward; otherwise, the algorithm loops through collision resolution.

Step 2: Using the COLREG rules for head-on, crossing, and overtaking scenarios, each pair of ships is assigned give-way or stand-on roles. Typically, the give-way ship attempts starboard maneuvers first; if no improvement in CPA emerges, the stand-on vessel may intervene as a fallback. For crossing situations, the ship that sees the other on its starboard side is the give-way vessel, while in overtaking, the trailing ship must yield. This role-based approach ensures the system remains consistent with the COLREG framework even in multi-vessel interactions.

Step 3: Give-way ships test incremental starboard offsets—up to a maximum heading range—to find the best CPA improvement. After each turn, collisions are recalculated; this may repeat multiple times in a single step. If the give-way fails, the stand-on vessel takes limited action.

Step 4: Once vessels have been collision-free for several steps, they gradually return to their course heading. The process continues until all ships reach their destinations collision-free.

Step 1	Step 2	Step 3	Step 4
Collision detection using CPA and TCPA	Scenario Classification and Role Assignment	Check which action improves the CPA & Apply it	Revert Heading

Results

We present simulator screenshots demonstrating overtaking, crossing, and head-on scenarios, each resolved in full compliance with COLREG rules. Additionally, we include multi-ship scenarios that showcase how the algorithm handles overlapping collisions and incremental maneuvers. These examples illustrate the step-by-step decision-making process, from collision detection to smooth heading reversion.

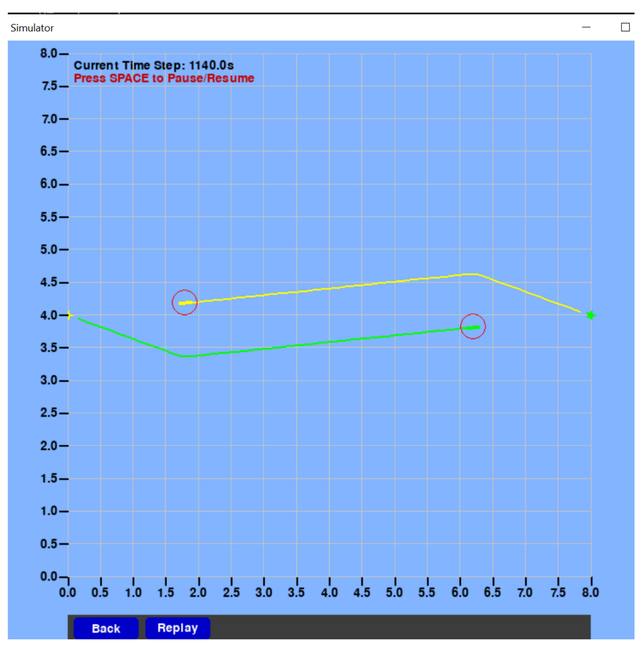

Figure 2. Head-on scenario of 2 ships, both applied with "give-way" role and turn starboard.

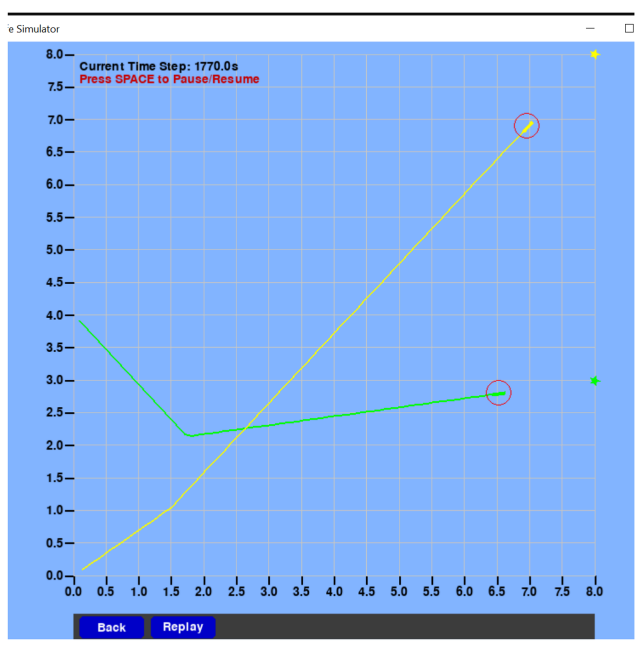

Figure 3. Crossing scenario of 2 ships, green ship is applied with "give-way" and turn starboard.

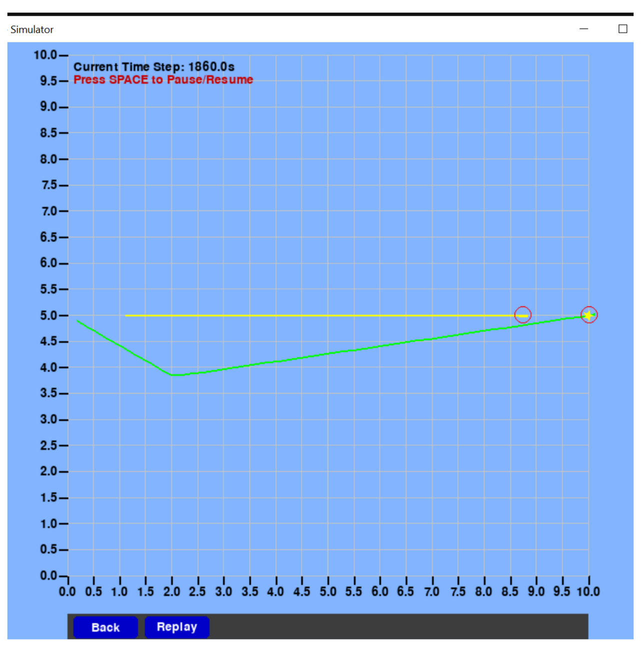

Figure 4. Overtaking scenario of 2 ships, the overtaking ship is applied with "give-way" role and turns starboard to do the overtaking.

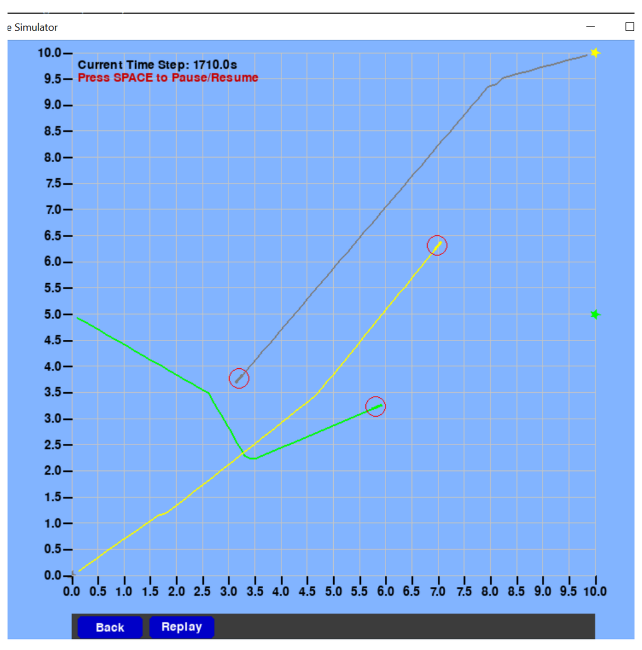

Figure 5. Multi-ship scenario, 3 ships where 2 classified as head-on and one as crossing.

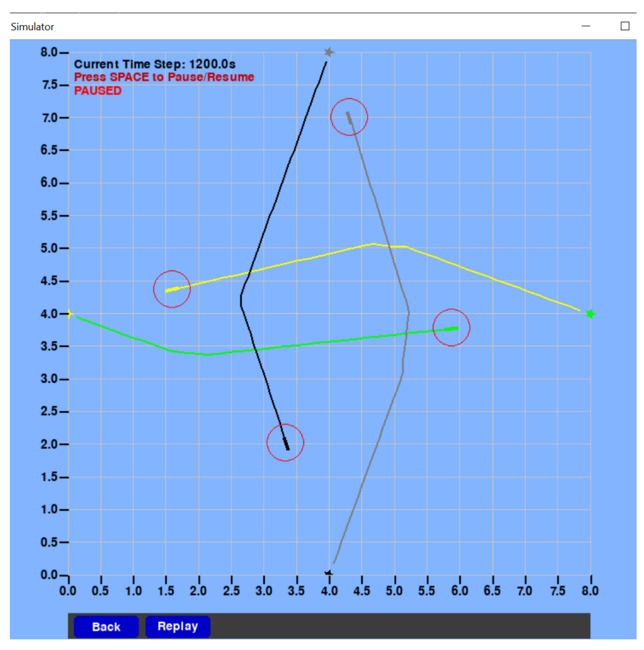

Figure 6. Multi-ship scenario, all ships turn starboard to avoid collision, that behavior is a "roundabout" like.

Conclusion

In summary, this project develops and tests a multi-ship collision avoidance algorithm designed to maintain COLREG compliance in complex, nested collision scenarios. By using discrete time steps and assigning vessel roles, the system detects collisions and applies incremental heading changes, enabling ships to avoid close approaches before smoothly returning to their original courses. Although currently focused on power-driven vessels, the framework can be extended to include variable speeds, and more advanced decision logic, further enhancing safety and autonomy in maritime operations.

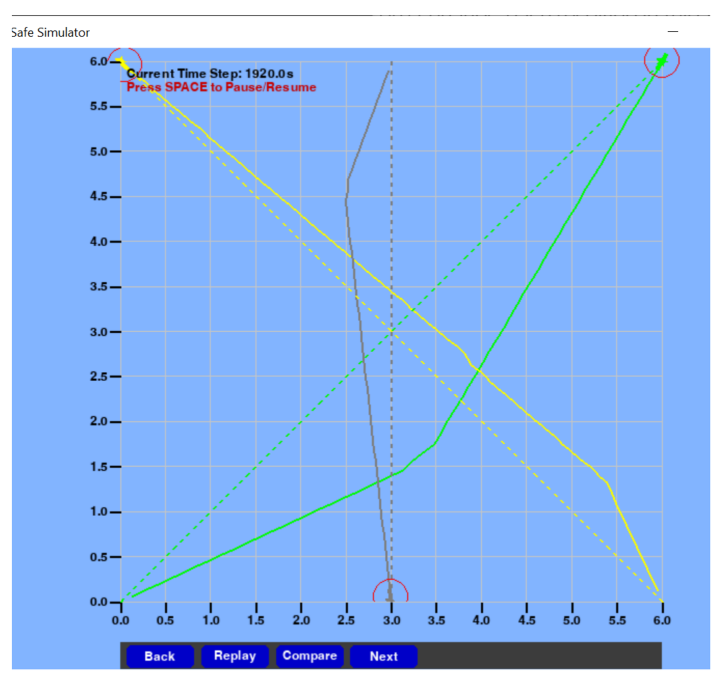

Figure 7. Multi-ship scenario, with original paths to destination