Intelligent Decision Making Framework for Ship Collision Avoidance based on COLREGs

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Outline

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• Intelligent Decision Making Framework.
• Computational Simulations.
• Experimental Results.
• Conclusions.
Introduction

- Conventional maritime transportation consists of human guidance; 75-96% of maritime accidents and causalities are affected by some types of human errors.
- 56% of the major maritime collisions include violations of the (Convention on the International Regulations for Preventing Collisions at Sea) COLREGs rule and regulations.
- Most of the wrong judgments and miss operations of humans at the sea ended as human casualties and environmental disasters.
- Limiting human subjective factors in shipping and replacing them by intelligent guidance can reduce maritime accidents and respective causalities.
- Digital tools that will enhance the navigation safety in shipping.
  - From e-Navigation to Autonomous Navigation.
Objectives

• Autonomous Navigation strategies for shipping
  – **Autopilot Framework** – Deep Learning?
  – **Collision Avoidance Framework**
    – Vessel Traffic Information.
    – Collision Detection.
    – Collision Avoidance.

• Navigational aids from Vessel Traffic Monitoring & Information Systems.

• Collision Detection/Risk under complex ship navigation conditions.

• Intelligent decision-action execution process for collision avoidance among vessels.

• Regulated prevention of collisions in shipping by the COLREGs rules and regulations.
Intelligent Decision Making Framework

• Vessel Traffic Monitoring & Information System (VTMIS).
  − Detection and tracking of vessels, states estimation and navigational trajectory prediction.

• Collision Avoidance System (CAS).
  − Parallel collision avoidance decision making and sequential collision avoidance action formulation.

• Vessel Control System (VCS).
  − Steering and speed control sub-systems.

Collision Avoidance System (CAS)

- **Own-Vessel Communication Module:**
  - Vessel state information collection.

- **Collision Risk Assessment Module:**
  - Relative Course-speed vector and Time and Place until collision estimation.

- **Parallel Decision Making Module:**
  - Fuzzy logic based collision avoidance decision making process.

- **Sequential Action Formulation Module:**
  - Bayesian network based sequential collision avoidance action formulation process.

Collision Detection

- Own and Target vessels maneuvering trajectories.
- Collision detection:
  - Relative course-speed vector.
  - Time and place until collision.
- Absolute & relative vessel positions, velocities and accelerations are estimated by an extended Kalman Filter.
- Relative course-speed vector derivation from relative velocity vectors.
- Target vessel relative trajectory with respect to:
  - Own vessel course.
  - Own vessel heading.
- Cross and dot vector product for target vessel predicted trajectory.

Collision Risk

- Relative bearing vector of Target vessel estimated by Own vessel.
- Relative course-speed vector with respect to Relative bearing vector of Target Vessel can be used to estimate the Collision Risk (CR).
- Relative motions of Target vessel with respect to the heading of Own vessel should be considered.
- Decision making process of collision avoidance under complex navigation conditions.
- The time and place unit collision between two vessels should be estimated.
- This information will transfer to the SAF module.

Decision Making Framework

- **Two vessel** collision situation.
- **Multi-vessel collision** situation is a combination of **two vessel collision** situations.

- Decision regions:
  - Own vessel domain.
  - Target vessel range: 3 Regions.
  - Own vessel collision regions: 10 regions.
  - Target vessel orientation: 8 divisions.

- Decision making framework => **Experienced helmsman actions**.

- **Three distinct situations** involving the risk of collision:
  - Overtaking, Head-on and Crossing.
  - COLREGs Rules and Regulations.
Parallel Decision Making Module

• Fuzzy logic.
  - **Input Fuzzy Membership functions**: Range FMF, Speed Ratio FMF, Bearing FMF, and Relative Course FMF
  - **Output Fuzzy Membership functions**: Course Change FMF and Speed Change FMF

• **Fuzzy rules** are formulated with respect to COLREGs rules and regulations and expert knowledge in Ship Navigation.

• **Mamdani** type Fuzzy inference system.

• **Fuzzy inference** via min-max configurations.

• **Defuzzification** by center of gravity method.

Fuzzy Rule Failures

- To overcome the Fuzzy Rule Inference Failures in the decision making process.
- The solution => Bayesian network.
- Parallel Decisions into Sequential Actions.
- Gaussian distribution type:
  - Collision Risk Function (CRF).
  - Collision Avoidance Action Functions (CAAF).
  - Collision Avoidance Decisions into Actions.
**Sequential Action Formulation Module**

- Network Nodes
- Time until the collision situation
- Collision Time Estimation
- Collision Risk
- Collision Avoidance Decisions & Actions
- Action Delay (Time Delay)
- **Mean and Covariance values** of the CRF and CAAF are updated through the Bayesian network.
- CAAF's are executed on the vessel control system.

Computational Simulation

$V_0 \approx 12\text{Knots}$, $\psi_0 \approx 0^0$, $x_0 \approx 0\text{NM}$, $y_0 \approx 0.43296\text{NM}$, Time $\approx 130\text{s}$
$V_o \approx 11.9258\text{Knots}$, $\psi_o \approx 0.54145^0$, $x_o \approx 0.0010252\text{NM}$, $y_o \approx 1.5836\text{NM}$, Time $\approx 476\text{s}$
Computational Simulation

\[ V_0 \approx 11.9237 \text{Knots}, \ \psi_0 \approx 0.54145^0, \ x_0 \approx 0.014563 \text{NM}, \ y_0 \approx 3.0197 \text{NM}, \ \text{Time} \approx 910 \text{s} \]
$V_o \approx 11.9292 \text{Knots}, \omega \approx 6.6177^0_0, x \approx 0.036601 \text{NM}, y \approx 3.6674 \text{NM}, \text{Time} \approx 1106 \text{s}$
$V_0 \approx 12.002\text{Knots}, \psi_0 \approx 13.1752^0, x_0 \approx 0.10054\text{NM}, y_0 \approx 4.0366\text{NM}, \text{Time} \approx 1219\text{s}$
Computational Simulation

\[ V_0 \approx 12.0402 \text{Knots}, \ \psi_0 \approx 6.8583^0, \ x_0 \approx 0.40724 \text{NM}, \ y_0 \approx 5.6338 \text{NM}, \ Time \approx 1707 \text{s} \]
Computational Simulation

\( V_0 \approx 12.034 \text{Knots}, \, \psi_0 \approx 6.9786^0, \, x_0 \approx 0.53463 \text{NM}, \, y_0 \approx 6.7036 \text{NM}, \, \text{Time} \approx 2030 \text{s} \)

\[ y \ (\text{M}) \times 5 \ (\text{sec}) \]

\[ x \ (\text{M}), \ \text{Collision Risk} \ (%) \times 10^4, \ \text{Course Actions} \ (%) \times 10^4, \ \text{Speed Actions} \ (%) \times 10^4 \]
Autonomous Vessel

• Autonomous Ship represents a scaled self-propelled model of the tanker ship Aurora.

• The model is constructed in single skin glass reinforced polyester, with plywood framings.

• For the reasons of design simplicity, the screw propeller and rudder were manufactured as geosims of the full-scale originals.

• The maximum registered speed of the model is 1.03 m/s which is even higher than 0.983 m/s corresponding to the full-scale design speed 15.5 kn.

Main particulars of the model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall</td>
<td>2.590 m</td>
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<tr>
<td>Length between perpendiculars</td>
<td>2.450 m</td>
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<tr>
<td>Breadth</td>
<td>0.430 m</td>
</tr>
<tr>
<td>Depth</td>
<td>0.198 m</td>
</tr>
<tr>
<td>Draught</td>
<td>0.145 m</td>
</tr>
<tr>
<td>Displacement</td>
<td>0.1156 m</td>
</tr>
</tbody>
</table>
Hardware Structure

- The hardware structure consists of:
  - Command and monitoring unit (CMU)
  - Communication and control unit (CCU)
Collision Avoidance Experiments

- Autonomous Ship in **Collision Avoidance Situations**: the lake of "Lago do Campo Grande", Lisbon, Portugal.
- Onboard CAS: **A scaled version** used during these experiments due to the practical difficulties (i.e. wind and wave conditions).
- Own vessel represented by the ship and the Target vessel was simulated.
- Creating **collision situations** can be extremely difficult:
  - sudden course variations in the vessel due the wind conditions.
- **An additional algorithm** has been developed for the Target vessel;
  - Target vessel searches a proper collision situation with the Own vessel
  - Target vessel implements the course to simulate a collision situation
- **Several collision situations** created and appropriate actions by the Own vessel observed.
- **Target vessel** is moving in **constant speed and course** and not honor any navigational rules and regulations of the sea.
Experimental Results:
Experimental Results:

Own Vessel Positions

Target Vessel Positions

Collision Avoidance Decisions: Speed Control

Collision Avoidance Decisions: Course Control
Conclusions


• Collision Detection:
  – A comprehensive methodology for Detecting Collision Situations among vessels.

• Collision Avoidance:
  – A novel method with Decision Formulation and Action Execution Process for collision avoidance in shipping.

• CAS consists:
  – Fuzzy logic based parallel decision making module whose decisions are formulated into sequential actions by a Bayesian network based module.
  – CAS capabilities of collision avoidance involving multiple vessels, while respecting the COLREGs.

• Successful results in collision avoidance decisions-actions:
  – Computational Simulations.
  – Experimental Results.
Thank You

Questions?