Robotics-enabled roadwork maintenance and upgrading

Book Chapter

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Chapter 11

Robotics-Enabled Roadwork Maintenance and Upgrading

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In the contemporary era, road infrastructure stands as a paramount public asset, serving as a linchpin for economic expansion and societal progress by facilitating access to essential services such as education, health, and employment opportunities. These complex networks, critical for sustaining modern economies, necessitate meticulous upkeep and modernization efforts to ensure the safety, health, and efficiency expected by road users. This chapter delves into the strides undertaken by the EU-funded HERON project, aimed at transforming the maintenance landscape of road infrastructure through the implementation of an advanced integrated system. This project heralds a significant evolution in road management strategies, potentially lowering the frequency of accidents, diminishing maintenance expenditure, and amplifying the capacity and efficiency of the road network at large. Central to the HERON project is the advent of a sophisticated autonomous robotic ground vehicle, augmented with the support of independent drones. These technological advancements work in synergy, utilizing high-resolution sensors and

3D mapping scanners to bring a new dimension of accuracy and foresight to road maintenance protocols. Moreover, the integration of artificial intelligence toolkits serves to streamline and coordinate maintenance and upgrade workflows, thereby heralding a new era of efficiency and safety in road infrastructure management. This chapter provides a comprehensive overview of the HERON project, exploring its potential to redefine road infrastructure maintenance and usher in an epoch of prosperity and well-functioning economies, sustained by robust and well-maintained road networks.

11.1 Introduction

In the burgeoning field of infrastructural technology, the synergy between robotic platforms and computer vision is reshaping the paradigms of road infrastructure monitoring. This integration heralds a new era of scientific innovation and societal progress, catering to the dual objectives of efficiency and safety. The following sections will delve deeper into the nuances of this transformation, setting the stage for an insightful exploration in subsequent chapters of this book.

To begin with, the scientific impacts of these advancements cannot be overstated. Not only do they promise unprecedented automation in data collection, but they also facilitate real-time monitoring and analysis of road conditions, a leap forward from traditional methodologies. These technologies have transcended barriers, enabling remote sensing capabilities to probe into areas previously deemed inaccessible, thus broadening the horizon for comprehensive infrastructure assessment. This constitutes a significant leap in scientific innovation, paving the way for data-driven insights and decision-making processes that are grounded in precision and accuracy.

From a societal perspective, these technological strides offer a plethora of benefits, enhancing the safety and efficiency of road monitoring systems. Robotic platforms can navigate hazardous areas or high-traffic zones with ease, thereby mitigating risks to human personnel. This advancement not only ensures the well-being of the workforce but also augments the pace of response to infrastructural issues, thereby fostering a safer and more streamlined road network for the general populace.

Furthermore, the amalgamation of these technologies with existing systems such as Geographic Information Systems (GIS) promises an integrated approach to urban planning and traffic management. This collaborative approach is likely to facilitate informed decision-making, thereby contributing to the development of urban landscapes that are well-orchestrated and conducive to smooth traffic flow, a change that has far-reaching implications on community satisfaction and overall societal well-being.

The advent of predictive maintenance, empowered by machine learning algorithms, denotes a significant shift in infrastructure management strategies. This proactive approach facilitates timely interventions, optimizing resource allocation and reducing the probability of escalated damages, thus ensuring a smoother, more reliable road network for society. Moreover, the automated reporting systems integrated into these platforms expedite the response times to emerging issues, offering a direct societal benefit in the form of efficient traffic management and safer road conditions.

At the economic frontier, these approaches are sculpting a cost-effective path for road infrastructure maintenance, reducing the dependency on labor-intensive practices. This evolution promises not only financial savings but also an optimized maintenance schedule, circumventing the necessity for expensive emergency repairs and fostering economic prudence in resource management.

Finally, in the realm of research and development, these technologies serve as a fulcrum for further innovation. The data amassed forms a rich repository for researching road wear patterns, facilitating the development of robust materials and construction techniques. Additionally, these data points are critical in developing simulations and models that test new road materials and designs, nurturing an environment of continual growth and innovation in road construction.

11.1.1 Previous Approaches

HERON stands as one of the initiatives funded by the European Union under the Horizon 2020 program, specifically focusing on the maintenance of road infrastructure. Within HERON's scope is the implementation of a road infrastructure blueprint developed by affiliated projects. The primary objective of HERON is to pioneer advanced engineering solutions for interconnecting and facilitating seamless transitions between different transportation modes in the event of severe disruptions affecting one mode of transportation [1].

Numerous projects, similar to HERON, have received funding from the European Union to create an autonomous ground robotic vehicle, complemented by autonomous drones. This initiative is intended to enhance the monitoring, assessment, and maintenance of road infrastructures. One such EU-funded project, known as InfraROB [2], is dedicated to the automation, robotization, and modularization of road construction and maintenance tasks. More specifically, it will design autonomous robotized equipment and machinery for tasks such as line marking, repaving, and the repair of cracks and potholes. Additionally, collaborative robotized safety systems will be developed to ensure the safety of both construction workers and road users. The project also seeks to integrate pavement management and traffic management systems, aiming for a comprehensive, unified approach to the management of road infrastructure and real-time traffic [3].

In parallel, the OMICRON project [4], which is financially supported by the European Union, aims to create an intelligent asset management platform (IAMP) equipped with a diverse array of region-specific cutting-edge technologies. These technologies are intended to enhance the construction, maintenance, renewal, and enhancement of the European Union's road network. The project will encompass the entire road network system and will specifically involve the implementation of digital inspection technologies, the development of a road digital twin, the creation of a decision support tool, advancements in intelligent construction, and the provision of intervention solutions for infrastructure-related issues. To facilitate this, the IAMP will be seamlessly integrated with a digital twin built around the principles of Building Information Modeling (BIM). This integration will enable the industrialization and automation of various road management functions and will be demonstrated in Italy and Spain.

Finally, the PANOPTIS project [5] has set its sights on enhancing the resilience of road infrastructures and ensuring their continued functionality in adverse conditions, such as extreme weather events, landslides, and earthquakes. The project's primary goal is to amalgamate downscaled climate change scenarios tailored for road infrastructures with simulation tools encompassing structural and geotechnical aspects, as well as real-time data collected from both existing and innovative sensors. This amalgamation will result in an integrated tool designed to empower operators in the more effective management of their infrastructures across the planning, maintenance, and operational phases.

All of the previously mentioned projects, including HERON, are recipients of funding from the European Union's Horizon 2020 Research and Innovation Programme. It's worth noting that HERON represents one of the three Research and Innovation Actions supported within the scope of ameliorating environmental impacts and achieving fully automated infrastructure upgrades and maintenance under the Horizon 2020 program SOCIETAL CHALLENGES – Smart, Green and Integrated Transport.

11.1.1.1 The HERON contribution

The HERON project stands as a beacon of innovation, setting its sights on revolutionizing the process of maintaining and upgrading road networks. At its core, the initiative seeks to create an integrated automated system capable of handling a range of roadworks tasks. These encompass a plethora of activities including sealing cracks, patching potholes, rejuvenating asphalt, autonomously replacing CUD elements, and refreshing road markings. Moreover, it extends its functionality to support both the pre and post-intervention phases, which notably involves conducting visual inspections as well as automated and controlled deployment and retrieval of traffic cones.

Delving into the specifics, the HERON system embodies a multi-faceted approach. Firstly, it incorporates an autonomous ground robotic vehicle, which works in harmony with supportive drones to meticulously coordinate both maintenance works and the necessary procedures before and after the intervention phase. This vehicle serves as a hub, housing a diverse range of robotic equipment furnished with an array of sensors and actuators. These tools are adept at executing tasks such as cutting and filling, placing surface materials and compacting them, installing modular components, and undertaking 3D mapping through laser scanners.

Furthermore, an advanced sensing interface finds its place both on the robotic platform and within the Road Infrastructures (RI), enhancing the monitoring capabilities. This interface grants a heightened situational awareness, offering a detailed insight into the structural nuances and functional conditions of the RI, along with scrutinizing road markings.

The operational heart of the system is a sophisticated control software, which seamlessly bridges the sensing interface with the active robotic equipment, thereby orchestrating a synchronized performance. This software is complemented by Augmented Reality (AR) visualization tools, which grant the robotic system the ability to discern surface defects and scrutinize road markings with an unprecedented level of detail.

In its pursuit to streamline operations, HERON employs AI-based toolkits that function as a middleware, serving dual pivotal roles. Firstly, these toolkits are entrusted with the task of optimally coordinating road maintenance and upgrading workflows, ensuring a seamless operational cadence. Secondly, they are responsible for the intelligent processing of data harvested from both the vehicle and infrastructure sensors. This data processing is crucial in guaranteeing safe operations while avoiding disruptions to regular traffic flows and other routine operations.

Central to the functionality of HERON is an enhanced visualization user interface which integrates all collected data, thereby offering a comprehensive platform that facilitates informed decision-making. Furthermore, communication modules are intricately woven into the system, fostering Vehicle-to-Infrastructure or Vehicle-to-Everything (V2I/X) data exchanges. These exchanges are fundamental in not only foreseeing maintenance requirements but also augmenting user safety.

HERON emerges as a pioneering venture, promising a modular design that can adapt to various transport infrastructures. By doing so, it harbors the potential to significantly diminish fatal accidents and maintenance costs while alleviating traffic disruptions. Ultimately, this leads to an uptick in network capacity and efficiency, marking a substantial step forward in the domain of road infrastructure maintenance and management.

The rest of this chapter is structured in the following way. Section 11.2 presents the project demonstration sites and discusses the application scenarios. Sections 11.3–11.5 present the HERON technological components, starting with the developed computer vision toolkits (Section 11.3), the robotics platform (Section 11.4) and the project's components responsible for visualization and increasing the overall situational awareness (Section 11.5). Section 11.6 presents the chapter's conclusions.

11.2 Application Scenarios

11.2.1 Demonstration Sites

HERON will deploy the technological innovations described in Sections 11.2–11.4 in three different demo sites, in France, Greece, and Spain.

11.2.1.1 Greek demo site: Olympia Odos

Olympia Odos is a Motorway Concession Project of particular strategic importance on national and regional levels for the development of the Peloponnese and Western Greece, as it connects Athens with North Peloponnese, Western Greece and the Port of Patras.

The Motorway is 202 km in length and comprises of two existing motorway sections, i.e. Elefsina – Korinthos (ELKO) 64 km long, and Patra by Pass (PbP) 18 km long, along with 120 km of the new Korinthos-Patra (KOPA) motorway, whose construction was completed in 2017, apart from the area of Rio I/C, that was completed in February 2018.

For the needs of the operation, the road has been divided into two Districts with facilities as shown in the following diagram (see Figures 11.1 and 11.2).

Figure 11.1. "Elefsina – Korinthos" Existing Section "Patra bypass" Existing Section.

Figure 11.2. Project operation diagram into two districts.

The Pilot Site will be in the "Elefsina – Korinthos" section. The whole length of this section is 64 km with the following characteristics:

- Dual carriageway with 3 lanes (3,50 m width left lane, 3,75 m. with middle and right lane) & 1 Emergency Lane (varies from 2,50 to 4,50 m.) per direction, with concrete New Jersey safety barriers in the central axis of the motorway;
- Kakia Skala tunnel complex (5 tunnels of total length ~4,5 km) and 16 bridges;
- 2 large mainline toll plazas and 3 pairs of ramp toll plazas.

11.2.1.2 Spanish demo site: ACCIONA

The pilot project is set to launch on a section of the A2 Motorway managed by the company, specifically the R2–CM42 section starting from Madrid and ending at the border of the Guadalajara and Soria provinces in Spain. This operation also includes the traffic control center situated near Torija village. The roadway, governed by the Spanish National Road Authority, spans 77.5 km and is officially referred to as the "Public Works Contract for the Maintenance and Operation of the A-2 Dual Carriageway from Mile Marker 62.0 to 139.50. Section: R2 – L.P. Soria/Guadalajara."

This section features four lanes (two in each direction) and is situated in a region with a Continental-Mediterranean climate, known for its harsh winters and hot, dry summers. Due to high levels of heavy traffic, the road surface needs regular maintenance to remain in good condition. The A2, which connects Madrid to Barcelona, is a significant highway in Spain and is a component of the Trans-European Transport Network (TEN-T) and the CEF corridor.

Figure 11.3. Overview of the A2 motorway.

Figure 11.4. The Torija traffic control centre.

The contract is managed from the ACCIONA headquarters in Madrid and from the traffic control centre located in the small village of Torija. The traffic control centre is in charge of monitoring the motorway status, visualizing and assessing the data provided by CCTV, inductive loops, GPS-based fleets, weather stations, weigh-in-motion systems, etc. It is also the basecamp for all assets needed for maintenance (e.g., machinery).

11.2.1.3 French demo site: Transpolis

Transpolis is a proving ground of more than 80 ha which has been created by 5 entities among which Univ. Eiffel and has been opened officially in 2019. It is typically used to test autonomous vehicles in a secure and controlled environment thanks to several kilometers of road (notably 12 km in the "city area") and all reinforced concrete buildings. Many types of Vehicle to Everything (V2X) and Vehicle to Infrastructure (V2I) communication means are also available, as well as camera monitoring.

Concerning telecommunications, Transpolis is equipped with more than 320 km of optical fiber that allows access to an Ethernet network at almost any

Figure 11.5. Aerial View of the Transpolis site.

Figure 11.6. Several types of road markings at Transpolis.

point of the tracks. Thanks to an open LoRa network that covers the whole proving ground, a wide range of Internet of Things (IoT) sensors can be installed and used on Transpolis. Transpolis is also covered by a 5G network coming from an antenna located in the middle of the tracks. As far as energy is concerned, a private electrical distribution network guarantees power supply on the whole proving ground, especially in the "city area".

Transpolis will provide the proving ground for several use cases, namely:

- Detection and repair of road markings,
- Detection and repair of reinforced concrete cracks,
- Continuous V2I communication, between the vehicle and roadside units.

11.2.2 Demonstration Scenarios

In the HERON project, a series of demonstration scenarios are planned to illustrate the effectiveness of automated road maintenance and inspection procedures. The demonstrations are as follows:

1. Sealing Cracks: In this setup, UGVs equipped with sensors and the robotic arm are deployed to identify and seal cracks. They use high-resolution imagery to detect the cracks before sealing them with the necessary materials, helping to maintain a safer road surface.
2. Patching Potholes: This scenario demonstrates the project's ability to identify and repair potholes. The robotic units are equipped to detect potholes and fill them with appropriate materials, restoring the road's surface and preventing further decay.
3. Replacement of RUP Elements: This demonstration focuses on the removal and replacement of damaged or worn-out Removable Urban Pavement (RUP) elements. The robots are designed to identify these elements, remove them, and install new ones to maintain road safety standards.
4. Repainting of Road Markings: In this part, the HERON system showcases its capability to refresh faded or eroded road markings. The robots repaint the necessary lines and symbols with precision, ensuring clear and safe road demarcations.
5. Visual Inspections: This scenario involves the conducting of detailed visual inspections of road infrastructure. Using cameras and other sensors, they can collect comprehensive data on the condition of roads, aiding in informed decision-making regarding maintenance and repair tasks.

Across all these scenarios, an auxiliary function involves the deployment and removal of traffic cones to demarcate work zones, ensuring both the safety of the robotic units and the smooth flow of traffic. This aspect demonstrates the project's commitment to seamless integration into existing traffic systems while undertaking maintenance tasks.

Each demonstration is a testament to HERON's potential to improve road safety and lifespan through technological advancements and automation.

11.3 Computer Vision Toolkit

One of the main objectives of HERON is the identification of points of interest, i.e. the automatic detection and segmentation of cracks and potholes. For this task computer vision models have been developed based on the SegFormer [1] architecture. The SegFormer architecture, specifically designed for semantic segmentation tasks, merges the capabilities of transformers and convolutional neural networks (CNNs) to facilitate the categorization of different segments in an image. The structure begins with a hybrid backbone, a primary component responsible for extracting features from the input image. This backbone is constructed from a blend of convolutional and transformer layers, which are adept at extracting hierarchical features from images. Following this is the multi-level feature fusion, a vital element in aggregating features from diverse layers of the backbone. This helps in preserving both the high-level semantic information and the low-level spatial details, which are imperative for effective segmentation tasks.

At the heart of the SegFormer architecture lie the transformer layers, which play a pivotal role in modeling long-range dependencies between different regions of the

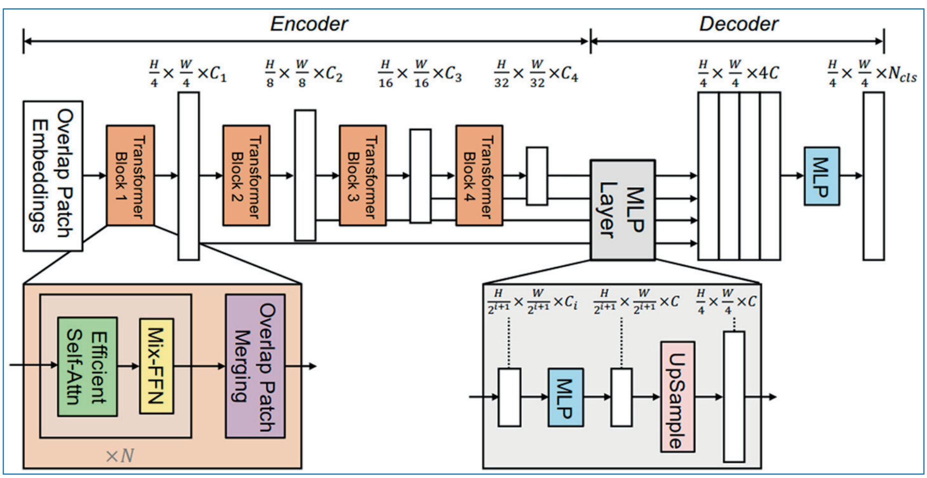

Figure 11.7. Segformer architecture.

Figure 11.8. An example of segmentation robustness on a corrupted (gaussian blur) sample from Cityscapes-C benchmark dataset. It is compared to a previously state-of-the-art model, DeepLabv3+. Source [1].

image. This facilitates an enhanced understanding of the semantic interrelationships between varying regions. Subsequently, the segmentation head comes into play, functioning to create the segmentation map. This segment assimilates the output from the transformer layers, transmuting them into segmentation masks. It might employ a straightforward convolutional layer or a complex structure to carve out detailed segmentation maps.

11.3.1 Performance Evaluation

The SegFormer architecture was trained using data captured by the project, as well as the "Cracks and Potholes in Road Images Dataset" by Passos *et al.* [7]. This is a publicly available dataset, and it was developed using images made available by the Brazilian National Department of Transport Infrastructure. It contains images of defects (cracks, potholes) in asphalted roads in Brazil, and it was made in order to be used for a study on the detection of cracks and potholes in asphalted roads. For the training process, the total of 2235 images have been split by a 80–20% ratio, for the training and validation data respectively from the cracks and potholes dataset. During the training process, the images has been randomly cropped to a 640 × 640 ratio to match the input size of the Segformer model.

The Segformer has been trained and evaluated in a Linux machine utilizing an NVIDIA1080Ti, of 12GB VRAM. The batch size for the training was 2 to 8, depending on the configurations of the various experiments run. The performance is illustrated in the figures below.

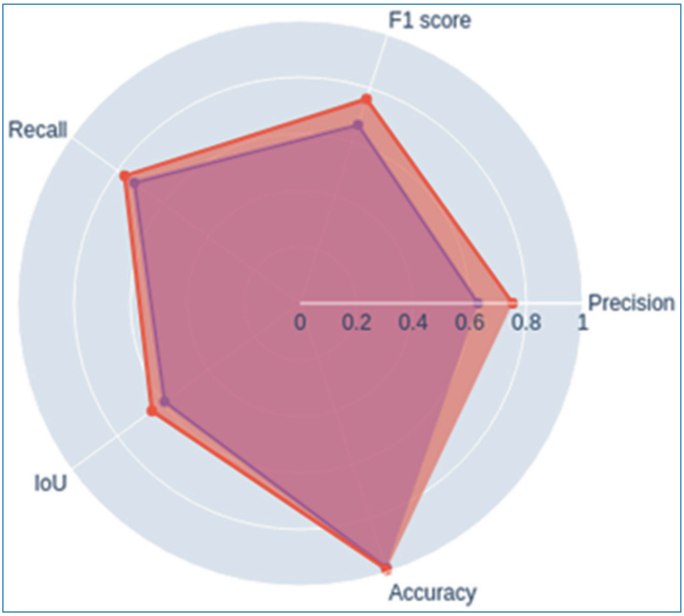

Figure 11.9. Visual representation of average metrics as presented in Table 4. Orange: Segformer, Blue: U-Net.

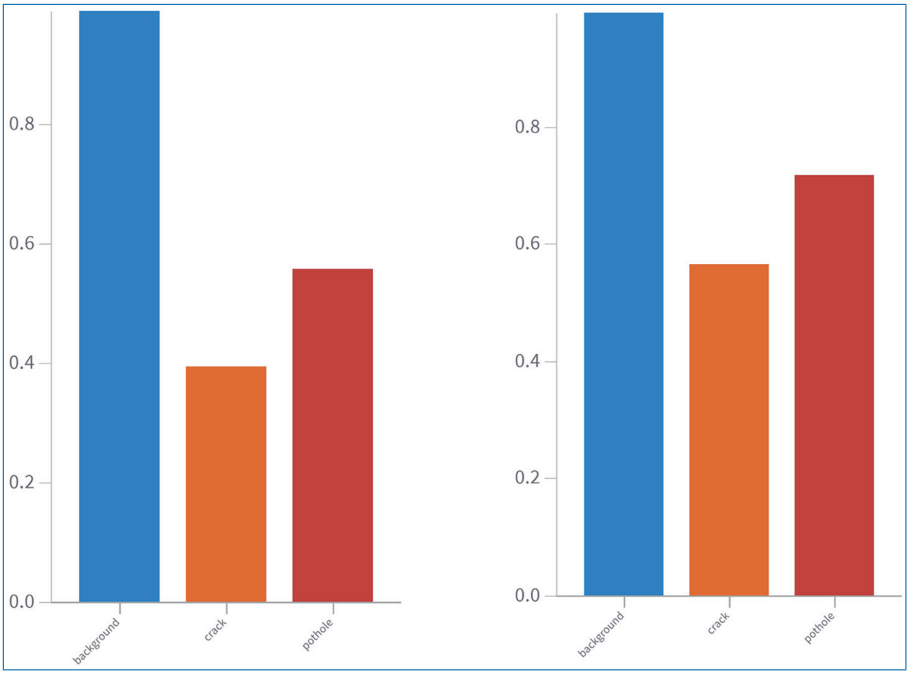

Figure 11.10. Segformer Performance for each individual class. Left: IoU score, right: F1 score.

11.4 Robotics Platform

The robotic platform system is structured around four fundamental elements. The control software houses the principal modules that facilitate the manipulation of the hardware system's functionalities and carry out actions imperative to fulfill the objectives outlined in the HERON project. The application software incorporates elements that amalgamate components derived from the control software segment, aiming to realize the targeted results of an intervention. The high-level planner serves to depict intervention tasks through the utilization of lower control software units, concurrently supervising them to ensure successful implementation. Lastly, the UGV interface acts as a conduit for communication between the UG and additional components involved in the HERON project.

11.4.1 UGV Interface

Considering the heterogeneous characteristics of the components within the HERON project and the projected creation of middleware proficient in interlinking them, it becomes evident that the robotic platform must facilitate communication with the entire system. Nonetheless, incorporating current software that

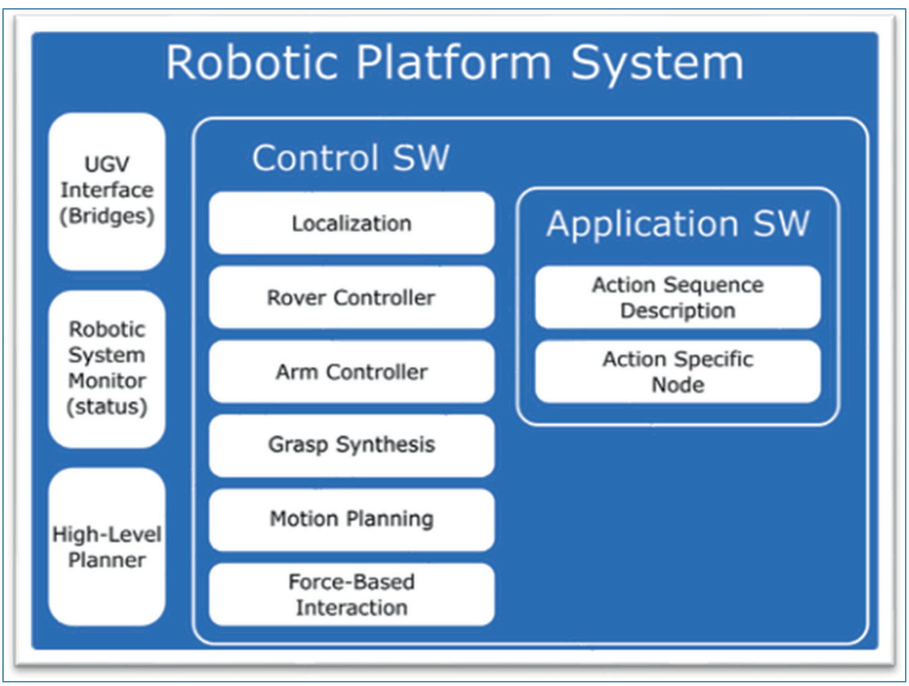

Figure 11.11. Overview of the robotic platform components.

encompasses certain foundational functionalities in the robot necessitates the retention of ROS-associated middleware at the robot's inferior levels. This component aims to unveil the robot's functionalities through various commands and signals, in conjunction with any necessary system feedback. Messages will be converted to ensure coherent communication between the specialized middleware and robot topics and services. Additionally, sensors pertaining to the robot will utilize this component to present the data available. Consequently, the UGV interface is poised to process an extensive variety of command calls and parameter setups, allowing it to engage with and adjust the system. This component's outcome consists of status feedback along with the data derived from the robot's sensors.

11.4.2 High-Level Planning

The high-level planning segment directs multiple actions accessible to the robot, orchestrating them to accomplish the intended task results. This procedure will leverage a domain-based planning representation to contemplate the interdependencies among actions and their pre and post-conditions, guaranteeing the creation of valid action sequences. The component functions based on a symbolic representation of both the environment and accessible actions. The target state is depicted using the identical symbolic representation, which a planning algorithm utilizes to delineate the series of actions needed to reach the goal.

11.4.3 Localization

The localization segment grants the robot the ability to gauge its location within a real-time evolving map of the environment. This system leverages cameras, inertial measurement units, and laser sensors to craft a volumetric metric depiction of the surroundings.

11.4.4 Robotic System Monitor

There exists a probability that the internal statuses of various sub-components need recognition and comprehension to convey the overarching status of the robotic platform. A comprehensive snapshot will also be presented, encompassing hardware availability and operational configurations, along with the requisite alerts and logs. In this vein, the component will assimilate input from both control software components and hardware specifics. This data is then employed to trigger alerts where needed while cataloging data for subsequent analysis and offering a summary of the system's condition.

11.4.5 Rover Controller

The HERON UGV is built upon a commercial Robotnik Robot, which will be customized for the maintenance tasks undertaken within the project. Fundamental movement functionalities form this component's nucleus, supporting various abstraction levels to accommodate diverse command types. In all instances, steering and traction motions will be directed to this component for conversion into motor actions. Commands will be accepted in the standard ROS movement command format, comprising linear velocity and steering angle directives, to be executed by an onboard closed-loop controller within the rover.

11.4.6 Arm Controller

The projection of incorporating a robotic arm to facilitate manipulation tasks within the project is anticipated. Several pre-existing arm options are under evaluation, contingent on the specific requirements of the use case. In all situations, proprietary drivers form the base layer for collaborative robotic arms, where manufacturers usually offer comprehensive APIs for robot interfacing. Yet again, a component translating user requirements into executable device instructions will be necessary. The arm controller will interpret inputs as either full motion plans, operation sequences, or individual directives. The outcome of any such input is the closed-loop adherence to the issued commands, accompanied by feedback.

11.4.7 Secondary Elements Controller

Supplementary operational elements that will be installed on the platform, like pumps, compressors, sprayers, raw material storage, level monitoring, and dispensing systems, will rely on a dedicated controller to synchronize actions with other HERON systems engaged in specific repair assignments, facilitating the mandated maintenance activities.

11.4.8 Grasp Synthesis

The grasp synthesis segment generates potential grasp points on object surfaces based on 3D reconstruction of the concerned object or scene. This technique demands a point cloud voxelized reconstruction of the object or scene in question, along with the robot's positioning and the manipulator's joint data. This module yields a list of positions and orientations for the end-effector on the object or scene's surface, promising a high grasp success probability.

11.4.9 Motion Planning

The motion planning segment devises trajectories that, when adhered to, guide the robotic system or its sections, such as the mobile base or manipulator, into a preferred setup. This planning mechanism necessitates an environmental representation in the form of an occupancy map. Besides the map, the mobile base and manipulator's locations are essential inputs to the planning structure. The objective is defined in terms of the state the robot aims to achieve with its mobile base and manipulator, along with any other pertinent data like operating volume, kinematic constraints, etc. The motion planner's output is a strategy, embodying a series of positions and speeds, executable by the lower-level control systems.

11.4.10 Force-Based Interaction

This component empowers the manipulator to engage with the environment in a way that deliberately fosters contact between the environment and the end-effector or manipulated object. The component demands the mobile base's position state and the manipulator's joint details. Along with this state information, the trajectory to be executed and any additional interaction constraints, such as maximum force, are required. The enactment of force-based interactions necessitates data concerning the forces and torques influencing the end-effector, and ideally the individual joints. This results in a high-frequency stream of control commands, consistently updated in alignment with the system's state alterations.

11.5 Visualisations & Improved Situational Awareness

The HERON system is designed to enhance situational awareness for principal parties involved in road maintenance (RM) and road inspection (RI) processes. Situational awareness involves recognizing the elements and events within the environment as they relate to time or space, understanding their significance, and forecasting their impending status. The strategy adopted by HERON is predicated on leveraging three primary components to offer users a continuous real-time (RT) data feed, thereby amplifying their situational awareness. These components are the Common Operational Picture (COP) module, an Augmented Reality (AR) application, and the Incidence Management & Decision Support System (IMS&DSS) application. The objective is to furnish decision-makers, operators, and field personnel with the comprehensive data necessary to streamline their operational plans and carry out effective road inspections and informed decision-making endeavors.

11.5.1 IMS & DSS

The IMS&DSS will be developed on the foundation of the lightweight client from the PANOPTIS H2020 project's IMS (refer to www.panoptis.eu). This foundation will be expanded to integrate with the HERON Middleware and to accommodate the unique specifications and business logic identified in the HERON case studies. Utilizing a containerized architecture, this system encapsulates software and its prerequisites in a discrete unit, facilitating streamlined server-side information processing and secure, efficient remote connections through a reverse proxy server. This server setup not only ensures load balancing and request tracking but also maintains a degree of anonymity for bolstered cybersecurity.

The system's infrastructure, housing a database server, adeptly manages diverse data inputs, processes it for uniformity and consolidation, and securely stores it in a distributed, resilient file system ready for retrieval and utilization by the IMS/DSS system.

Delving deeper, the IMS architecture comprises several elements:

1. Web Server: Dispatches the web application to browsers, administering the application business logic by coordinating user requests and actions with various servers and systems.
2. Reverse Proxy Server: Processes incoming http requests, enhancing them with HTTPS encryption and compression before rerouting them to the corresponding upstream server.
3. Database Server: Safeguards vital IMS information, including user data, access privileges, and sensor data acquired from middleware operations.
4. Video Management Server: Facilitates the ingestion and streaming of video content sourced from UxVs and road operator CCTV networks.
5. IMS/DSS App: A comprehensive web application fostering remote engagement with robotic resources and functionalities in field operations.

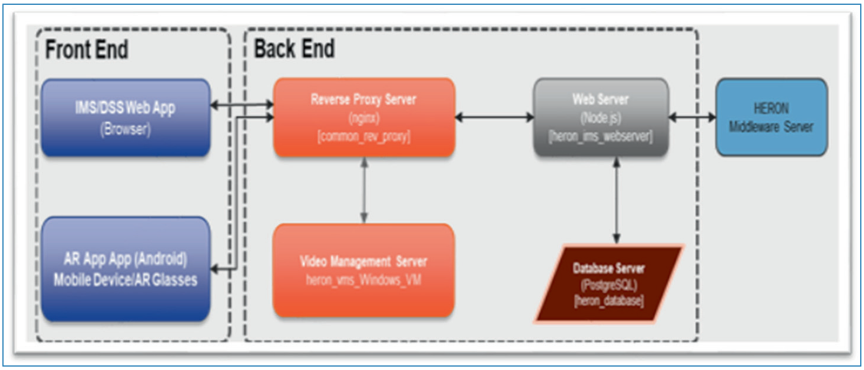

Figure 11.12. IMS system architecture.

6. AR App: A dynamic augmented reality application assisting users in pinpointing and analyzing structural road flaws or significant road components.

Together, these modules empower the IMS to cultivate and disseminate a Common Operational Picture (COP) among road inspection teams and pertinent road authorities, fostering collaborative efforts with various regional and local stakeholders as necessary. To sustain coherent communication and streamline processes, the IMS will employ specific protocols to nurture multi-level and multi-actor interactions, ensuring a unified approach to task execution

11.5.2 COP

As highlighted earlier, the HERON initiative enhances situational awareness capabilities by distributing detailed information obtained from all HERON sensors. This information is complemented by data from fusion processes, navigation modules, and positioning and advanced planning units, all of which are encompassed in what is termed the Common Operational Picture (COP). This centralized virtual representation of the HERON Robotic platform controller acts as a vital resource for robot operators and decision-makers in road inspection companies, enabling them to organize their assignments proficiently.

The COP's complex elements will be segmented into various layers and categories of information, creating a flexible system that operates on a "need-to-know" basis. This is in anticipation of the diverse user profiles and roles that will interact with the HERON tools and services through the AR, IMS, and DSS systems.

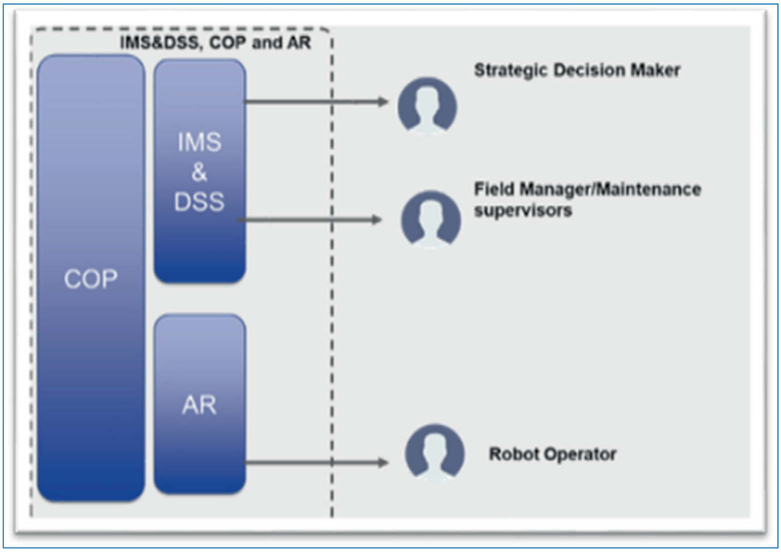

Figure 11.13. IMS, COP, AR user and roles.

11.5.3 AR App

The AR system will undertake the task of delivering real-time graphical data on the environment surrounding the robot operators. The AR application, specifically designed for Android-based AR devices, will facilitate the visualization of existing defects, automating the detection and severity classification of pavement flaws. Furthermore, the Android AR application will employ 3D model overlays to reveal potentially concealed structural elements that might influence the maintenance procedures or cause further damage. The display of functional elements will also be accessible through relevant commands.

11.5.4 Middleware and Data Fusion

The overall middleware and DF architecture of HERON are presented in the following figure.

The HERON middleware is structured to integrate data from various HERON elements and sensors, interfacing efficiently with the application layer while maintaining high reliability and scalability. This structure is divided into two main layers.

The first layer focuses on essential data pre-processing (Figure 11.14), consolidating information from multiple sources into unified data models using

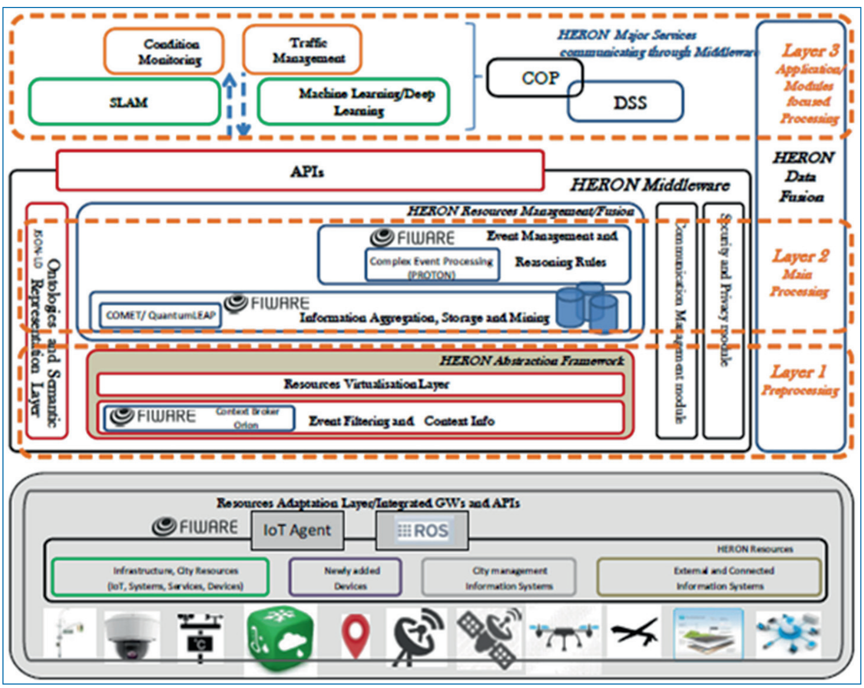

Figure 11.14. Schematic diagram of HERON middleware.

established FIWARE data models and JSON schemas for a straightforward key-value representation of context data.

The second layer is concerned with data storage, processing, and forwarding it to the application layer. Here, data undergoes virtualization into objects and is normalized and stored. This layer manages the primary processing of data from Layer 1, where it works closely with Resource management to create additional events and manage the data fusion process. Through Event Management, it handles, categorizes, and processes events and data from different sources, making them readily accessible via the API to the DSS system and other modules that need extra data. It also makes raw data available for further processing by high-level modules and applications.

To ensure the safety and integrity of the data, the middleware only accepts and stores data from trusted sources, allowing access to authorized requests only. It employs a policy-based management framework with mechanisms for data encryption, access control, and privacy protection, supplemented with tools for intrusion detection and prevention.

Finally, the system will establish necessary interfaces and protocols to communicate with different data sources and user services, managing aspects such as time synchronization, scheduling, communication path selection, fault tolerance, and traffic shaping seamlessly.

11.6 Conclusions

In conclusion, the HERON project stands as a beacon of innovation and advancement in the realm of road infrastructure maintenance, proposing a holistic, automated system buttressed by an autonomous ground robotic vehicle. This groundbreaking initiative not only pioneers the use of cutting-edge technology in infrastructure upkeep but also serves as a catalyst for enhanced safety, efficiency, and adaptability across diverse transportation networks.

Central to the HERON project is its innovative approach to road infrastructure maintenance. The integration of an autonomous ground robotic vehicle signifies a paradigm shift, fostering a more proactive and responsive system capable of adapting to the myriad demands of contemporary transport infrastructures. This transformative vehicle is envisioned to be the nucleus of the HERON system, orchestrating a seamless and continuous vehicle for infrastructure data exchange. By doing so, it aims to significantly heighten user safety through the constant monitoring and rapid response to changing road conditions.

Moreover, the HERON initiative is designed to fully harness and maximize the capabilities of modern technology to foster adaptability across various transport infrastructures. This adaptability is seen as a cornerstone in reducing the incidence of fatal accidents, a pressing issue that plagues road networks globally. Furthermore, by introducing a streamlined, automated approach, the project stands to significantly mitigate maintenance costs and traffic disruptions, thus fostering a more fluid and efficient transport environment.

Looking towards the future, the HERON project is poised for further evolution and refinement. The forthcoming phases anticipate the meticulous integration of individual components such as sensors, actuators, and tools, each playing a critical role in the system's overall functionality and efficiency. These components, working in synergy, are expected to bring unprecedented levels of precision and reliability to infrastructure maintenance.

Furthermore, the project embarks on the journey towards the on-site demonstration of the HERON system, a critical milestone that stands to validate the potential and efficacy of this revolutionary approach. This demonstration aims to showcase the real-world applicability and benefits of the HERON system, potentially serving as a blueprint for similar initiatives globally.

In essence, the HERON project represents a promising stride towards a safer, more efficient, and responsive road infrastructure network, marrying technology and innovation to meet the complex demands of modern societies. It serves as a testament to the potential of collaborative efforts in bringing about substantial advancements in road infrastructure maintenance, potentially ushering in a new era of safety and efficiency on the roads that connect us all.

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