PoC Reference: Industry Management Remote Controlled Robotic Inspection Use Case

Classification: APPROVED REFERENCE DOCUMENT

Confidentiality: Public

Version 1.0

December 13, 2023

[IM RCRI RIM PoC Reference]

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1. Introduction

The Innovative Optical and Wireless Network Global Forum (IOWN GF) has defined the Cyber Physical System Industry Management Use Case (IM UC) [IOWN GF CPS UC] and developed the Reference Implementation Model (RIM) for Remote Controlled Robotic Inspection reference case (hereafter, the RCRI RIM) [IOWN GF RCRI RIM]. This PoC Reference provides guidelines for conducting the Proof of Concept (PoC) of the RCRI RIM to prove the validity and efficacy of the RIM.

1.1. Purpose

To deliver specifications for IOWN technologies satisfying market demands rapidly and efficiently, IOWN GF is taking an iterative approach of

- developing a RIM based on the IOWN GF Use Cases,
- executing PoCs for evaluating the RIM using a defined Benchmark Model and
- providing outputs of the executed PoCs for developing specifications and feeding back to the next version of the RIM.

The RCRI RIM [IOWN GF RCRI RIM] document defines:

- The Benchmark Model for RCRI metrics for evaluating implementation models
- The initial RCRI RIM yields the best evaluation results for the Metrics defined in the Benchmark Model.

This document provides guidelines for conducting PoCs to evaluate the RIM as the part of the iterative approach to validate how IOWN technologies enable low-latency and high-reliable remote inspection of the RCRI UC.

1.2. Objectives

Toward the purpose stated in 1.1, this document defines the objectives of the PoC for RCRI UC as follows:

- To aid in developing the specifications of IOWN technologies satisfying the market's demand rapidly and efficiently by accelerating through the iterative approach with PoCs for RCRI UC for evaluating the RCRI RIM,
- To implement critical parts of the RCRI RIM, which have difficulty being realized economically with the current technologies,
- To measure the metrics related to the operational feasibility and the system cost and
- To find potential technical improvements and provide feedback to future releases of IOWN technologies and RCRI RIM studies.

1.3. Scope

Currently, many use cases perform factory inspections using a single drone-mounted camera, but all 4K images are processed offline, and there are no use cases that process image data in real-time or synthesize images from multiple angles by multiple cameras. Therefore, if IOWN can enhance the entire network environment, including RAN, use multiple drone operation systems and video synthesis systems, and share the processed video with remote locations simultaneously, it can be a use case that attracts the interest of plant engineers involved in IM, thus proving IOWN's value through productivity improvement and complete examination with multi-angle video productivity.

To achieve the objectives outlined above, this document defines a two-step PoC scope that includes the critical parts of the RCRI RIM: Step 1 presents the requirements necessary for feasibility checks in an experimental environment, and Step 2 defines additional requirements that are applicable to the actual plant environment.

- Step 1: Inspection by remotely operated cameras
  - Scope: Mobile robot/drone with camera, Local Aggregation Node, Navigation Application, and Presentation Device.
  - Important points to be confirmed: using video images from multiple cameras, the detailed state and possible equipment defects can be observed in real-time from remote locations.
  - Some features that are expected to be realized in actual plants but are not essential to confirm the basic scenario above are defined as optional.
- Step 2: Inspection by remotely operated cameras in a real plant site.
  - The scope is basically the same as step 1. Additional requirements for the protection of robots and wireless network equipment, such as complying with explosion protection regulations, are needed in the actual factory environment.

The scopes of both steps are shown in Figure 1 in the context of the full RCRI RIM, which is slightly simplified from Figure 5 of the RCRI RIM document for explanatory purposes.

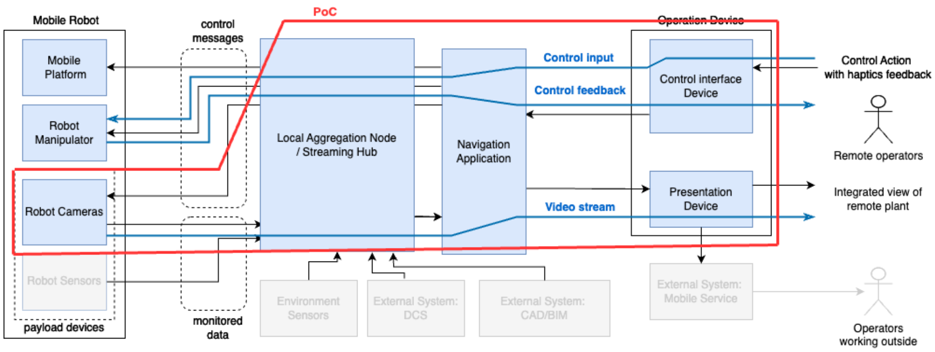

Figure 1: RIM architecture of IM RCRI UC

This document provides an overview of the PoC, required components, advanced optional features, and the expected benchmark in section 2.

2. PoC: Inspection by remotely operated cameras

This section describes the requirements of the PoC named Inspection by remotely operated cameras. The overview of PoC is provided in 2.1. Required components for the PoC are discussed in 2.2. All PoC reports need to cover at least the features in 2.2. Then, the advanced optional features for PoC are highlighted in 2.3. Finally, the expected benchmark of the PoC and other considerations the PoC Team should take into account are described in 2.4 and 2.5, respectively.

2.1. Overview

This section describes the basic scenario of PoC along with its background and objectives. This PoC will cut out a portion of the RCRI RIM configuration and work first on configurations that have a strong need and high priority in the Plant field to demonstrate real-time remote inspections that take advantage of the high speed of IOWN, especially Open APN. The PoC system will prove that it will be possible to provide a substantial on-site response in refineries and chemical plants without having to visit the site, even for fault information that is difficult to convey by words, photos, or videos. This scenario demonstrates that remote inspections can be implemented to provide a real-time understanding of the site rather than an offline verification of the remote site. The system also aims to eliminate the need to visit plants for on-site inspections of products by enabling instructions and confirmation from the office without having to go to the site.

Devices and data flow are as follows:

- Video cameras at an on-premise site (simulating a real plant site) capture video streams of targeted objects to be inspected.
- Captured videos are transferred to a local aggregation node on the site (or MEC) via a wireless network.
- Aggregated video streams are transferred to a navigation application via Open APN.
- Remote operators can view and inspect target objects using presentation devices.
- Remote operators can also remotely control the on-premises video camera to change the camera's range of view and the object to be inspected.

Note: Since this PoC does not perform data hub/streaming hub functions (e.g., data storage), it is treated as a single node integrated with the local aggregation node.

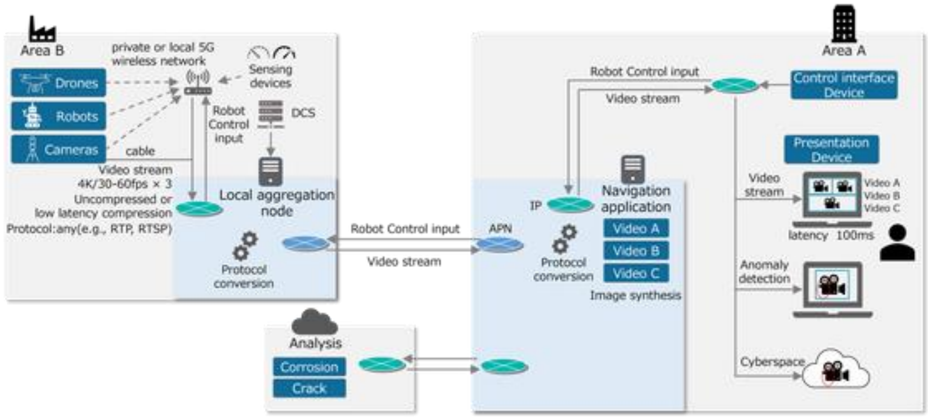

Figure 2: An overview of PoC

2.2. Required components

PoC system consists of camera devices, communication between cameras and a local aggregation node, navigation application, and presentation devices. The following subsections describe the selected features of each component for the PoC.

2.2.1. Camera and sensing devices

- Components
  - At least three sets of video cameras mounted on robots or drones needed to provide a comprehensive view of the site environment with multi-angle images.
- Functional features
  - Video definition: 4K, 30-60 FPS
  - Encoding: Uncompressed or low latency compression (such as Motion JPEG or JPEG-XS)
    - If sufficient bandwidth in the wireless network is unavailable, a preliminary evaluation using common compression encodings (e.g., H265) may be performed.
  - Network: wireless real-time transmission of video streams
  - Video transfer protocol: any (e.g., RTP)
- Optional features
  - Sensing devices
    - Pressure Gauge (～ 20Kbps)
    - Vibration meter (～ 20Kbps)
    - Temperature (～ 20Kbps)
- Non-functional features
  - Drones should be easily operated by a drone operating system.

2.2.2. Wireless network

- Components
  - A local or private 5G wireless network system with sufficient bandwidth to accommodate traffic from the camera and sensing devices

2.2.3. Local aggregation node

- Functional features
  - Can receive video streams via a wireless network and send them via Open APN
  - Protocol conversion between the IP-based transfer over the wireless network and non-IP-based transfer over the Open APN, such as RDMA-based transfer (ref: [RCRI RIM] section 5.1.3) if applicable

2.2.4. Navigation application

- Functional features
  - Receive video streams from the Local aggregation node via Open APN
  - Render output video screens to show to remote operators
- Optional features
  - Image synthesis from multiple video streams
  - Image synthesis with visualization of sensor data
  - Anomaly detection, such as corrosion and cracks

2.2.5. Presentation device

- Components
  - 4K display or HMD device

2.3. Advanced Optional Features

This section describes advanced features expected to make remote inspection more productive. It is optional and not required.

2.3.1. Volumetric Image Transmission

Using volumetric capture of real objects to view their 3D holographic images at remote locations is another important approach to improve the efficiency of remote site inspection. This PoC reference defines volumetric image transmission integrated with point cloud data as an optional feature, as described in this section. PoC executor may perform this additional verification for this feature. Since this feature attempts to evaluate independent scenarios, the PoC reference also accepts PoCs specific to this optional feature.

In the real use case, the object size will be within 10m x 10m x 10m, and the 3D holographic can be viewed by moving the viewpoint freely. As an optional feature of this PoC, a 3D holographic image scale is approximately 30 cm cubic and remotely projected to prove it can be virtually reproduced. As a benchmark, a 3D holographic image is projected at a remote location by combining the images from 4 to 8 cameras and point cloud data. Four sets of camera modules mounted and fixed on tripods or similar devices are used, each with two cameras mounted at high and low positions to surround the space to be transmitted. The video data captured by the cameras and the point cloud data are transmitted and processed in real-time from the remote site, and the 3D images are projected to make it appear as part of the site.

The following additional devices are necessary to verify this feature.

- On-site equipment
    - 4 to 8 video capture devices (digital cameras):
    - Point cloud acquisition device (LiDAR sensor):
        - Detection distance: 0.5~200m
        - Detection distance resolution: 0.0625m
        - Detection angle of view: 120° horizontally, 15° vertically (24 lines)
        - Detection angle resolution: 0.12° horizontally, 0.6° vertically
        - Scanning frequency: 10 times/sec
        - The data rate will be about 8 Mbps (without compression)
- Remote-site equipment
    - Navigation Application Node that performs video data/point cloud data integration
    - An XR video projection device with 6DoF

Integrated (output) PoV video specifications:

- Full HD (1080P), 30 fps

Other considerations:

- A wireless network should be connected to capture devices (cameras and LiDAR sensors)

Note: Remote transmission through an Open APN is preferred but not required if only this optional feature is validated.

2.4. Expected Benchmark

This PoC will demonstrate that remote inspectors can detect non-steady state conditions by viewing video from remote locations in real-time to prevent equipment failure during plant operation. To evaluate the feasibility of the remote inspection, the following values should be reported and evaluated as benchmarks.

System configuration:

- System configuration, including RAN, fixed networks, servers, and applications used in the evaluation
- Estimated system and operational costs
- Bottleneck points identified in measuring the following benchmarks

Technical evaluation:

The table lists the technical indicators to evaluate and report.

ITEM	INDICATORS	POC TARGET
Total system data rates	data rates (uplink and downlink)	(not specified)
Specifications of video	• resolution, frame rate • encoding • bit rate • number of streams	• 4K, 30-60 FPS • Uncompressed or low latency compression • (not specified) • >= 3
Latency of video streams	delay ms (motion-to-photon latency is desirable) *1	100 ms, ideally, and 500 ms at the latest *2
Stability of video transmission	frame drop rate	< 0.1 %
Defect detection AI (when implemented)	• accuracy • delay of detection	(not specified)

*1 Latency reduction effect of RDMA transfer using Open APN and additional delay due to image synthesis or superimposed sensor data are also reported when implemented.

*2 RCRI RIM uses 1,000 km as a benchmark for distance between sites.

Operational evaluation:

Operational assessments should report whether measured technical indicators are sufficient for a real-time understanding of remote locations and obtaining adequate feedback from a remote inspector or supervisor. In addition, other characteristics of the transmitted video will also need to be evaluated similarly. The following are examples of such indicators, but where other indicators are important, they should also be included in the report.

- Distance between camera and objects to be inspected
- Delays related to robot/drone movement and camera angle change operations

Economic feasibility is another important aspect of RCRI PoC. For this reason, this report requires an evaluation of the cost of the system configuration used for the PoC, such as the gap between the cost of the system and the cost that would be acceptable in the future. The evaluation also needs to consider the following operational improvements that this PoC would demonstrate, as referred to in the RCRI RIM: personnel costs for travel, inspection costs, and operational safety. With these in mind, the reporter is expected to consider the extent to which these aspects can be improved by the results of the PoC.

Notes:

For this PoC, it is assumed that the total data rate will be constrained by the RAN with the equipment that can be available at this time. Therefore, it is necessary to report the specifications of the RAN equipment to be used for the PoC and the specifications of the video that can be accommodated by that equipment.

With respect to minimum delay, it is best to relay the video stream as it is without processing but to improve the work efficiency of real-world operations, multiple streams of the video should be combined and displayed or superimposed with sensor data at the relevant locations. The delay in adding this additional functionality should also be reported if these optional features were implemented. It would also be desirable to report the quantitative effect of RDMA over Open APN in reducing video delay.

2.4.1. Expected Benchmark for 3D Volumetric Image Transmission

To evaluate the feasibility of remote inspection using 3D volume images, the following parameters should be evaluated to determine the range within which work efficiency can be ensured.

- Motion-to-photon latency
- Degree of freedom to move the viewpoint
- Range in which objects can be zoomed in and out
- Number of cameras required to capture an object with sufficient accuracy
- Impact of using LiDAR data on image accuracy and work efficiency

2.5. Other Considerations

If the PoC is performed in an actual factory as step 2 described in section 1.3, additional requirements need to be applied, especially those related to explosion protection for safety.

- Of the devices described in Sec 2.2, those to be installed in the explosion-proof area of the on-premise plant site, such as wireless equipment, robots, drones, cameras, etc., must all have explosion-proof certification.

3. Summary

This document defines the scope of the PoCs for RCRI RIM. This PoC will facilitate the development of IOWN technology specifications specifically aligned with manufacturing market needs, facilitate the realization of complex aspects of RCRI RIM that are economically challenging for existing technologies, quantify metrics related to operational feasibility and system cost, and identify requirements for identifying potential technology enhancements.

IOWN GF eagerly expects to receive PoC reports related to this PoC reference. The findings from these reports will be thoroughly evaluated and serve as a catalyst to refine and guide the ongoing development of the RCRI RIM and associated IOWN technology specifications.

Reference

- [IOWN GF CPS UC] IOWN Global Forum, "Cyber-Physical System Use Case Release-1," 2021.
- [IOWN GF RCRI RIM] IOWN Global Forum, "Reference Implementation Model (RIM) for the Remote Controlled Robotic Inspection Use Case," 2023.

Note: The above documents are available on https://iowngf.org/.

History

Revision	Release Date	Summary of Changes
1.0	2023/12/13	Initial Version

