5GEARING

5G DEPLOYMENT FOR SMART INDUSTRY USAGE

CALL: BREITBAND AUSTRIA 2030: GIGAAPP
THEME: DIGITIZATION & BROADBAND
PROJECT TYPE: COOPERATIVE R&D PROJECT
PROJECT START: 1 MAY 2023
PROJECT DURATION: 18 MONTHS

D3.2 APPLICATIONS AND ALGORITHMS NEEDED FOR NAVIGATION OF ROBOTS IN INDUSTRIAL SETUP

5GEARING project is funded under the research and technology development of gigabit applications as part of lighthouse projects Breitband Austria 2030: GigaApp financed by the Austrian Federal Ministry of Finance and by the Austrian Research Promotion Agency (FFG) under the grant agreement n. FO999899772. Breitband Austria 2030: GigaApp was initiated by the Austrian Federal Ministry of Agriculture, Regions, and Tourism.

Document Information	
Project acronym:	5Gearing
Project number:	FO999899772
Deliverable number:	D3.2
Deliverable full title:	Applications and algorithms needed for navigation of robots in industrial setup
Submission date:	31.8.2024
Status:	[Draft]
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1 Executive Summary

The use of robots has highly increased the productivity in manufacturing in the last decades. Industrial robots are usually permanently installed on production lines and perform certain tasks. Nowadays, more and more Autonomous Mobile Robots (AMR)s are used, for example, to transport materials or goods from the warehouse to the production lines. These AMRs move alongside human workers on the factory floor and therefore have to be equipped with advanced sensors and safety features that allow them to operate in close proximity to humans without posing a risk. This document focuses on the applications and algorithms needed for a collaborative work between robots on basis of a pick and place operation between a Collaborative Robot (cobot) and an AMR that transports goods between production isles on a factory floor. Moreover, a streaming application was also developed using an industry grade video camera to monitor the latency of a high-quality video stream over the 5^{th} generation (5G) network.

2 Orientation and navigation of the AMR

AMRs use a set of sensors for a reliable localization and navigation on the factory floor. In the case of the Omron LD-250 as shown in Figure 1 the following sensors are available:

- **Safety scanning laser:** Provides range data within a 240° field of view for detecting obstacles and maintaining an accurate understanding of its location in the environment.
- **Low front laser:** Detects objects below the plane of the main laser.
- **Time of flight sensor:** It is located at the rear end of the LD-250 and senses objects close behind the AMR.
- **Gyroscope:** Provides rotational velocity data.
- **Wheel encoders:** Provides the navigation system with odometry information.

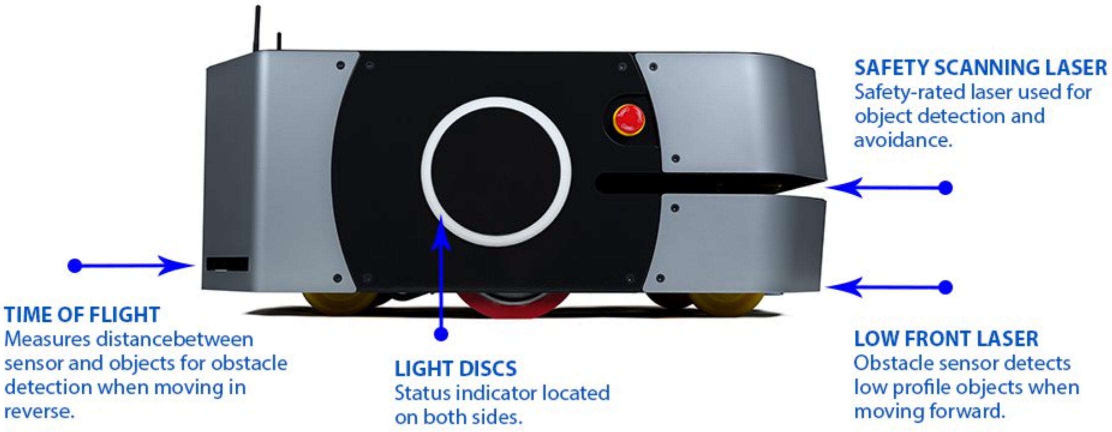

Figure 1: Omron LD-250 sensor (Source: https://www.omron-ap.com/)

In order for the AMR to navigate autonomously through its environment, the environment has to be scanned manually in advance. The AMR creates a map out of this data which is stored locally on the robot controller. For localization the LD-250 analyzes the odometry data together with the LIDAR data from its navigation laser. To guarantee a reliable localization the work environment is supposed to be static. Laser-only localization becomes difficult if changing features exceed 80% of the objects detected by the laser. This includes workspaces such as ware-houses, where objects such as shipping pallets or rolling carts either change locations often, or block the laser's view of mapped features. In such cases vision-based systems placed on top of the the AMR enhance the location accuracy.

To align with machinery the standard positioning system may not be accurate enough. The stop position repeatability of the LD-250 to a standard target is ±25mm and ±2°. For more precision to the possible cost of an increased cycle time the following high accuracy modes are available:

- **Cell Aligment Positioning System (CAPS):** CAPS uses the AMR's existing sensors to detect a fixed-mount target in the workspace. It provides a stop position repeatability of ±8mm and ±0.5°.
- **High Accuracy Postioning System (HAPS):** HAPS involves placing a magnetic line on the floor and installing additional sensors on the underside of the AMR so it can more accurately follow a path. It provides a stop position repeatability of ±8mm and ±0.4°.

Each single AMR basically operates on his own. However, to increase the efficiency of a fleet of robots management software can be used. This software for example assigns tasks to AMRs nearest to a production line or optimize the traffic flow of the AMRs by collecting the information of all AMRs to perform advanced path planning.

3 Camera-based object detection

Exact positioning is a requirement for a successful pick-and-place operation between collaborative robots. The pose repeatability of the Universal Robots 5e (UR5e) is of high accuracy with a value of ±0.03mm. As mentioned in the previous section the stop position repeatability of the LD-250 to a standard target is±25mm for operation of a single AMR and increases to ±35mm for multiple AMRs operating as part of a fleet. Even if the provided higher accuracy positioning modes, such as CAPS and HAPS, are used a successful pick-and-place operation can not be guaranteed. Therefore, a camera-based objection detection is implemented. This also makes the pickup process robust to an arbitrary orientation of the material/good to be picked and additionally ensures more safety by acting only on objects that are correctly detected in terms of shape or other unique features.

A fast integration of a camera-based system for the UR5e cobot is supported by installing a wrist camera from ROBOTIQ [3] on the cobots arm as shown in Figure 2. The software package runs locally on the robot controller and offers the following object training methods:

- **Parametric Object Teaching:** The Parametric Object Teaching mode builds a model based on parameters of a basic 2D shape like a circle, ring, square or rectangle. This quick method allows the vision system to recognize and locate with high robustness objects like raw material blanks, which have few distinctive features. It yields results faster than other methods for simple geometry and highly reflective objects.
- **Automatic Object Teaching:** The Automatic Object Teaching mode builds a model based on images and multiples scans of the object. Particular features, such as object edges and colors, can be added and parametrized to enhance the detection robustness.

Figure 2: Wrist camera mounted on the UR5e cobot

Automatic Object Teaching was used to train a model that detects the edges of an object shown in Figure 3. The processing time of the image takes approximately 1.5s which includes taking the snapshot, doing the object detection and actuating the gripper.

Figure 3: Object to be detected in the pick-and-place use case

4 Collaborative framework

Robot manufacturers use different interfaces and command sets to control their robots and to provide data to external devices. To make robots of different manufacturers to collaborate with each other an own software interface has to be programmed that translates between the individual robots. Figure 4 shows the implemented framework that enables the pick and place operation between the UR5e cobot and the Omron LD-250 AMR.

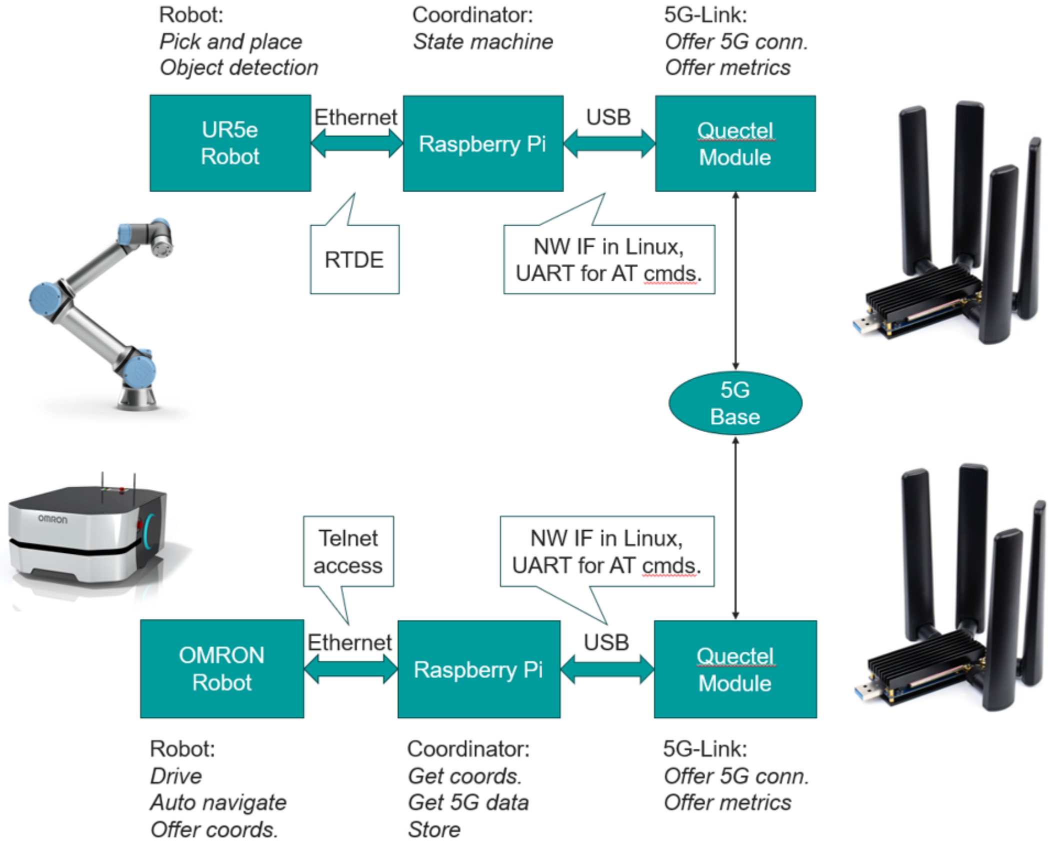

Figure 4: Block diagram of the collaborative robot interaction

A Raspberry Pi is used on both sides to enable remote control and status data collection of the robots over the local area network (LAN) ports as well as for establishing a 5G link for wireless communication between the robots. The Raspberry Pi connected to the LD-250 collects the coordinates and rotation data via the Advanced Robotics Command Language (ARCL) which is base on a Teletype Network (Telnet) protocol and informs the cobot when the AMR is approaching or has arrived for a pick or place operation. The Raspberry Pi connected to the UR5e cobot communicates via the Real-Time Data Exchange (RTDE) interface to control the actions of the cobot. After finishing a pick or place operation the AMR gets informed to move on to the next production isle. Moreover, a state machine is implemented to guarantee the right order of the processing steps and path movements. The interaction between the robots is realized via the Message Queuing Telemetry Transport (MQTT) protocol. For additional information about this protocol, please refer to Section 4.1 in Deliverable 5.2.

5 Video streaming

Visual systems can be used to enhance the location accuracy and object avoidance capability of AMRs. To meet safety constraints in an industrial environment, these visual systems have to work with high resolution at low latency. Within the scope of this project we implemented a software that can be used to analyze the trade-off between H.246 compression ratio and encoding/network latency. The Allied Vision G1-319c industrial camera [1] was used as visual device. Industrial cameras are high-performance cameras that are specifically designed for use in industrial and commercial environments.

Figure 5: Allied Vision G1-319c industrial camera

The key features of the Allied Vision G1-319c are:

- Ethernet interface
- Maximum resolution of 2064 x 1544 pixels
- Sony IMX265 sensor
- A maximum of 37 fps @ 122 MByte/s (Monocolor 8 bit)
- Typical power consumption: 3W @ 12VDC, Power over Ethernet possible (3.3W typical)

Figure 6 illustrates the workflow of the latency measurement. The camera is connected to a Raspberry Pi that acts as the client in the network and implements a GStreamer [2] pipeline for encoding and packaging of the video stream. GStreamer is a pipeline-based multimedia framework that links together a wide variety of media processing systems to complete complex workflows. GStreamer works by using a series of interconnected elements that perform specific media processing tasks. Each element performs a specific function, such as decoding a video stream or scaling an image, and the elements are connected together in a pipeline to create a complete media processing workflow.

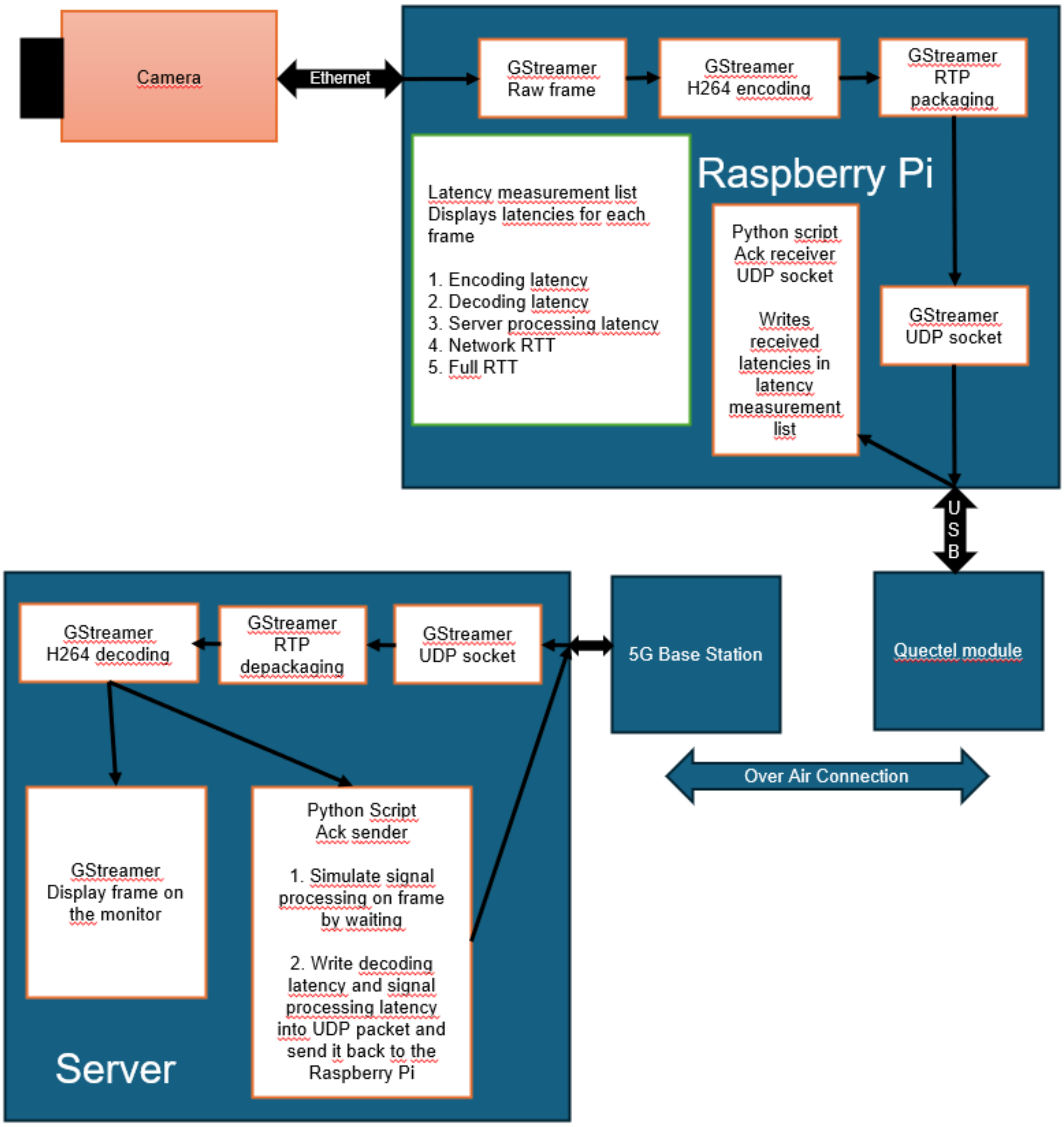

Figure 6: Block diagram of the video stream latency measurement

Every encoded video frame gets an unique ID number for later assessment of the round trip time (RTT) and is sent over a User Datagram Protocol (UDP) socket via a 5G link to the server where the video stream is de-packed, decoded and displayed on a monitor. On the server, some processing on the video stream is simulated by introducing a processing delay and the values of the determined decoding and processing latencies are written into the UDP packet before again sent back to the client over the 5G link. The client can do RTT measurements based on the ID numbers. This allows to measure network latency and latency of the complete processing chain including H.264-encoding/decoding, which is dependent on the video compression ratio.

6 Conclusions

Today's AMRs use Wireless Fidelity (WiFi) connectivity to share their status data and to interoperate with each other via some management software installed on a server. A 5G connectivity is not available out of the box and has to be deployed individually. In this work we set up a reliable operating 5G framework that enables low-latency collaboration between robots of different manufacturers by using components available on the market. Moreover, a streaming interface was developed that can be easily integrated into the 5G network to offload video data from the mobile robots to a central server.

Acronyms

5G 5^{th} generation. 2, 6, 8, 9

AMR Autonomous Mobile Robots. 2–4, 6, 7, 9

ARCL Advanced Robotics Command Language. 6

CAPS Cell Aligment Positioning System. 4

cobot Collaborative Robot. 2, 4

HAPS High Accuracy Postioning System. 4

LAN local area network. 6

MQTT Message Queuing Telemetry Transport. 7

RTDE Real-Time Data Exchange. 6

RTT round trip time. 8, 9

Telnet Teletype Network. 6

UDP User Datagram Protocol. 8, 9

UR5e Universal Robots 5e. 4, 6

WiFi Wireless Fidelity. 9

References

[1] *Allied Vision Webpage.* URL: `https://www.alliedvision.com/en/`.

[2] *GStreamer Webpage.* URL: `https://gstreamer.freedesktop.org/`.

[3] *ROBOTIQ Webpage.* URL: `https://robotiq.com/`.