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Road maintenance operations guided by XR technologies combined with a robotic modular platform.

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Contents

Foreword

This CEN Workshop Agreement (CWA XXXX:YYYY) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop CEN/WS Intelligent Road intervention processes, the secretariat of which is held by UNE – Spanish association for standardization consisting of representatives of interested parties on 07-10-2024, the constitution of which was supported by CEN following the public call for participation made on 2024-08-08. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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The following organizations and individuals developed and approved this CEN Workshop Agreement:

- CEMOSA – CENTRO DE ESTUDIOS DE MATERIALES Y CONTROL DE OBRA SA - Jose Solis-Hernandez and Paula López Arévalo
- Università degli Studi di Genova – Alice Consilvio and Mohammad Abbasi
- Laboratory for Manufacturing Systems and Automation - Themis Anastasiou
- Fundación Tekniker - Ander Ansuategi
- EIFFAGE INFRAESTRUCTURAS S.A. – Rafael Martinez and Miguel Angel Aragón
- UPM – Jesús Rodríguez
- European Science Communication Institute gGmbH – Mara Van Welie
- CERIB – Thibaut Le Doeuff
- SPW – Gauthier Michaux

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Introduction

For effective highway maintenance, several activities shall be regularly performed under hazardous conditions. Traditionally, these maintenance tasks are handled exclusively by experienced road operators. According to statistics, such operations rank among the most dangerous for workers, presenting a significant modern challenge. Specifically, Eurostat reports that in 2020, the road worker fatality count in the EU reached 3.355, an increase of 53 deaths from the previous year [1]. This data highlights the urgent need to automate these operations, both to enhance efficiency and to minimize human risk.

In response to this issue, this CWA provides guidelines for a comprehensive framework designed to automate various road maintenance activities. The goal is to develop a versatile robotic solution, guided by XR (Extended Reality) applications, that can be adapted to multiple tasks rather than being restricted to a single function. This framework includes a modular robotic platform, a robotic system, perception algorithms, and XR applications to support road workers.

This framework was initially developed as part of the H2020 OMICRON research program under grant agreement No. 955269. Within this project, all these tools were integrated to address challenges such as installing road safety barriers or signals, sealing road cracks, removing paint using lasers, cleaning road assets, and placing and collecting cones.

With this framework, formerly hazardous tasks have been transformed into human-robot collaboration (HRC) operations. The robot handles the most challenging and dangerous aspects, while road workers focus on monitoring and controlling the system via user-friendly XR applications. Consequently, this framework reduces the number of workers required for these operations, improves efficiency, and decreases cycle time.

This CWA is focused on the development of XR applications, considering this framework as a specific case study. Throughout the document, various guidelines and instructions are provided for developing such applications. Rather than detailing the development of a specific application, the CWA presents a general methodology.

1 Scope

This CEN Workshop Agreement centres on a complete and flexible framework for performing road maintenance operations, utilizing XR applications integrated with a modular robotic platform (MRP). The CWA aims to provide guidelines and best practices for the development of such applications, presenting the basic challenges and highlighting the most crucial aspects of the framework.

In the next sections of the CWA, a **complete methodology** will be presented for designing and developing XR applications integrated with the MRP to perform road maintenance operations. More specifically, the methodology involves the following:

- Guidelines for selecting the proper XR device for developing and executing the application.
- Guidelines for creating the virtual objects and the immersive environments.
- Guidelines for developing different functionalities for controlling industrial robots.
- Guidelines for defining the exact procedures of each road maintenance operations and specify the steps of execution.
- Guidelines for receiving information from sensors and V2X communication.
- Guidelines for the integration of XR applications with the MRP and other software systems.
- Guidelines for increasing the safety of the road workers through the XR applications. (Annexe A)

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp/

— IEC Electropedia: available at http://www.electropedia.org/

3.1

Road Maintenance Operation

various activities and tasks performed to ensure that roadways remain safe, functional, and in good condition for all users

3.2

XR

real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables

[SOURCE:ISO 5927:2024, 3.1.5]

3.3

VR

set of artificial conditions created by computer and dedicated electronic devices that simulate visual images and possibly other sensory information of a user's surrounding with which the user is allowed to interact

[SOURCE:ISO 9241-394:2020, 3.8]

3.4

AR

interactive experience of a real-world environment whereby the objects that reside in the real world are augmented by computer-generated perceptual information

[SOURCE:ISO/IEC 18038:2020, 3.2, modified]

3.5

MRP

flexible, configurable system composed of individual robotic modules that can be assembled, reconfigured, and adapted to perform various tasks.

3.6

HRC

a structured task or process in which humans and robots work together interactively to achieve a shared objective.

3.7

V2X

technology that allows a vehicle to exchange additional information with infrastructure, other vehicles and other road users

[SOURCE:ISO/IEC 4804:2020, 3.65]

3.8

User Interface

set of all the components of an interactive system that provide information and controls for the user to accomplish specific tasks with the interactive system

[SOURCE:ISO/IEC 9241-110:2020, 3.10]

3.9

Egocentric AR

an immersive AR experience that uses a first-person perspective, allowing users to view and interact with digital content as if it's directly overlaid onto their immediate surroundings.

3.10

Robot Operating System (ROS)

an open-source framework designed to aid the development of robotic applications, providing tools, libraries, and conventions for creating complex and scalable robot software systems.

4 Framework for the use of XR in road maintenance

Extended Reality (XR) technology, comprising both Virtual Reality (VR) and Augmented Reality (AR) technologies, is generally used for providing immersive environments with visualizations, animations and displayed information. Through this technology applications can provide assistance to operators for operations in several sectors such as manufacturing and construction. For assisting a road maintenance operation in combination with an MRP, this CWA presents the **three following applications**:

- **AR application for operator support on-site**. This application is designed to assist road workers in the field by providing step-by-step instructions, textual information, and visualizations. It enhances operator awareness through warnings, indicators, and real-time information, which is integrated with a V2X communication system.
- **A VR teleoperation application**. This application is tailored for enabling the operator to control the MRP remotely from a safe distant place. The operator enters an immersive virtual environment from a safe location, such as an office, and is able to teleoperating the industrial robot, monitor the operation and acquire useful information about the operation site. For this purpose an environment is reconstructed, by receiving information from on-site sensors real-time.
- **A VR training application**. This application has been designed to train road workers for performing road maintenance operations using the innovative technologies and the MRP. The training application has been created to get the workers familiarized both with the XR applications and with the specific procedure of each maintenance intervention.

Figure 1 presents a basic architecture of the provided framework.

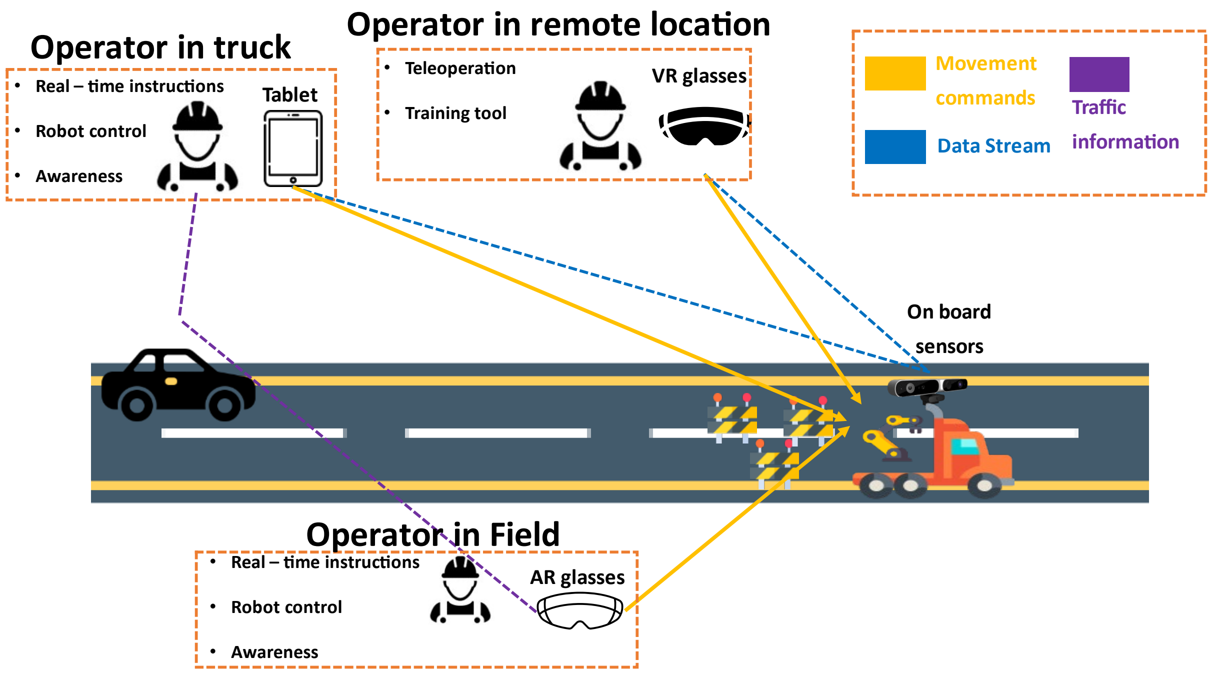

Figure 1. XR technologies architecture.

The XR applications grant to the operators several benefits. The most significant advantages are focused on the following points:

- Through the user-friendly interfaces, the operators can control the system with minimal knowledge about robotics or the specific operation. Even the most inexperienced operators are able to perform the operations properly by following the step-by-step instructions provided by the applications and controlling the industrial robot manually.

- The immersive visualizations of the XR tools, assist the operators to avoid potential mistakes throughout the procedure of the operations. The efficiency of the road workers is increased by providing real-time monitoring of the process with notifications and indicators when needed.
- By integrating the XR applications with the MRP, the cycle time of the road maintenance operations is also reduced. In this HRC operation, the road workers collaborate with the robotic platform to perform tasks at the same time, minimizing the overall duration of the operations.

NOTE The safety of the road workers increases significantly for three main reasons:

a) The number of the required workers for performing an operation is reduced.
b) The most dangerous or difficult tasks are assigned to the industrial robot instead of the road workers (e.g., lifting and manipulating heavy objects)
c) The applications provide safety indicators throughout the process

5 Methodology for the development of XR applications

5.1 XR device definition

Before developing an XR application one shall define the specific XR device that will be used to execute this application. For the road maintenance operations case study, the most suitable devices are the following:

- **VR headsets**: the VR headsets are tailored to display virtual environments, providing an immersive world for the operator to interact with. The operators can interact with the environment by using the controllers and they can control the operation by selecting specific virtual elements of the VR environment. The VR teleoperation and training tools that are presented in this CWA are executed in such headsets. If one wishes to develop a VR application, the VR headset is the only choice for executing the application.
- **Tablets**: Tablets provide a touch screen and a user-friendly interface. The familiarization with this device is faster than with the AR and VR headsets and the user interaction is restricted to simple taps on the screen. The tablets can be used to execute AR applications. In the tablet's interface, the live image of a camera can be displayed superimposed with virtual objects, such as lines and indicators. Also, the tablets can display textual information and provide User Interface (UI) elements to interact with, such as virtual buttons.
- **AR glasses**: The AR glasses is a device that blends the real world with the virtual objects. It is the best choice for egocentric AR applications to display information to the operator and assist in performing human-assigned tasks. The operator is able to observe the real world and see virtual objects superimposed on the environment around them. The operators can seamlessly interact with these objects using hand gestures and voice commands.

5.2 Virtual objects and immersive environments

The most crucial feature of the XR applications is the immersive virtual environments. These environments consist of several 3D virtual objects. According to the operation, the virtual objects achieve different goals. They may provide information to the operator, highlight real-world assets, or enable specific functionalities.

These virtual objects and environments can be either pre-designed or dynamic. The pre-designed objects are created and deployed into the application during the development process. They are placed at the appropriate positions, and they are programmed to have a specific behaviour. Some of these objects are designed to interact with the operator, while others provide information with no interaction required.

From the other hand, dynamic environments are crucial for providing real-time monitoring of the real operation and awareness to the operator. For the road maintenance interventions case study, dynamic environments can be designed with two ways:

- The operator can insert the coordinates of the location where the MRP is performing the operation. The application can create a virtual environment dynamically by receiving street view images. The images are used to create a skybox, leading to an immersive environment that resembles the real environment around the MRP.
- Using the live image of a stereo camera, an environment reconstruction process can be performed. According to this process, the camera feedback is used to create a virtual copy of the environment. This environment is loaded on the VR application, creating a realistic environment to provide information to the operator about the real environment at the location of the operation.

Both of these ways for dynamically generating environments are suitable for operations like the VR teleoperation application.

5.3 Robot control functionalities

To perform successfully road maintenance operations the operator may be able to control the industrial robot of the MRP manually from within the interfaces of the XR applications. The following methods are provided to facilitate this functionality:

- **End Effector Method**: The operator interacts with a virtual object to designate a destination position for the robotic arm. According to the XR device, the interaction method may be different (hand gesture, drag-and-drop, pressing buttons). This position will be the exact point where the end effector of the industrial robot will stop after the robot's movement is completed. Once the operator has designated a position, a signal will be sent to the robotic system to calculate and execute the movement of the robot towards that position. The XR application can visualize the future trajectories of the robot to increase the operator's awareness of the robot's tasks.
- **Joint Values Method**: Another method involves a user-friendly interface, providing the values of each robot joint. Typically, industrial robotic arms have several joints, which can be expressed in degrees or radians. The operator can interact with specific buttons to adjust the value of each joint and rotate it towards any direction.
- **Linear Movements Method**: One of the most useful methods is the method of linear movements. The XR application contains an interface with several buttons: one for each direction for both translation and orientation. By pressing each button, a signal is sent, and the robotic system moves the robot towards this direction. A slider is also useful for the operator to adjust the speed of the robot for this method.
- **Pre-defined Movements Method**: During the road maintenance operations, the robot might need to perform several sensitive movements. For such movements it is better to have pre-defined positions for the robot in order to minimize the risk of any potential collisions between the robot and any other object. The operator can trigger these movements by interacting with specific buttons on the interface of the XR applications.

5.4 Definition of maintenance sequence

One of the necessary functionalities of the XR applications is the provision of step-by-step instructions to the operator for the road maintenance operations. To facilitate this functionality, first the definition of the maintenance sequence should be performed.

This process refers to define the maintenance operation, and then break the operation down to specific steps. Each step will regard a task assigned to either the robot or the road worker. The task assignments should be performed in such way to facilitate a seamless collaboration between the operators and the robot, minimizing the cycle time of the operation. Also, it is important to assign to the robot all the difficult or dangerous tasks, increasing the ergonomic score of the operator's work.

Once the maintenance procedure has been defined, specific messages should be defined to inform the operator about the human-assigned tasks. These messages are displayed on the interfaces of the XR applications. For each step of the procedure, several visualizations are also designed for providing further assistance to the operator.

5.5 Integrating information provided by sensors and V2X communication

To increase the awareness of the operator, the XR applications can be integrated with all the available sensors that are installed on the area where the operation is executed.

Regarding the integration with the sensors, the following guidelines are provided:

- **Stereo cameras**: This is one of the most commonly used sensor, since it provides the capability for real-time monitoring of the operation. The live image of the cameras can be displayed in specific interfaces of the XR applications.
- **Safety sensors (scanners)**: These devices can scan the activity area and identify potential dangers such as a collision between the robot and another object or the operator. This information can be sent to the XR applications and in order to inform the operator about these dangers with specific visualizations (as described in Section **Error! Reference source not found.**).
- **V2X communication**: Most of the road maintenance operations are performed on the roads while there is still traffic on the next lanes. For providing information to the operator about the conditions of the area and any potential unexpected events, the XR applications can be integrated with V2X systems. This system facilitate the communication between the XR applications and the vehicles of the road for exchange useful information.

5.6 Integration between XR applications and MRP

The final step to facilitate a successful framework for the execution of road maintenance operations is the integration of the XR applications with the MRP. The MRP is a platform that consists of a lorry, loaded with an industrial robot and other useful hardware components, such as a desktop PC, a power generator and several road assets according to the operation. The desktop PC is used to execute the robotic system and any required perception modules. The XR application is integrated with all these software modules of the MRP to receive information and send appropriate signals.

To facilitate communication with the MRP, a communication framework has to be established, such as the Robot Operating System (ROS). This framework enables the applications to send and receive different types of messages containing the required information. Through this connection, the operator is also able to control the robot manually when needed.

6 Efficiency and limitations of the XR methodology for road maintenance operations

6.1 KPIs and efficiency assessment

The XR applications for performing road maintenance operations should be validated against the following KPIs:

- KPIs related to the number of road workers needed to be on-site for performing the operation with the XR applications.
- KPIs related to the cycle time of the operation using the XR applications combined with the MRP.
- KPIs related to the accuracy of the results of the operations when performed using the XR applications combined with the MRP.

6.2 Lighting issues for the visualizations display

One notable limitation of the XR utilization for road maintenance operations is that the difficulty of the AR glasses devices to display visualizations under bright light. These devices have been designed to work indoors where there is only artificial light. Due to the fact that most of the road maintenance interventions are performed outdoors during the day, the road workers shall be wearing the AR glasses under direct sunlight.

To overcome this issue, tinted film can be applied over the lenses of the AR glasses to block the sunlight and make the visualizations visible. With this film, the operator will be able to observe both the real world and the virtual objects at the same time even when he operates in bright light, similar to as they wore sunglasses.

6.3 Network connection challenges

Regarding the network connection, the following important points can be taken into account:

- The AR tools require to be connected to a local network. The MRP should be connected to the same network for a proper communication to be established.
- The VR training application can operate completely offline with no network connection required.
- The VR teleoperation tool is a web-based application. This means that it requires a remote connection between the PC that executes the VR application and the MRP. For this purpose, both networks should have proper internet coverage. This can pose an important challenge when the MRP is located in a remote area (e.g., in distant highways). To provide internet coverage to the MRP, mobile hotspot is commonly used. In order to reduce the latency of the remote connection satellite internet can also be used, which can operate regardless of the geographic location of the MRP. In addition, most communication frameworks (such as ROS) are designed only for local networks. To overcome this issue, a VPN should be established for the VR teleoperation application, connecting the two networks and facilitate communication between the remote connection.

Annex A (informative)

Guidelines for increasing the safety of the road workers

The safety of road workers is one of the most significant aspects of the XR applications. Through these applications, the safety is increased with several methods as explained in Section 1.

First of all, by assigning tasks to the industrial robot, fewer operators are needed at the activity area. Additionally, most operations may be performed by the robot exclusively. In such operations, the road worker can be located in a safer place, such as within the cabin of the MRP, controlling and monitoring the operation from an XR application. As a result, the number of people required for executing the operations is reduced. Also, by utilizing the VR teleoperation application, the operator is completely safe from a distant location without reducing the efficiency of the operation.

Furthermore, several safety indicators can be developed within the XR applications. These indicators can notify the operator in case of any danger in cases such as when the operator is very close to the robot or any dangerous event has occurred on the road. The indicators may be either specific visualizations and animations, or textual notifications.

Finally, to enhance the safety of the HRC, two visualizations can be designed for the AR application: the safety zones and the future trajectory robot hologram. The safety zones are usually circular visualizations showing the dangerous areas around the robot according to its reach. The operator can observe these visualizations to make sure where they should be located while the robot is moving. The robot hologram is a virtual object that visualizes the future trajectories of the robot. While the robot is moving, the operator can observe these trajectories to make sure that there is no possibility of any potential collision between the robot and any other object. In case the operator detects any danger caused by a robot's movement, they can immediately terminate the system with either a virtual (from within the interface of the AR application) or a physical emergency button.

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