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Autonomous Inland Vessels: Simulation, Demonstration, and Advancements in Automated Navigation of Inland Ships

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Abstract

The research project *Autonomes Binnenschiff - Simulation und Demonstration von automatisiertem Fahren in der Binnenschifffahrt* (Autonomous Inland Vessel - Simulation and Demonstration of Automated Navigation in Inland Shipping) aimed at the fully automated navigation of an inland cargo vessel. The project activities comprised the generation of a simulation environment for development and virtual training; the development of algorithms and functionalities required for safe navigation; the installation of environmental and proprioceptive sensors, along with actuator interfaces, on a test ship; and, the on-board integration, testing, fine-tuning and live demonstration of the developed automation system. While algorithms implemented for guidance, navigation and control have been published before, [1 - 7], we will here focus on the virtual environment setup and real-world trials.

The virtual environment provided a digital twin of the ship's environment including waterway, terrain, buildings and other infrastructure such as bridges and locks. Optimized memory requirements increased performance, while partially automated terrain generation and population helped to speed up the development process [8]. Dynamics models of the hydrodynamic maneuvering forces and the propulsion drive train were implemented to simulate the behavior of vessels.

Several virtual sensors were implemented, including LiDAR, GPS, monocular and stereo cameras, IMU, and radar. The sensors were adapted to match their real-world counterparts and included features such as configurable return point quality for the LiDAR system. The simulation environment also included virtual traffic participant's integration with a methodology for simple path tracking, route definition via KML files, and automated generation of diverse traffic participants with different routes and parameters.

The inland cargo vessel Niedersachsen 22 served as test ship. The equipment installed on board comprised of various sensors for environmental perception, access to RADAR and the NMEA communications stream, interfaces to propulsion and steering control units, a central server including data storage and LTE mobile communication to shore. We also addressed the development of a human-machine interface (HMI), including the creation of a database with relevant map data and the adaptation of a visualization system for HMI purposes. The HMI provided various displays for sensor data monitoring and visualization, path representation, and virtual obstacle rendering. Functionalities such as adding virtual obstacles, setting waypoints, and initiating virtual canal navigation were also implemented.

The implementation of automated vessel navigation algorithms involved the fine-tuning and coordination of algorithms for path planning, motion prediction, trajectory fusion, and ship localization. The algorithms were integrated into the simulation environment, and the integration with the vessel's dynamics and control systems was performed.

The research project included several test phases conducted with the Niedersachsen 22. These encompassed various scenarios such as path following, optimization of path controllers and planning algorithms, navigation with virtual obstacles and in a virtual canal. The trials were conducted on different waterways, including the Haringvliet in the Netherlands and the Dortmund-Ems Canal.

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