Intelligent Decision Making Framework for Ship Collision Avoidance based on COLREGs

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Nordic Institute of Navigation – Norwegian Forum for Autonomous Ships

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Outline

- Introduction.
- Objectives.
- Intelligent Decision Making Framework.
- Computational Simulations.
- Experimental Results.
- Conclusions.

Introduction

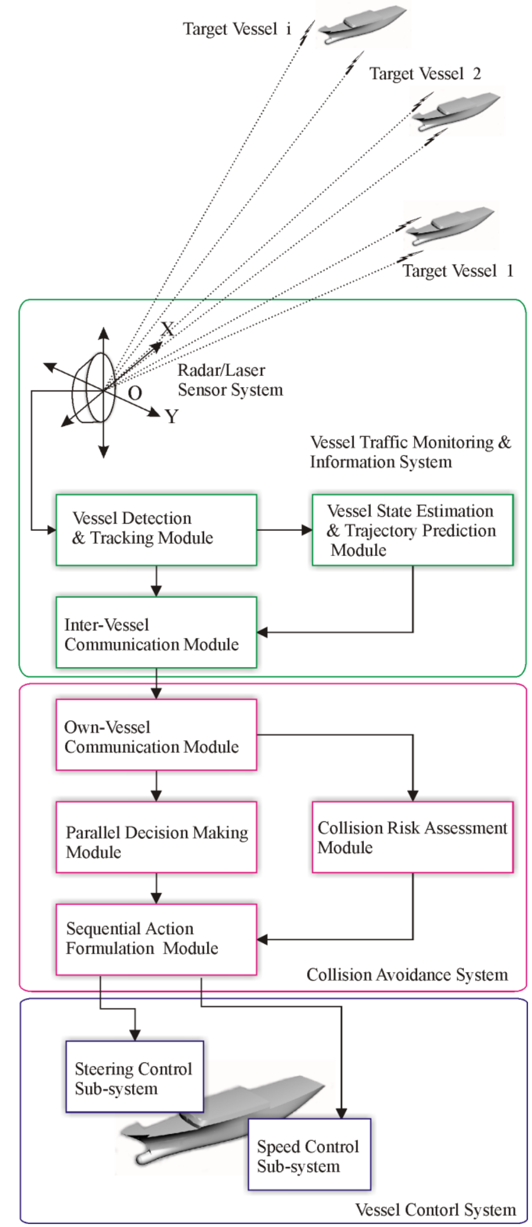
- Conventional maritime transportation consists of human guidance; **75-96% of maritime accidents and causalities** are affected by some types of **human errors.**
- **56% of the major maritime collisions** include **violations** of the (Convention on the International Regulations for Preventing Collisions 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.



(L.P. Perera, P. Oliveira and C. Guedes Soares, "Maritime Traffic Monitoring Based on Vessel Detection, Tracking, State Estimation, and Trajectory Prediction," IEEE Transactions of Intelligent Transportation Systems, vol. 13, no 3, 2012, pp 1188–1200.)

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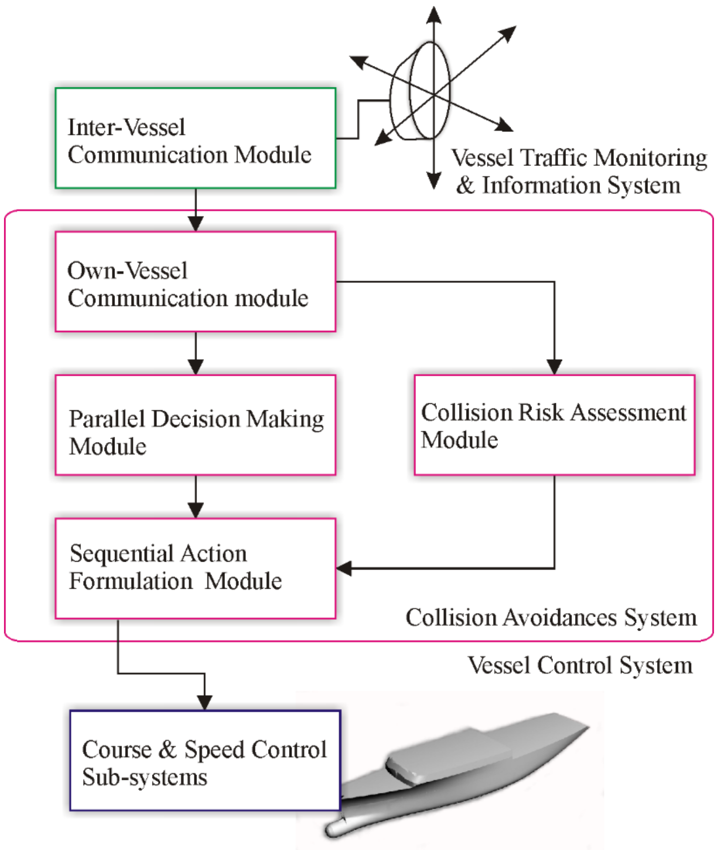
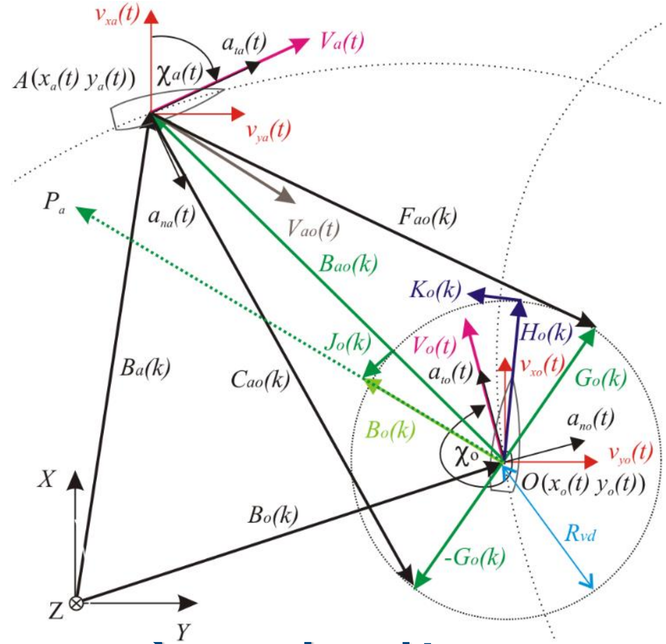
Collision Avoidance System (CAS)

- **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.



(L.P. Perera, J.P. Carvalho and C. Guedes Soares, "Intelligent ocean navigation & Fuzzy-Bayesian decision-action formulation," IEEE Journal of Oceanic Engineering, vol.37, no 2, 2012, pp 204–219)

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.

(L.P. Perera, "Navigation Vector based Ship Manoeuvring Prediction," Journal of Ocean Engineering 2017 (DOI: 10.1016/j.oceaneng.2017.04.017))

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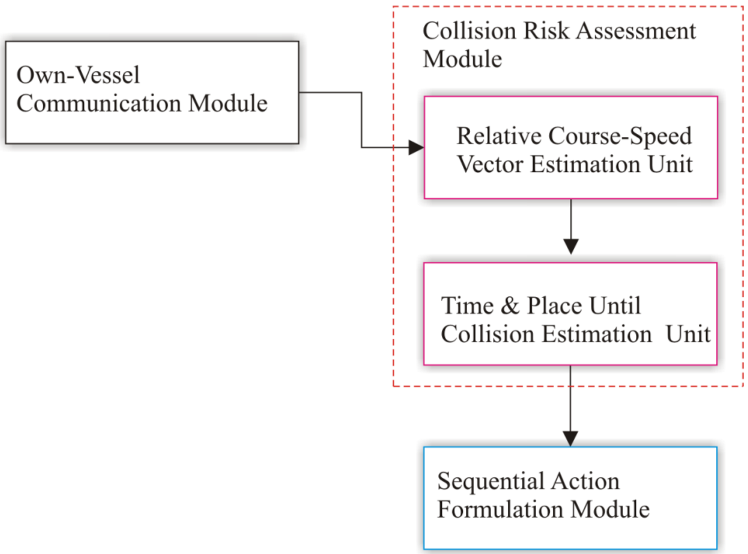
Collision Risk



- 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 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.**

(L.P. Perera, and C. Guedes Soares, "Collision Risk Detection and Quantification in Ship Navigation with Integrated Bridge Systems," Journal of Ocean Engineering, vol. 109, 2015, pp. 344-354.)

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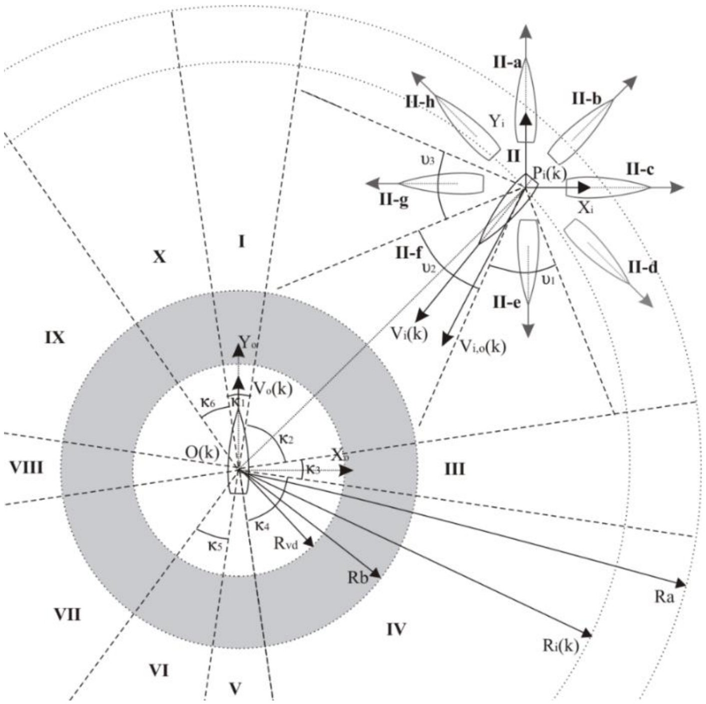
Decision Making Framework



- **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.

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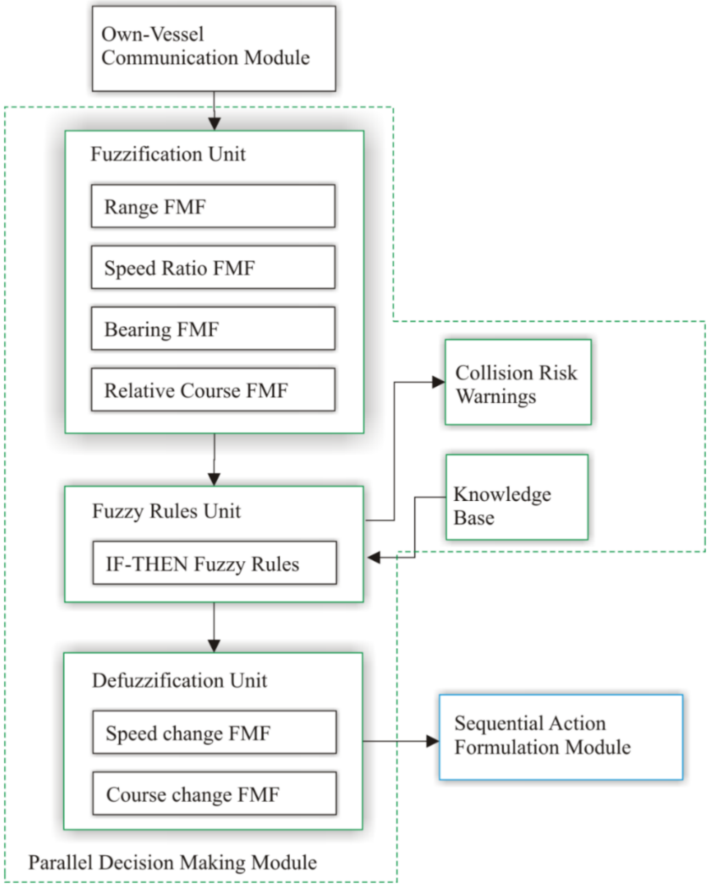
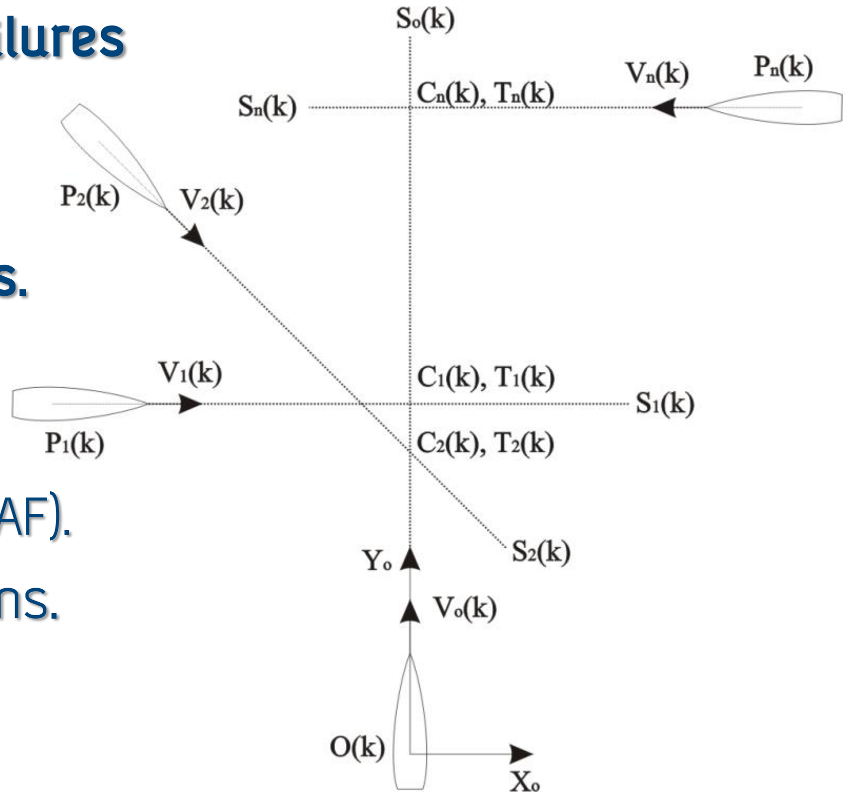
Parallel Decision Making Module

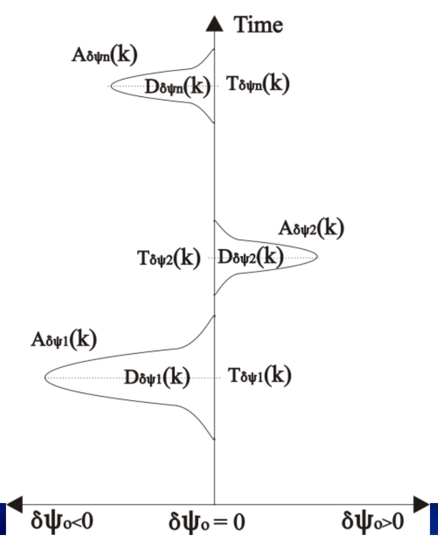
- Fuzzy logic.
  - **Input Fuzzy Membership functions** : Range FMF, Speed Ratio FMF, Bearing FMF, and Relative Course FMF
  - **Output Fuzzy Membership functions**: Course Change FMF and Speed Change FMF
- **Fuzzy rules** are formulated with respect to **COLREGs rules and regulations** and expert knowledge in Ship Navigation.
- **Mamdani** type Fuzzy inference system.
- **Fuzzy inference** via **min-max configurations.**
- **Defuzzification** by center of gravity method.



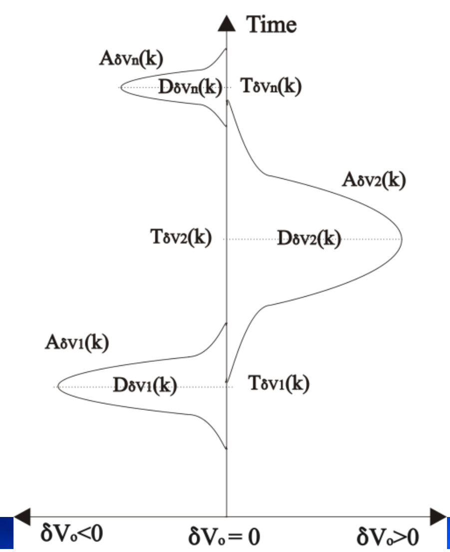
Fuzzy Rule Failures

- **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.





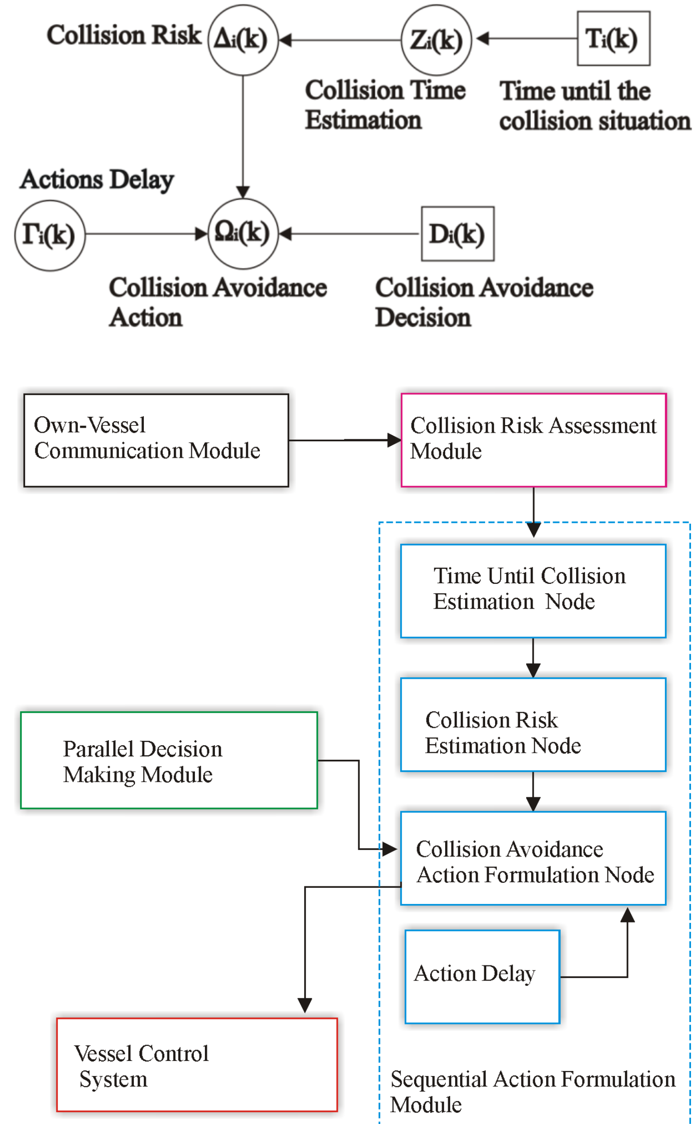
Course change action space



Speed change action space

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.
- CAAFs are executed on the vessel control system.



(L.P. Perera, V. Ferrari, F.P. Santos, M.A. Hinostroza, and C. Guedes Soares, "Experimental Evaluations on Ship Autonomous Navigation & Collision Avoidance by Intelligent Guidance," IEEE Journal of Oceanic Engineering, vol. 40, no. 2, 2015, pp 374-387.)

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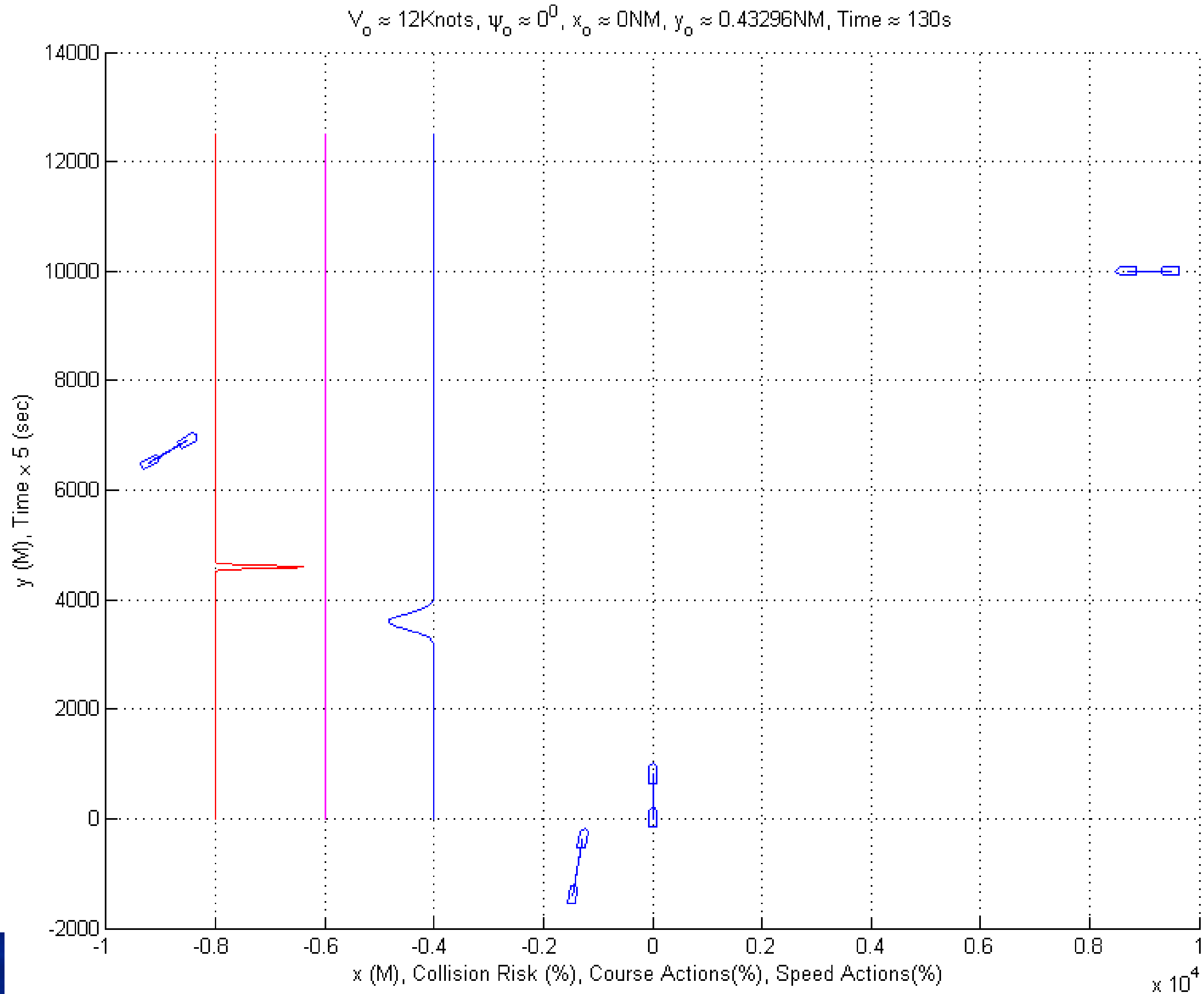
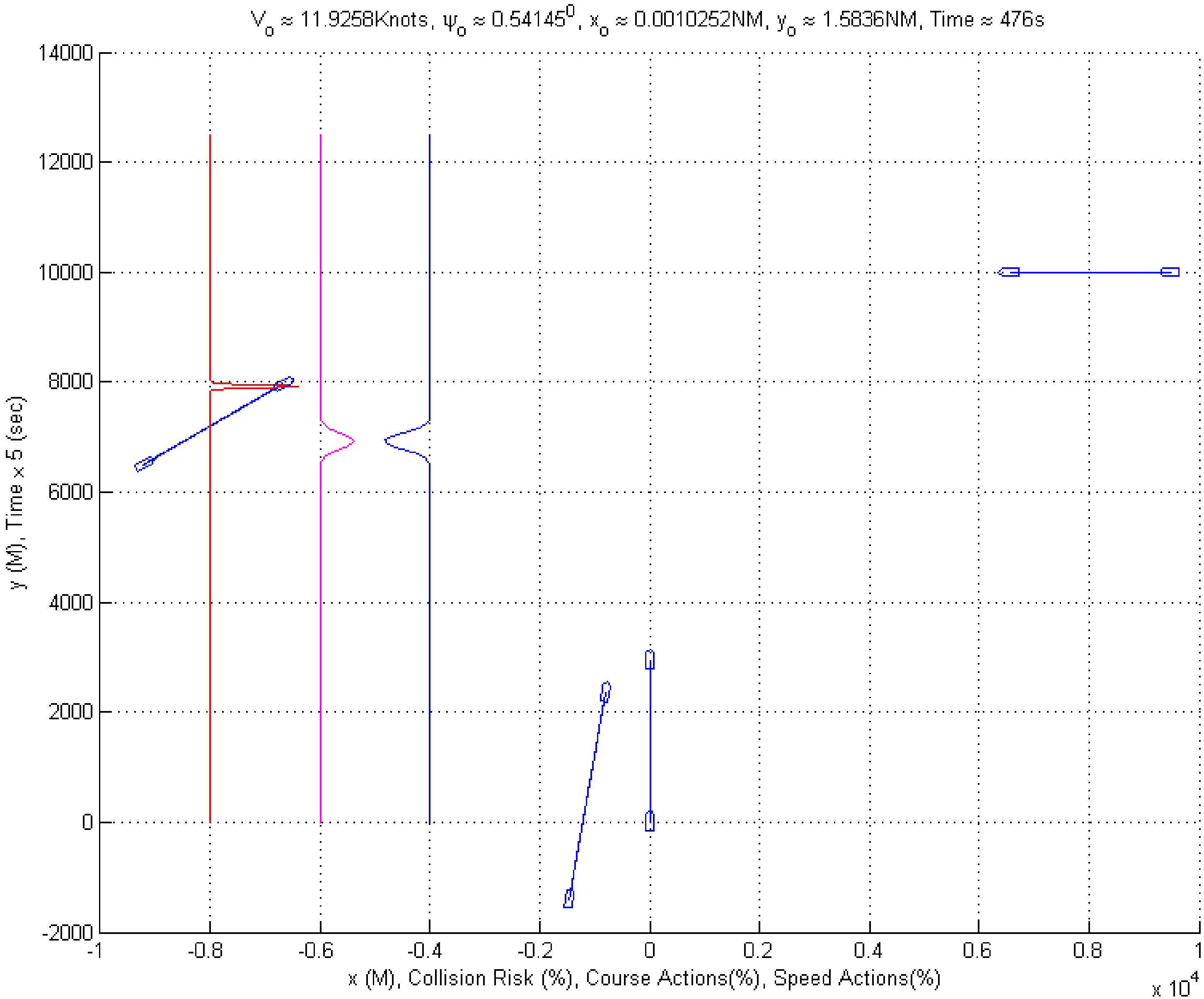
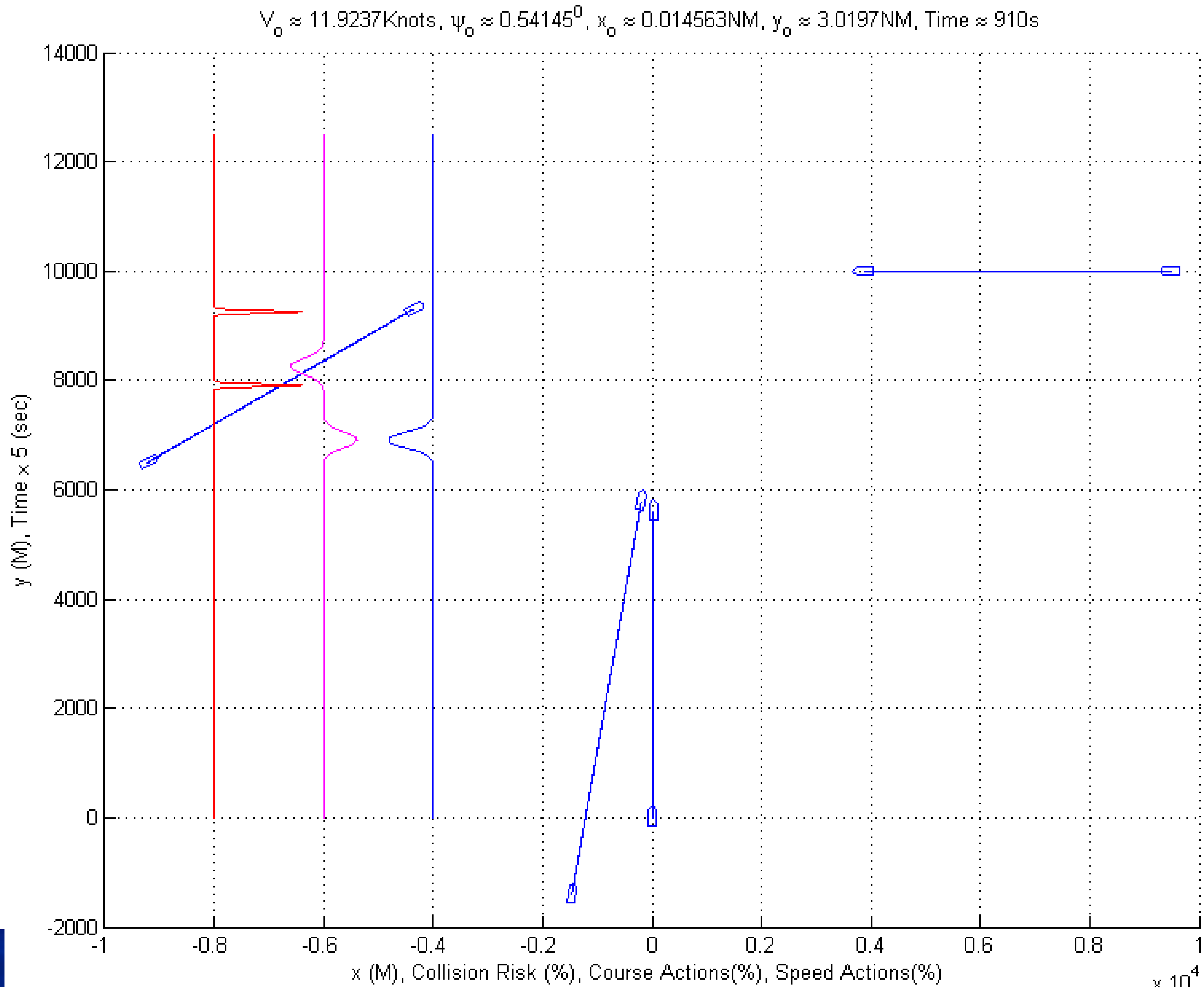
Computational Simulation



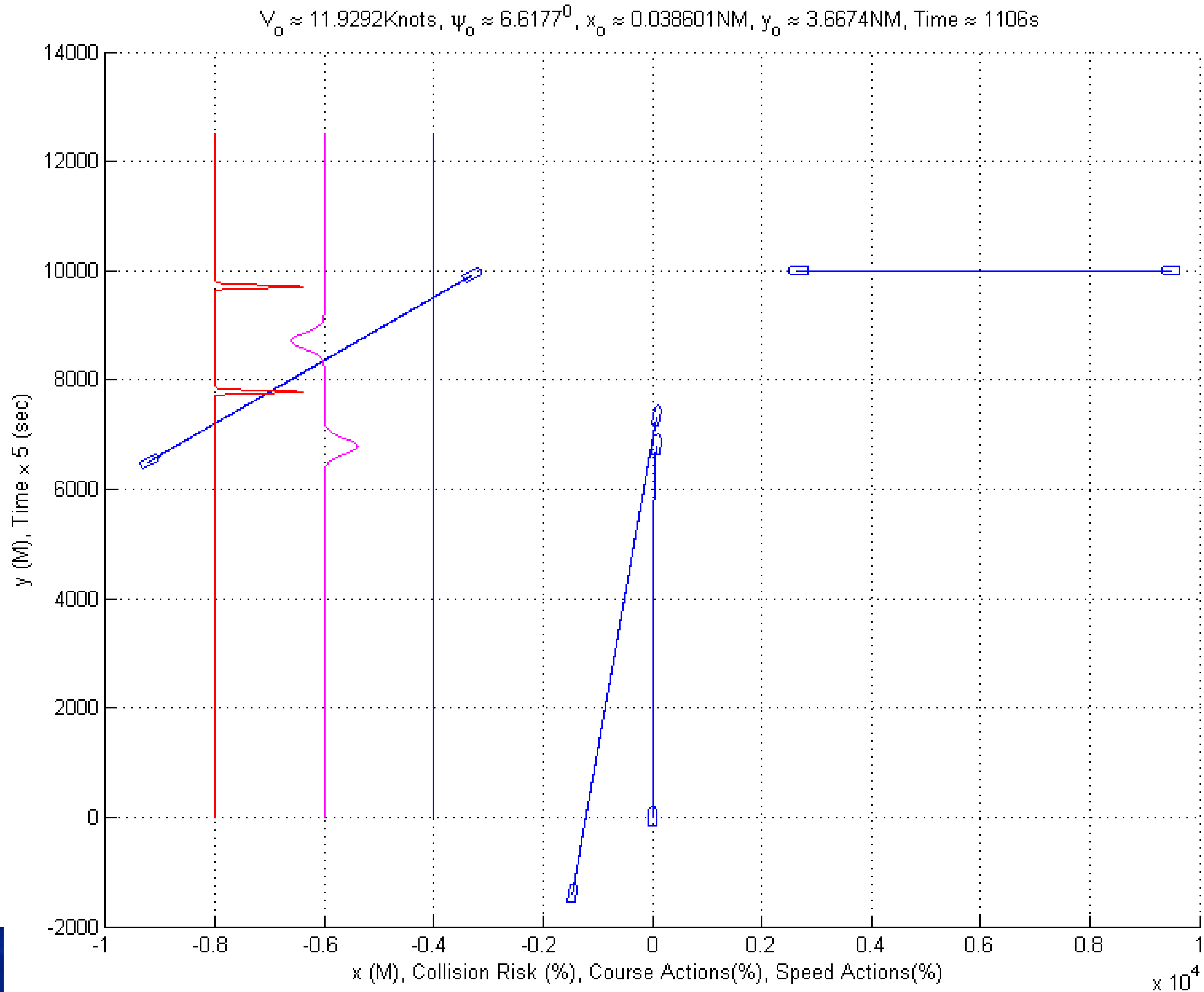
Computational Simulation



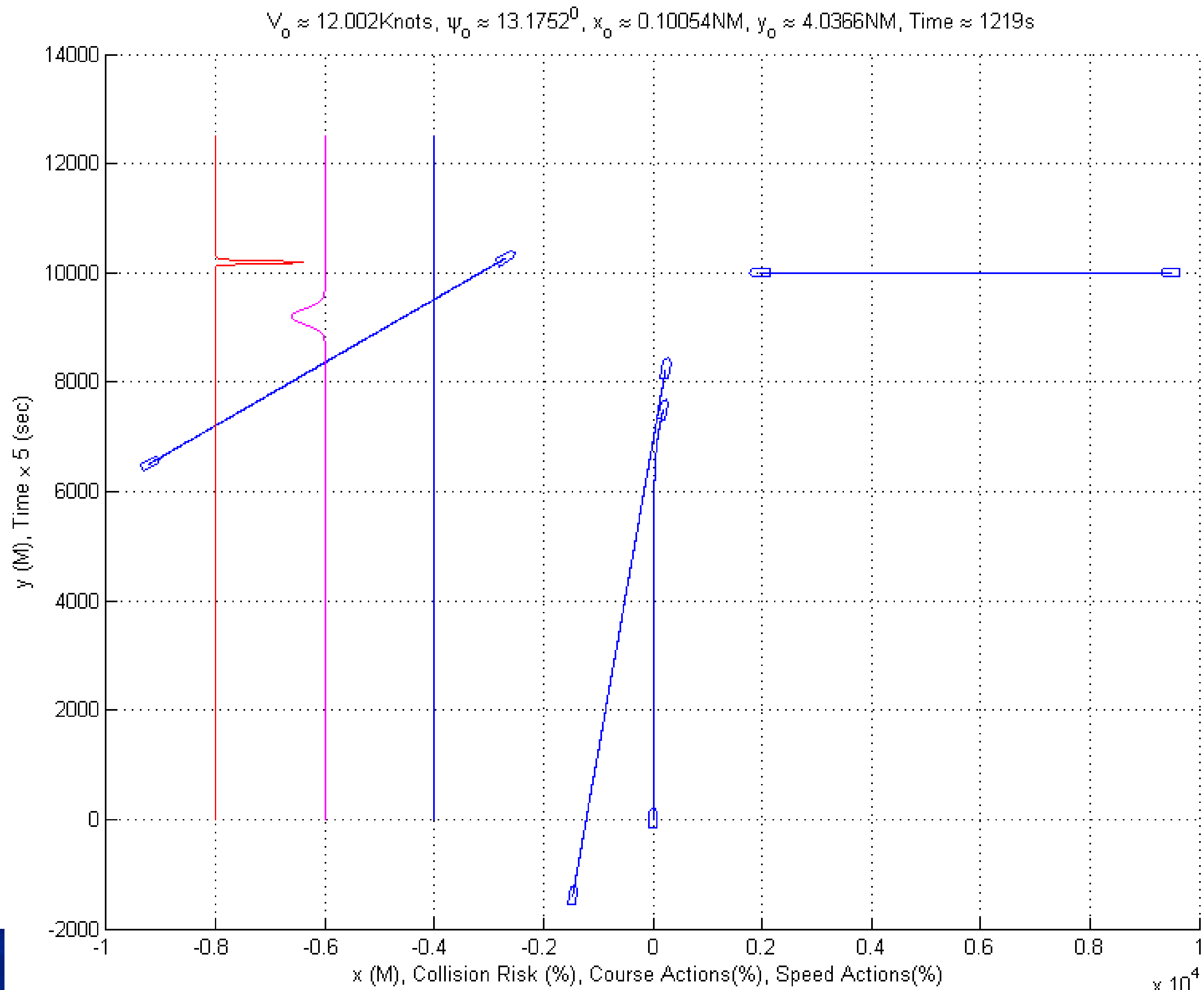
Computational Simulation



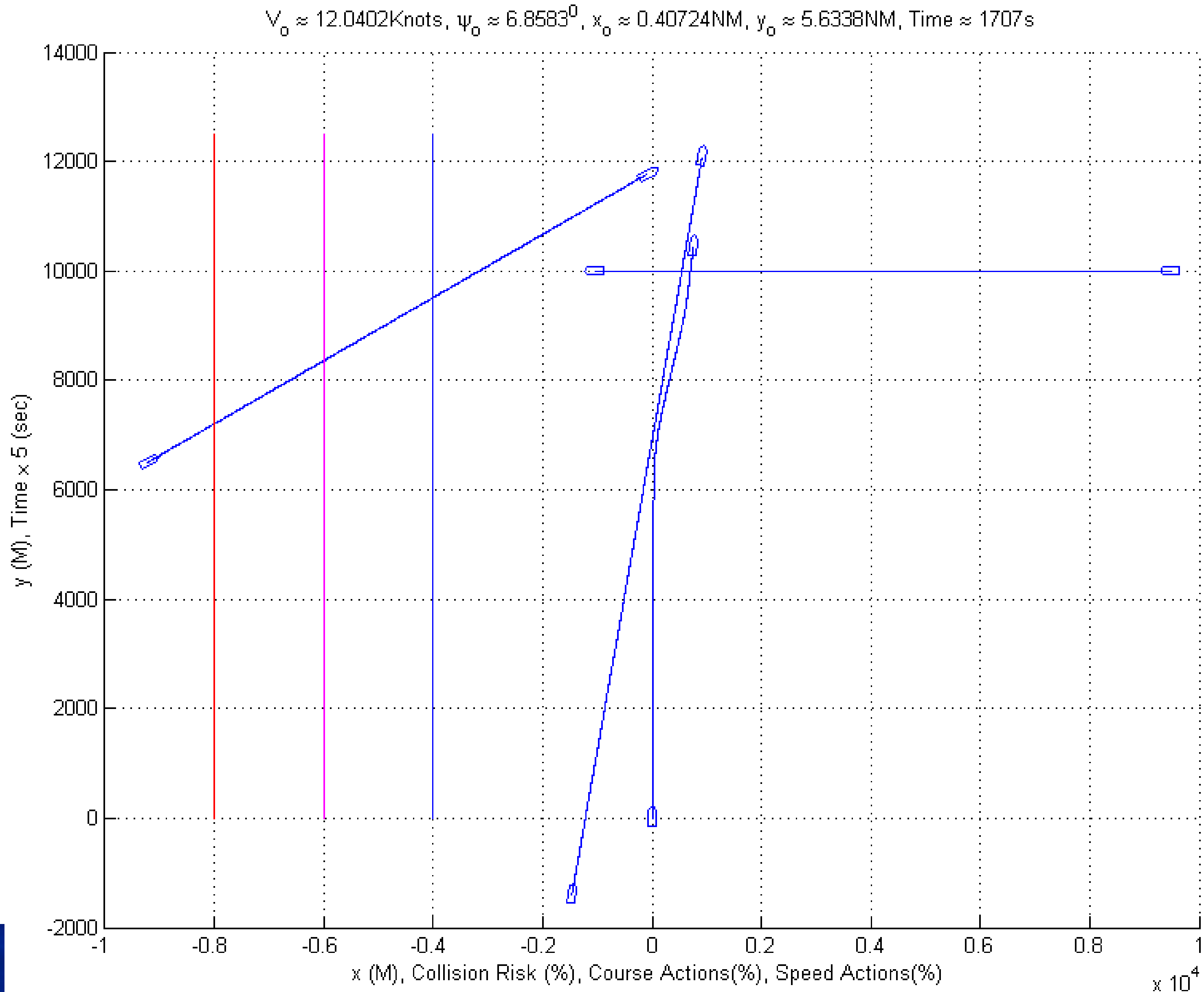
Computational Simulation



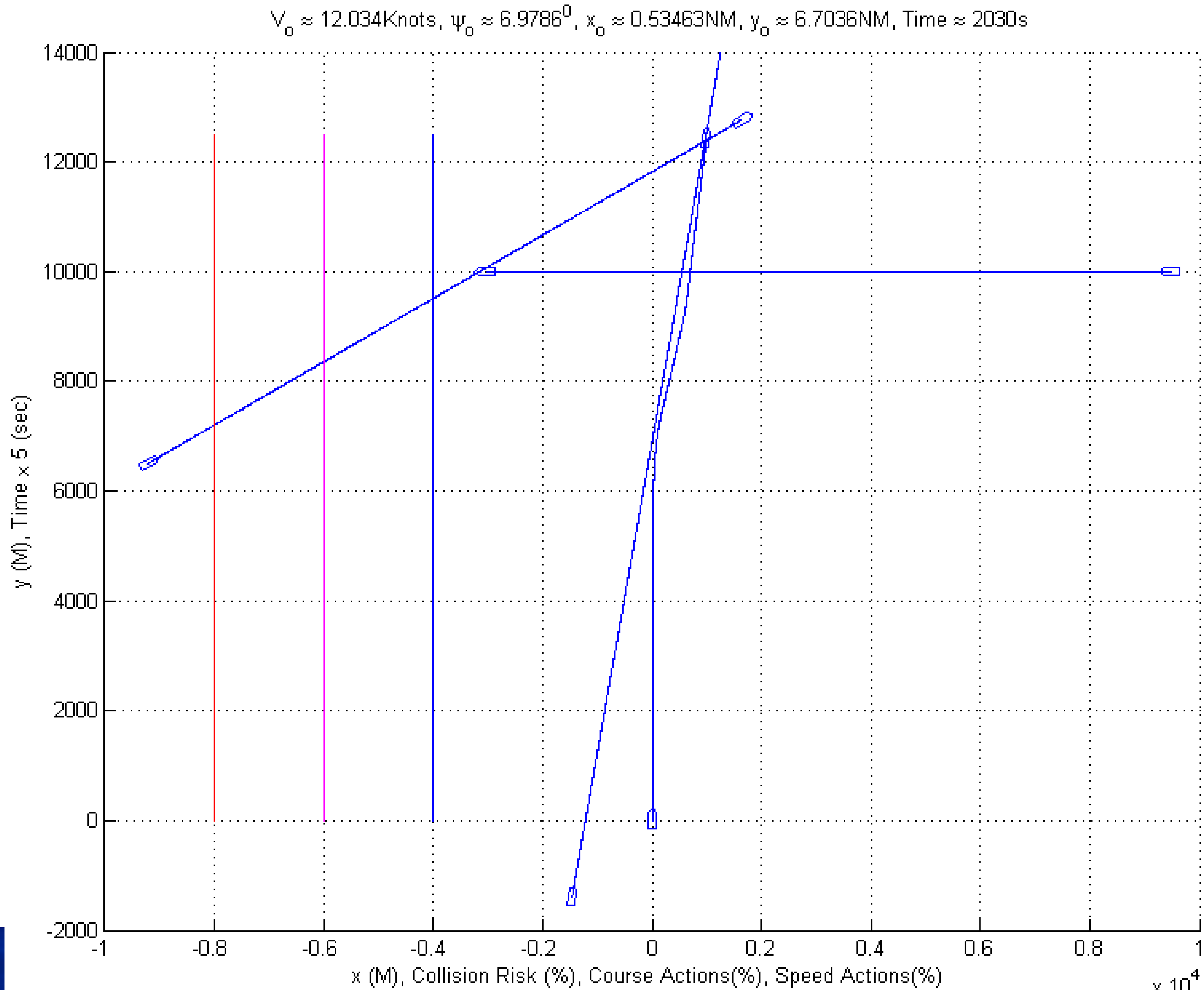
Computational Simulation



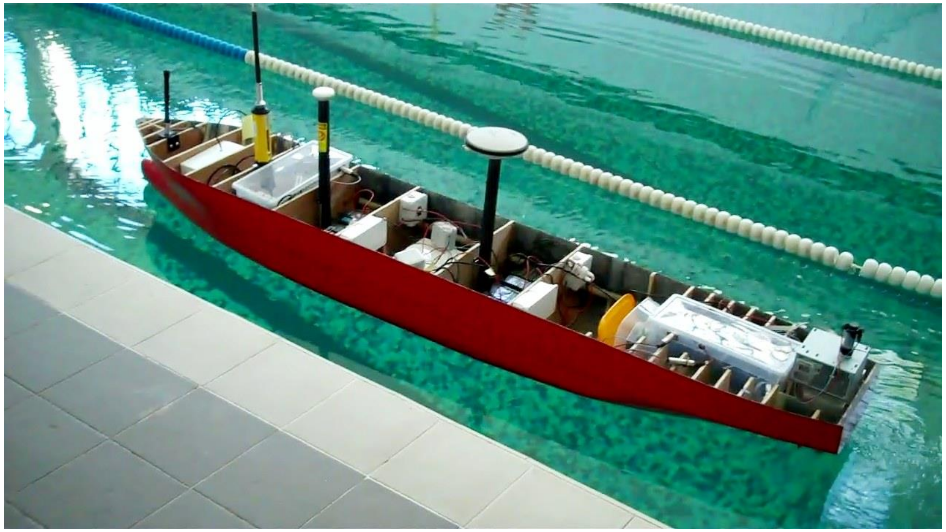
Computational Simulation



Computational Simulation



Autonomous Vessel



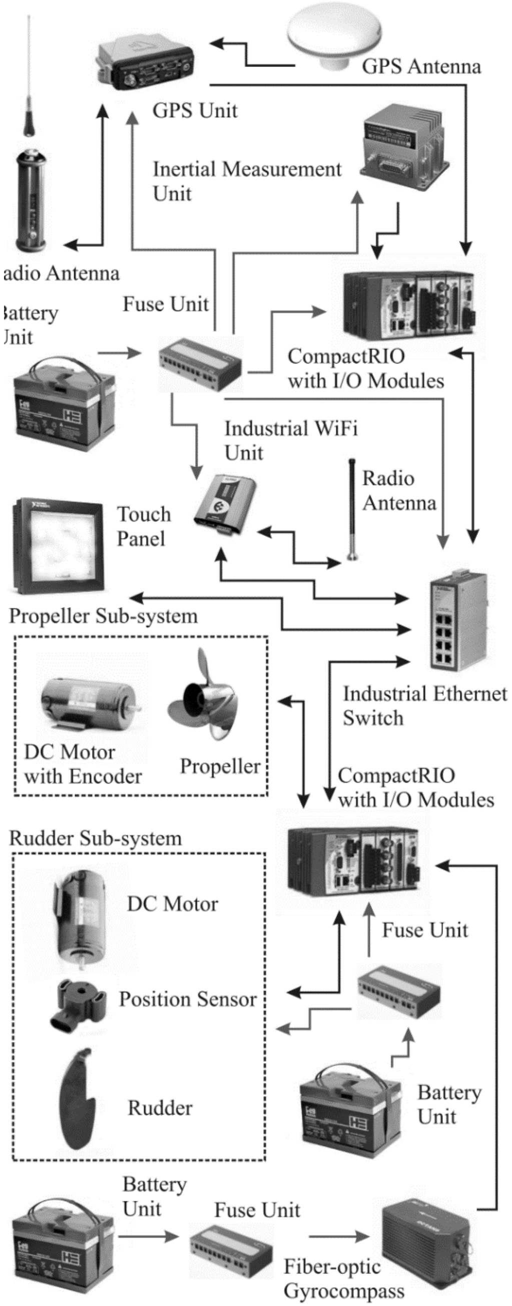
Main particulars of the model

Length overall	: 2.590 m
Length between perpendiculars	: 2.450 m
Breadth	: 0.430 m
Depth	: 0.198 m
Draught	: 0.145 m
Displacement	: 0.1156 m

- 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.

Hardware Structure

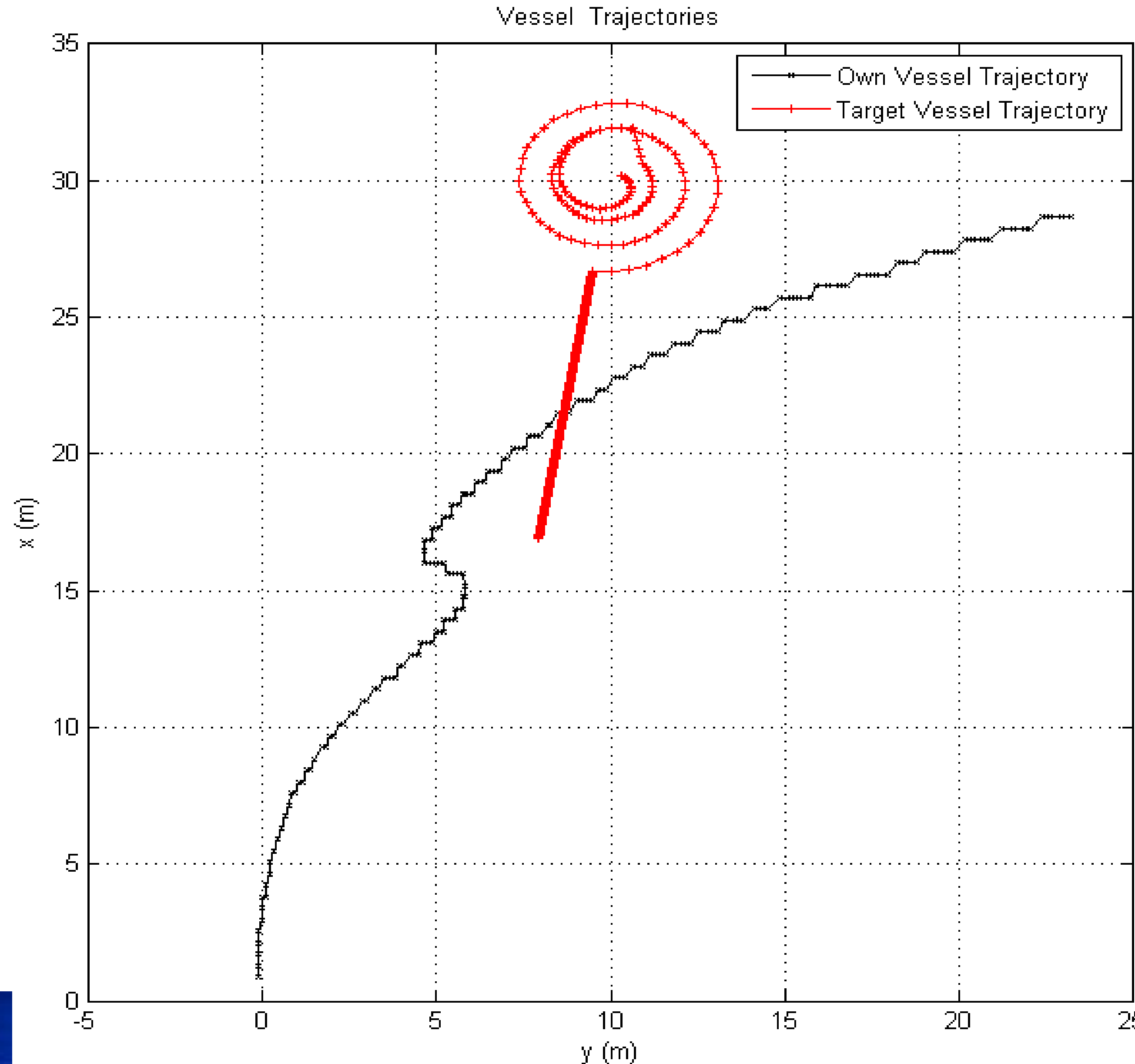
- The hardware structure consists of:
  - Command and monitoring unit (CMU)
  - Communication and control unit (CCU)



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:



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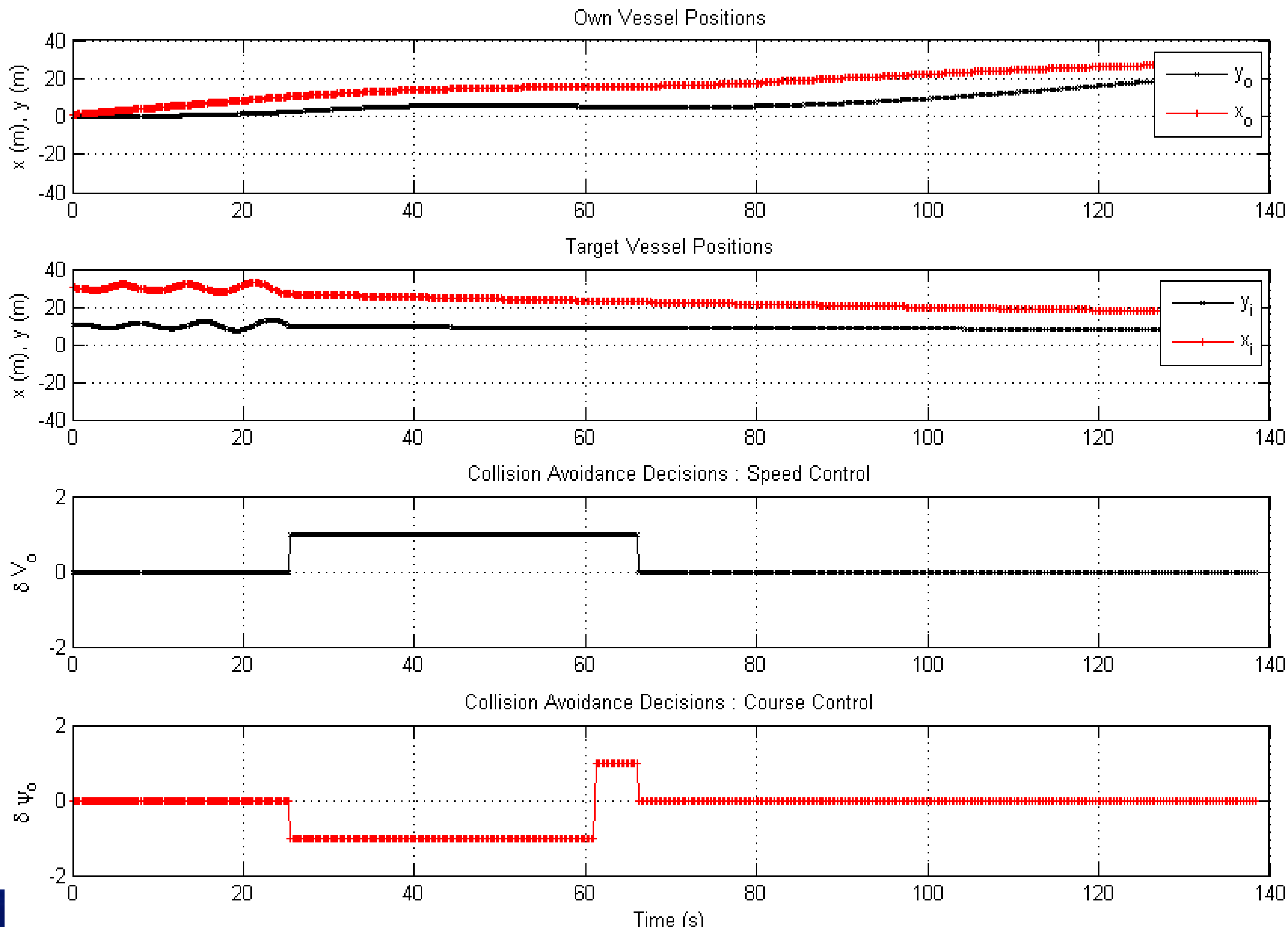

Conclusions

- **Intelligent Decision Making Framework for Autonomous Ship Navigation** with **Collision Avoidance Functionalities.**
- 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 ?