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WayWise: A rapid prototyping library for connected, autonomous vehicles

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ABSTRACT

WayWise is an innovative C++ and Qt-based rapid prototyping library designed to advance the development and analysis of connected, autonomous vehicles (CAVs) and Unmanned Arial Systems (UASs). It was deployed on model-sized cars and trucks as well as full-sized mobile machinery, tractors and UASs. It is actively being used in several European research projects. Developed by the RISE Dependable Transport Systems unit, the library facilitates exploration into safety and cybersecurity aspects inherent to various emerging vehicular applications within road traffic and offroad applications. This non-production library emphasizes rapid prototyping, leveraging commercial off-the-shelf hardware and the different protocols for vehicle-control communication, mainly focusing on MAVLINK. The utility of WayWise in rapidly evaluating complex vehicular behaviors is demonstrated through various research projects, thus contributing to the field of autonomous vehicular technology.

Code metadata

Current code version	8825fe4
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2024-139
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/3459141/tree/v1
Legal Code License	*GNU General Public License (GPL)*
Code versioning system used	*git*
Software code languages, tools, and services used	*C++, Qt*
Compilation requirements, operating environments & dependencies	*CMake, MAVSDK*
If available Link to developer documentation/manual	https://github.com/RISE-Dependable-Transport-Systems/WayWise/blob/main/README.md
Support email for questions	waywise@ri.se

1. Introduction

In the rapidly evolving field of autonomous vehicle research, the ability to quickly and effectively prototype, test, and validate new technologies is crucial. Rapid prototyping tools like WayWise are essential because they allow researchers and developers to iterate designs quickly, test hypotheses, and refine systems based on real-world data and simulations. They accelerate the development process, ensuring focus on the research questions at hand.

WayWise provides a modular, flexible and robust platform that supports the development of connected, autonomous vehicles (CAVs) as well as unmanned aerial systems (UASs) as summarized in Fig. 1. It integrates core aspects of vehicle dynamics, control systems, communication protocols and UI building blocks into a single framework. The library's design, built on C++ and Qt, targets commercial off-the-shelf (COTS) hardware, making it accessible and adaptable to various research and development needs. WayWise is highly scalable and has been implemented in various designs, from model-sized cars to a full-sized electric tractor equipped with four electric motors totaling 120 kW of power.

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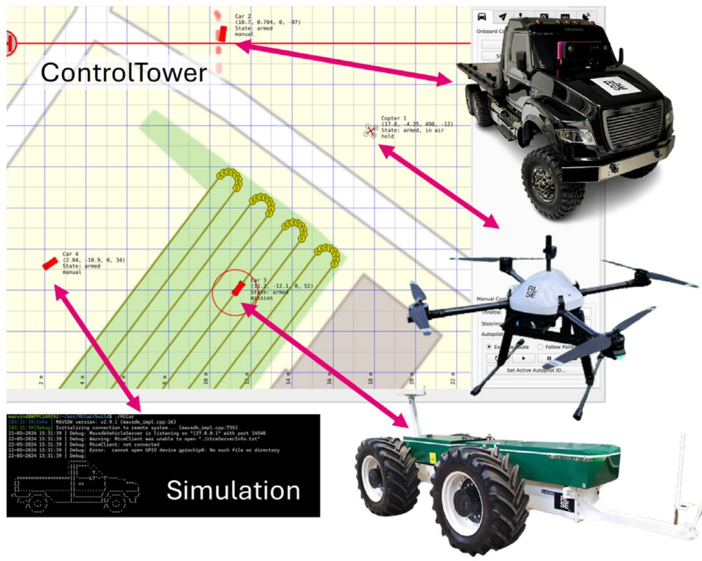

Fig. 1. Summary of WayWise's capabilities including control station and various types of vehicles.

RCCar[1] and ControlTower[2] are our flagship projects for WayWise, where RCCar represents the vehicle side and ControlTower the control system desktop application.

1.1. Key features

WayWise is organized into several components (highlighted in **bold** in the following) to address different aspects of autonomous vehicle development. At its foundation, the **core** component includes fundamental classes and headers for tasks such as storing positions and transforming coordinates, with support for both relative coordinates in East-North-Up (ENU) and global coordinates in longitude and latitude, ensuring precise geospatial handling. **Communication** is a crucial aspect, where WayWise handles both external and internal communication needs. Externally, it mainly uses the MAVLINK protocol implemented via MAVSDK [1], enabling robust and flexible interactions between vehicles and control stations. WayWise is generally protocol agnostic, though. For example, it additionally supports ISO/TS 22133 [2], a protocol for active safety and automated vehicle testing. The support was contributed by AstaZero, a full-scale test environment for autonomous transport systems in Sweden [3]. For internal communication in more complex vehicles, WayWise supports vehicle communication to lower-level controls using the CANopen protocol through the Lely CANopen library [4].

The **vehicles** component comprises classes that store the state of different vehicle types, facilitating straight forward kinematic simulations within a desktop application or on the vehicles themselves. Various vehicle types, including rc cars, drones, and full-sized machinery are supported. Sensor integration is another vital component, and WayWise includes broad support for **sensors** such as positioning using GNSS (including Real-Time Kinematic (RTK) with a focus on u-blox receivers [5]), IMUs, Ultra Wide Band (UWB, using Pozyx [6]). Further, DepthAI [7] has been integrated to prototype AI-enabled functionality like keeping a safe distance from or following persons.

Autopilot defines a generic interface, "WaypointFollower", for implementing autopilot functionalities. Notable implementations include a pure pursuit-based autopilot [8] and the "MultiWaypointFollower", which allows for switching between multiple WaypointFollowers. This flexibility supports complex use cases such as following a route, pausing for charging, and resuming the route. Also following moving points (like detected persons) is implemented here. WayWise further provides an easy-to-integrate **logger**, allowing data from vehicles to be efficiently logged and transmitted to the control station for analysis and debugging.

Additionally, the library includes **user interface** building blocks for creating desktop applications, most notably a map module for displaying vehicle positions on OpenStreetMap with modular extensions for creating routes and tracing movements. It further features **route planning** using a configurable route generator currently focusing on agricultural applications.

1.2. Technological advancements

WayWise demonstrates technological advancements in autonomous vehicle research through its modular and flexible architecture. Built on C++ and Qt, it allows seamless integration of vehicle dynamics, control systems, and communication protocols. It supports a wide range of vehicles, from model-sized cars to full-sized machinery, and provides effective means for both external (MAVLINK, ISO/TS 22133) and internal (CANopen) communications. Advanced sensor integration (GNSS, IMUs, UWB, DepthAI) enhances environmental perception and navigation, while its "WaypointFollower" autopilot functionalities support complex use cases effectively. Compatible with COTS hardware and offering cross-platform capabilities, WayWise provides a comprehensive toolset for rapid prototyping, making it a vital resource for developing and testing autonomous systems across various applications. Its design ensures that it can meet diverse research and development needs, supporting the exploration and validation of new technologies and methodologies in the autonomous systems domain.

2. Case studies and impact

WayWise has been integral to various research projects, showcasing its versatility and effectiveness in real-world scenarios. One notable application is within the **AGRARSENSE** EU project [9] under the Chips Joint Undertaking. AGRARSENSE aims to advance microelectronics, photonics, and electronic packaging tailored for the agricultural and

[1] https://github.com/RISE-Dependable-Transport-Systems/RCCar
[2] https://github.com/RISE-Dependable-Transport-Systems/ControlTower

forestry sectors. The project also seeks to enhance ICT and data management systems to support extensive field demonstrations that address genuine industrial demands. WayWise is being used to prototype functions that enhance safety-critical situational awareness of autonomous mobile machines in forest environments, both in model and real scale. Research questions include safety and cybersecurity aspects as well as using Unmanned Aerial Vehicles[3] to extend the machinery's point of view for protecting humans. More details on the use case and challenges can be found in [11].

In the **SUNRISE** EU project [12], which focuses on the safety assurance of Cooperative, Connected, and Automated Mobility (CCAM) systems, WayWise plays a vital role in prototyping and demonstrations. The project aims to develop a standardized safety assurance framework that will undergo rigorous testing through various realistic scenarios. These scenarios cover a diverse array of CCAM systems and applications, from urban and highway navigation of personal vehicles to automated parking of commercial freight trucks. Currently, WayWise is being utilized to develop a model-scale prototype of a truck with a trailer for showcasing automated parking in a logistics hub as an intermediate step toward real-scale testing.

Another significant application of WayWise is in the **LASH FIRE** EU project [13], which is an international research initiative aimed at minimizing fire risks aboard roll-on/roll-off (ro-ro) ships. The project explored the feasibility of integrating Unmanned Aerial Systems (UAS) into fire and rescue operations. The objective was to prototype and assess feasibility and usefulness of a UAS designed for the maritime environment that could conduct automated fire patrols, assist in fire resource management, and perform search and rescue missions. WayWise facilitated rapid prototyping of the system, providing valuable insights and feedback when creating a survey targeted at professionals in maritime operations and UAS technology that resulted in a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis. The findings will be presented in [14], a project report with technical details is available [15].

The **agrifoodTEF** EU project [16], spanning across Europe, focuses on assessing and validating third-party AI and Robotics solutions in real-world agricultural conditions. The Swedish "satellite" of agrifoodTEF, centered around the RISE Testbed Digitalized Agriculture, serves as a hub for developing, testing, and demonstrating products and services related to agriculture and food production. Key features of this testbed include a full-scale tractor prototype called Drever 120 with an electric driveline featuring four motors with 30 kW power each. Drever 120 was automated using WayWise and demonstrated together with a prototype automated battery swap system in front of all EU agriculture ministers [17].

Through these diverse projects, WayWise has demonstrated its utility and adaptability in various applications, reinforcing its role as an effective tool in the development and testing of autonomous systems across different sectors.

3. Future directions and conclusion

WayWise has proven to be an effective tool in autonomous vehicle research, providing a modular, flexible, and robust platform for rapid prototyping, testing, and validation of connected autonomous vehicles and UASs. Built with C++ and Qt, WayWise integrates vehicle dynamics, control systems, communication protocols, and user interface components, supporting diverse research and development needs with COTS hardware compatibility and advanced sensor integration. Its effectiveness is showcased in projects like AGRARSENSE, SUNRISE, LASH FIRE, and agrifoodTEF, enhancing situational awareness, safety, and operational efficiency.

[3] Implemented using PX4 [10] and communicating to WayWise via MAVLINK.

Looking ahead, the main developments on control station and vehicles side are multi vehicle support and ROS2 [18] integration, respectively. ControlTower recently received support to manage multiple vehicles including autopilot control and monitoring. This enables investigating research questions where vehicles interact more tightly, e.g., to increase worksite safety as in the AGRARSENSE project.

On the vehicle side, our recently established WayWiseR[4] project integrates the rapid prototyping capability of WayWise with ROS2. It accelerates the bringup of ROS2-powered vehicles by managing low-level functions, while extending functionalities for WayWise-powered vehicles with advanced ROS2 features like localization (e.g., SLAM), simulation (e.g., Gazebo [19], CARLA [20]) and advanced autonomous functionality.

Future research will continue to investigate safety and cybersecurity of AI-enabled autonomous vehicles, driving the development of WayWise in upcoming projects. We encourage collaboration to further advance WayWise's capabilities and drive innovation in autonomous vehicle technology.

CRediT authorship contribution statement

Marvin Damschen: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – original draft. **Rickard Häll:** Software, Writing – original draft. **Aria Mirzai:** Software, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.simpa.2024.100682.

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