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Abstract / Motivation for the research:

T2.2 Industry 4.0, standard integration [Arc, Kilobaser, Genomika, UNIGE, m1-30]. 1) Definition of the electromechanical interfaces and data and communication protocols. Standardization for collaborative work with today's standalone product like Kilobaser and Oxford Minion Nanopore or DNA archiving system and translation stage system. 2) High-volume data uploads by processes from different suppliers require a specific IT structure that needs to be validated. Communication standards will also be validated. 3) The asynchronous management of technology block requirements, the capacity to modify the layout and the number of technology blocks according to changing needs requires standardization of tested and validated systems.

Deliverable D2.4 – Industry 4.0 standard integration Version 1

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Deliverable Name	Industry 4.0 standard integration Version 1		
Type	DEM — Demonstrator, pilot, prototype	Dissemination Level	PU - Public
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Description
Interfaces definition, data and communication protocol and IT structure adapted to high volume data

KEYWORDS:

Autonomous machine, communication protocol, robot interaction, software interface

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ABBREVIATIONS

IP	INTERNET PROTOCOL
IPv4	INTERNET PROTOCOL VERSION 4
IT	INFORMATION TECHNOLOGY
PLC	PROGRAMMABLE LOGIC CONTROLLER
OT	OPERATIONAL TECHNOLOGY
OPC UA	OPEN PLATFORM COMMUNICATION UNIFIED ARCHITECTURE
TCP	TRANSMISSION CONTROL PROTOCOL

1. INTRODUCTION

One of the outcomes of the 4th industrial revolution is the realization of autonomous systems by the minimization of human intervention. The DNAMIC project plan to apply the idea of an autonomous micro factory for archiving data in DNA. An autonomous factory is mainly based on 4 concepts: autonomous machines, auto-adaptative production controlled by software, plug & produce machines and robotized materials transport. These concepts have the following implications on the project:

- All machines, robots and other devices need to be autonomous, or at least minimize the human intervention (e. g. given periodic maintenances could be done by human).
- The transport of the materials (product, consumable, waste, tools...) is automatized by robots
- All machines, robots and other devices are controlled by a software to perform operations
- All machines provide information about the auto-control of their operations
- The interface between machines, robots... with the control software is standardized

This document describes all the IT and OT requirements each part must adopt to be integrated in the DNAMIC micro-factory. It is an adaptation and translation of the similar document for the project HE-Arc Micro Lean Lab [1], because it is planned to use the same control software in both projects.

2. METHODOLOGY

One of the objectives of the Micro Lean Lab project (2019-2028), initiated by HE-Arc Ingénierie, is to build an autonomous micro-factory dedicated to the microtechnology industry. After a few years of studies and discussion with industrial partners, a first demonstrator is currently in preparation. It includes a control software and some standardized interfaces between machines, robots and softwares.

For the DNAMIC project, it is planned to reuse these results of the Micro Lean Lab project:

- The control software, which will be released under an open-source license, will be used, adapted and completed.
- The standardized interfaces for communication with this software will be applied to the different parts of the DNAMIC project.

An objective of the tasks 2.2 Industry 4.0 standard integration is to define these standards. In a first phase, the standards were presented to all project partners to initiate discussions on their implementation. This document presents the first version of these standards. In the next phase, these standards will be adapted and completed according to the specific requirements and constraints of the DNAMIC project. This second phase of the task will be documented in deliverable 2.5, planned for March 2025.

3. RESULT

3.1 Definitions

Tech station: Each individual machine or device inside de micro-factory and involved in the process to perform one or multiple operations sequentially.

Flow: List of operations describing the "life cycle" of a product or other transported material (e.g. consumable, tools...). It defines the sequence to transform it from its initial state to its final state. The flow is composed by several operations or group of operations.

Principal flows concern the products directly. In the DNAMIC project, the principal flows are the "info into storage" and the "info out of storage".

Secondary flow can be defined for consumable, tools and waste management: from a stock to a tech station or from a tech station to a stock.

Operation: Part of the flow performed by a single station on a product. An operation requires an interaction between the station, a robot or a store. For the station, an operation is an action or a

sequence of actions. The operation always starts with the product on a store associated to the station. An operation can start another flow too.

Stock: Location where consumable, waste or tools can be placed by human to be integrated in a flow. These are the material inputs and outputs of the factory.

Store: Temporary location associated to a station where the robot can put and take some material (product, consumable...).

Free move: Movement of a robot or other transport device to a required position without any material.

Loaded move: Movement of a material by robot or other transport device from the store of the source station to a store of the destination station.

3.2 Description of the control software and flow

As described in Figure 1, the autonomous micro-factory, i.e., all the technological stations and all robots for the transport between stations, are controlled by a software named "Control software" developed by HE-Arc. Inputs to this software are flow descriptions and factory settings. The software is responsible to:

- Control the stations and robots according to one or several flows.
- Choose which station or robot must execute each operation.
- React to the requests of the stations (bring consumable, change tool...).
- Synchronize actions with interaction between a station and robot.

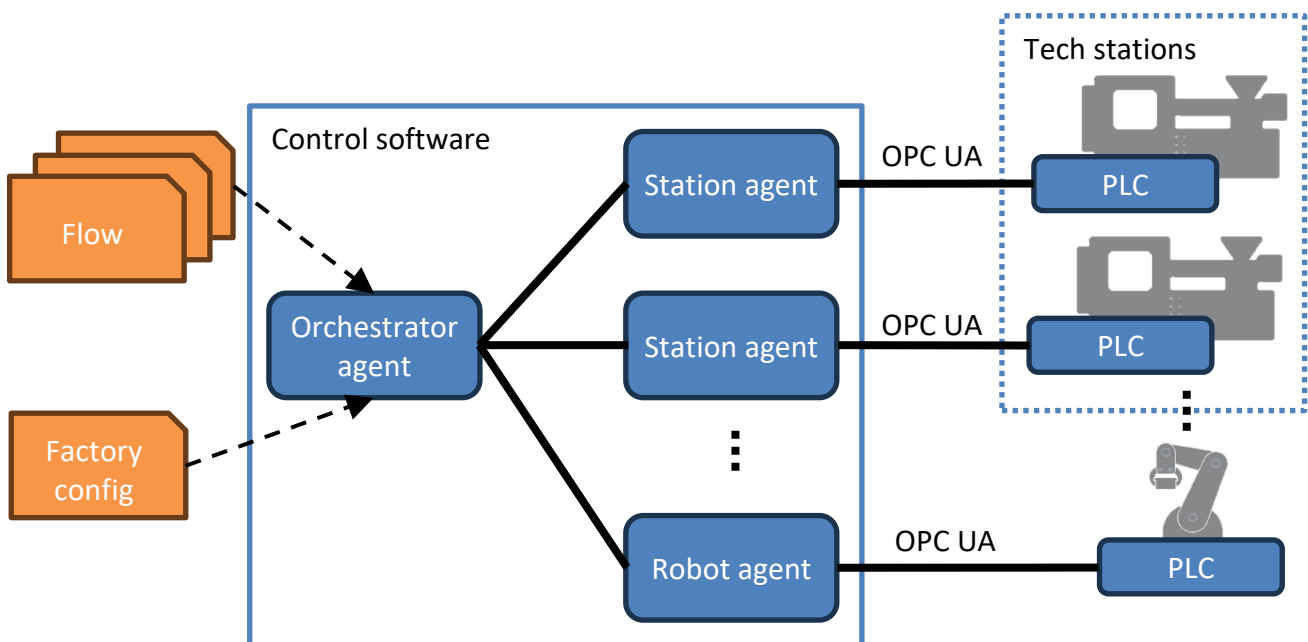


Figure 1 : Interaction diagram of the control software of the micro-factory

A flow is a list of operations to be performed on the stations of the micro factory, with the following constraints:

- An operation is not related to a specific station, but to a type of station able to perform it.
- The order of the operation is not defined by "the next operation to do after" but by one or several operations that must be done before.
- Some operations can split a product into several parts (new products) or assemble several parts in a new one.

In DNAMIC project, the two principal flows ("info into storage" and the "info out of storage") are started by a request done by a user on OLOS/DLCM. Several requests can be done and be processed in parallel by the factory.

3.3 Hardware and network considerations

The process of operation inside each tech station is not controlled by the *Control software*, responsible only of the flow between tech stations inside the factory. This process must be controlled by dedicated software, running on a PLC or eventually a computer dedicated or integrated to the tech station.

As presented in Figure 2, all PLC or computers of the factory are connected to a wired network based on IPv4 and Ethernet IEEE 802.3 protocols. The network is connected to Internet through a firewall, but private IP addresses are allocated inside it.

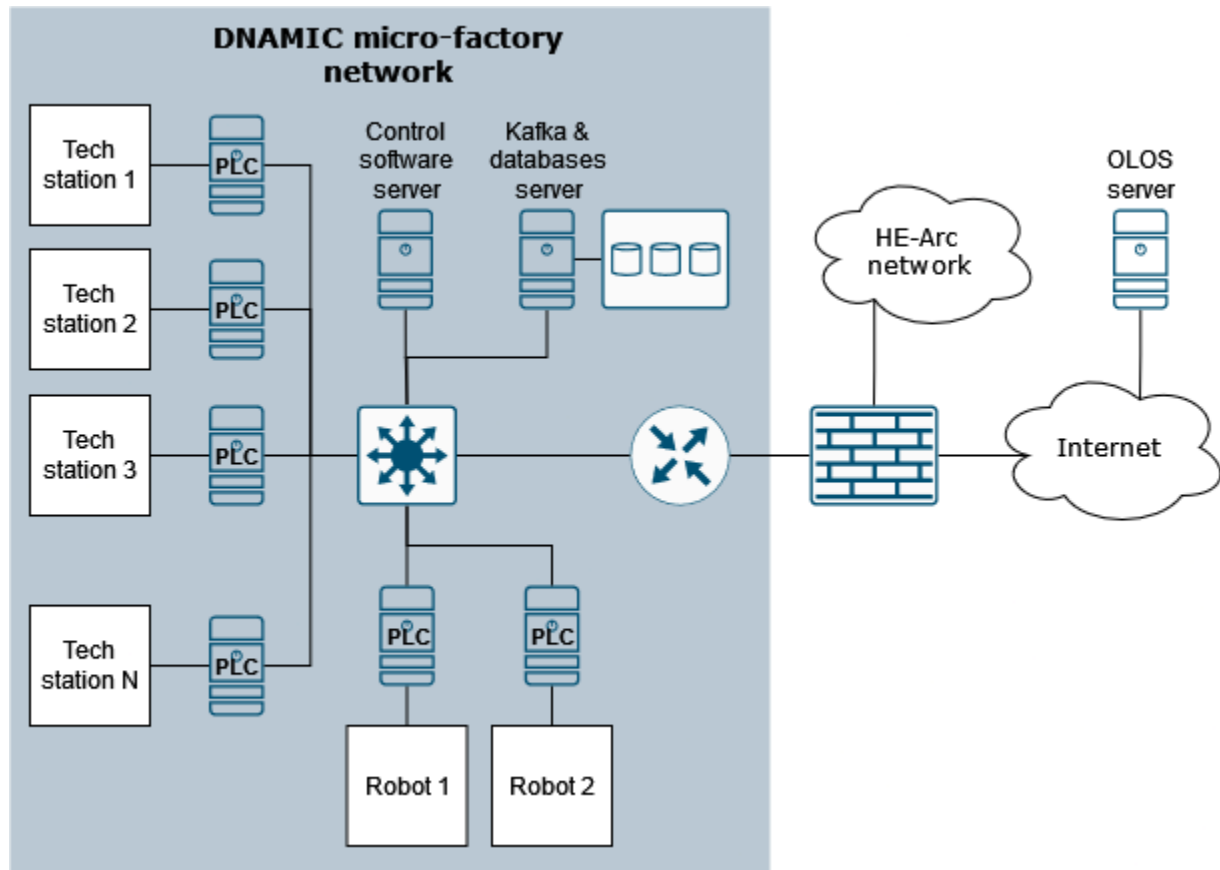


Figure 2 : Schema of DNAMIC micro-factory network

3.4 Flow concept

A flow can be presented as a block diagram. Each block represents an operation, and each link represents a loaded move. Some free moves can be required between the operations of the flow; the control software can order them when needed, but they are not part of the flow. Figure 3 shows a simple example of a flow that can take part in different use case of a micro-factory.

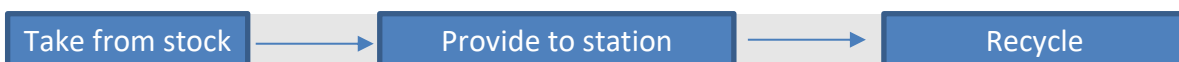


Figure 3 : Block diagram of an example of flow corresponding to the life cycle of a consumable

This block diagram shows the life cycle of a consumable. In this case, there are 3 operations, each block of the diagram. The 2 links are loaded moves. This is the list of actions that can be ordered by the control software when it run through this flow, in the most complex case:

- (if needed) Free move
- (Block 1) Take from stock

- (if needed) Free move
- (Link 1) Loaded move from stock station to destination station
- (if needed) Free move
- (Block 2) Take possession of the consumable by the station
- (if needed) Free move
- (Link 2) Loaded move to the recycle station
- (if needed) Free move
- (Block 3) Put in recycle station

3.5 Flow examples

3.5.1 Simple flow example

This flow corresponds to the processus to machining a metallic piece by milling and controlling it after. The initial pieces are stored in Store A, machined in a milling machine, controlled by a dedicated machine, and finally stored in Store B. As presented in Figure 4, the flow is composed of 4 operations and 3 loaded moves.

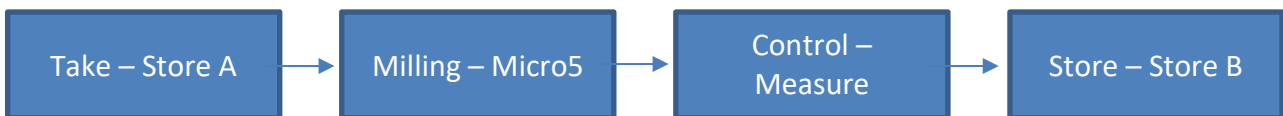


Figure 4 : Block diagram of a simple flow example

3.5.2 Flow example with AND operation

In this example, 2 control operations must be done on 2 different machines, but the order is not relevant. As shown in Figure 5, this must be described in the flow description with an AND operation that group together the operation that need to be done. Using that, the decision can be taken by the control software, for example when several flows are done simultaneously, by realizing different operations in parallel to optimize production.

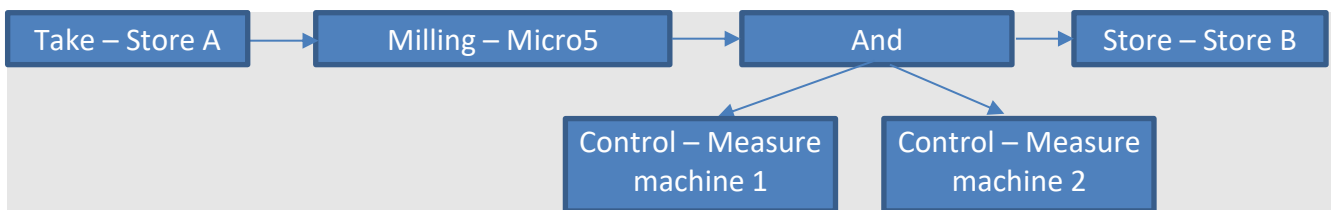


Figure 5 : Block diagram of a flow example with AND operation

3.5.3 Flow example with OR operation

In this example presented in Figure 6, an operation can be done by 2 different machines: The operations are interchangeable because they have the same function. In that case, these operations need to be grouped in an OR operation.

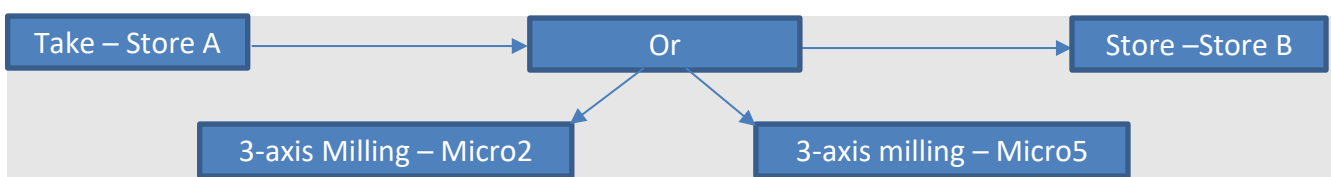


Figure 6 : Block diagram of a flow example with OR operation

3.5.4 Flow example with SEQ operation

In this example presented in Figure 7, several operations must be done by the same machine. The operation SEQ is used to group them. In that case, there is no loaded move between the operations (no arrows on the link in the block diagram).

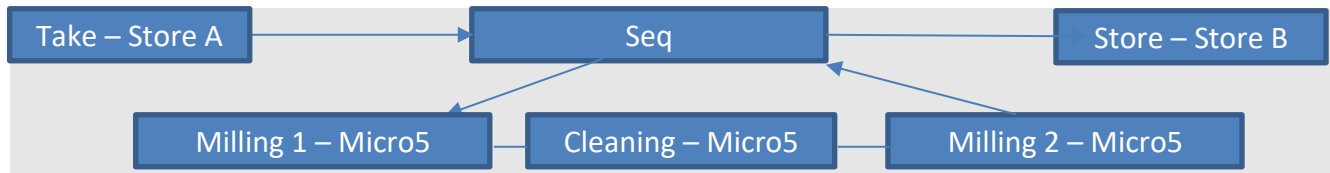


Figure 7 : Block diagram of a flow example with SEQ operation

3.5.5 Flow example with other flow invocation

It is possible inside a flow to invoke another flow as an operation. In that case, the invoked flow is started and all its operations are processed. This can be useful to share a flow between several flows, for example to change the tool of a machine, as shown in Figure 8. There is no loaded move before and after the invoked flow.

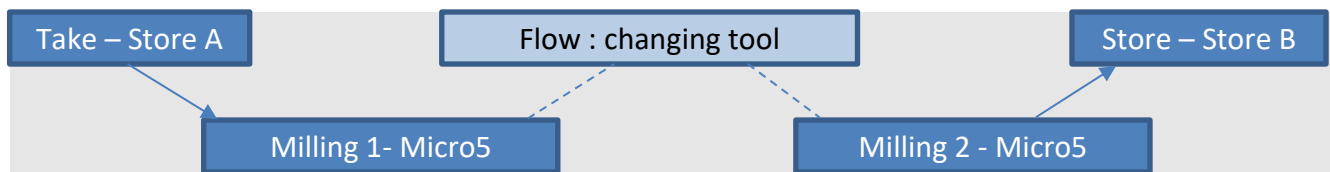


Figure 8 : Block diagram of a flow with other flow invocation

3.6 Operation concept

An operation can be presented as a sequence diagram as shown in Figure 9. Actors of the diagram are the robot and the station. The actions to be done are in 3 phases: input, work and output.

Input phase has 4 actions:

- 1) Initialization of the station
- 2) Placement of the material by the robot
- 3) Fixing of the material by the station
- 4) Free material by the robot

Work phase contains a single action:

- 5) Work by the station (this is the operation from the station point of view)

Output phase has 5 actions:

- 6) Unload preparation by the station
- 7) Take material by the robot
- 8) Free material by the station
- 9) Retract material by the robot
- 10) Post delivery by the station

During input and output phases, actors are not available for other tasks. However, during work the robot is free to execute other tasks. In that case, a free move is needed.

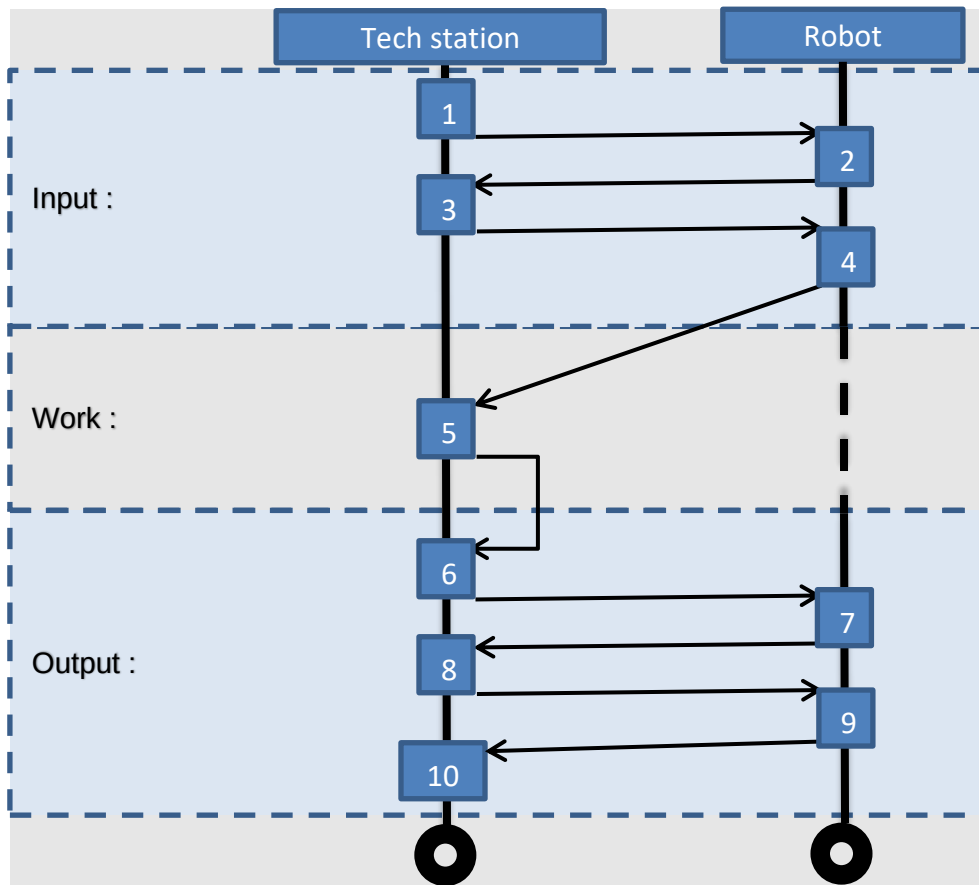


Figure 9 : Sequence diagram of an operation

This actions model applies to all operations. All actions must exist in the station and robot PLC, but they can be empty if the actor does not need to perform anything at this time (e.g., a station without an active fixing device for the material can let the action 3 empty).

3.7 Loaded move concept

Similar to an operation, a loaded move can be presented on a sequence diagram in 3 phases: engagement, movement, disengagement (see Figure 10). The actors of the move are the robots that will load and unload the material to move and the transport device. The process applies the same structure whatever the transport device used to perform the movement.

Engagement phase has 4 actions:

- 1) Positioning of the transport device
- 2) Unload material by the robot
- 3) Take material by the device
- 4) Retract robot without material

Movement phase contains a single action:

- 5) Execute movement from source station to the destination station

Disengagement phase contains 4 actions:

- 6) Positioning of the transport device
- 7) Take material by the robot
- 8) Free material by the device
- 9) Retract robot with material

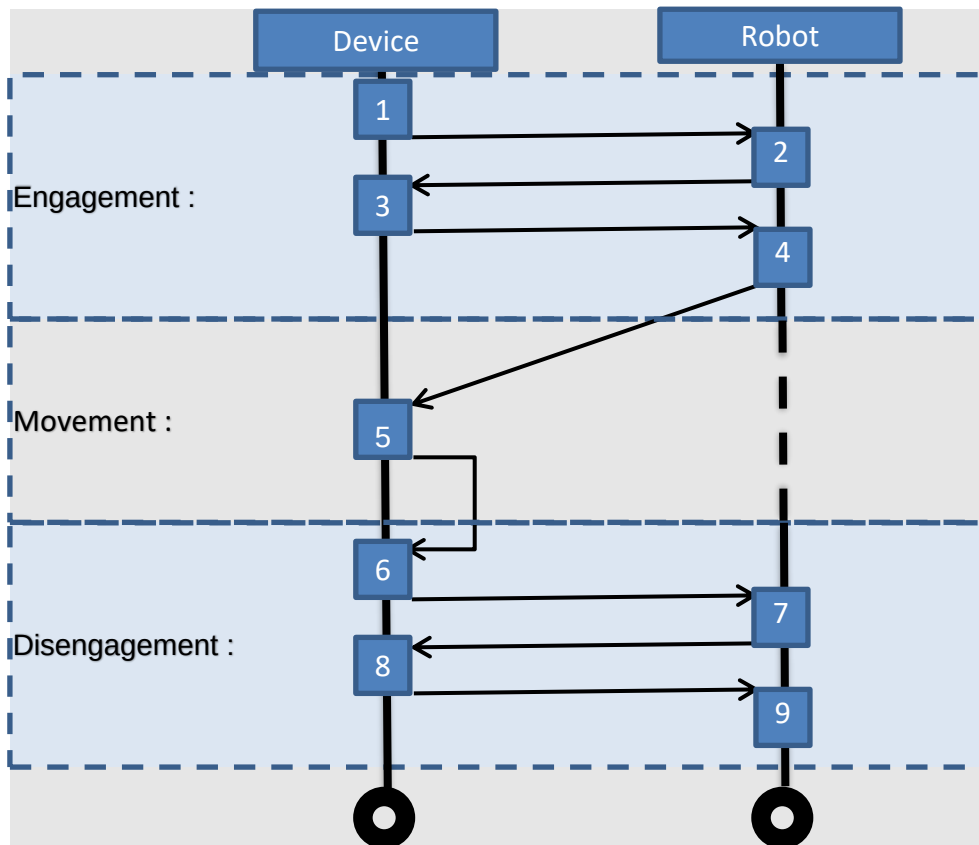


Figure 10 : Sequence diagram of a loaded move

3.8 OPC UA standard protocol

The protocol OPC UA [2] is dedicated to OT and IT applications communication, mainly for data exchange between devices (sensors, machines, PLC...) and software. As shown in Figure 1, this protocol will be used by the control software to communicate with the PLC of the machines and robots. OPC UA is a protocol of application layer. In DNAMIC project, network protocols used with OPC UA will be TCP/IP.

Using a single protocol for this communication and apply the concepts presented in the previous chapter allow us to reach the goal of plug & produce machines. The communication between the software and the machine does not depend on the machine producer or the operation done by the machine. Consequently, installing a new machine in the micro-factory does not require new software development and can be done rapidly. If a machine or robots does not support OPC UA, a specific software interface needs to be developed. But this will break the plug & produce concept for this device.

Each action presented in the *operation concept* and in the *loaded move concept* correspond to a PLC method called by the control software using OPC UA. If any data need to be transmitted to the PLC (e. g. operation ID, type of product...), this is done using the parameters of the method. These methods are grouped into interfaces depending on the type of the device.

Communication needs to be bidirectional. In the other way, machines and robots need to transmit information to the software: machine status (e. g. end of action) and errors. This is done using defined variables for each information type. The machine status must be based on the *Machinery Item State* standard [2]. Errors transmission and validation must be based on the *Alarms and Conditions* standard [3]. Other eventual information transmission from machine to control software should apply OPC UA standards if it exists.

3.9 High-volume data uploads

Autonomous machines should minimize human interactions. To achieve this, the machine needs to contain functions for auto-control or auto-correction (e. g. quality control). Some of these functions will be based on AI algorithms which need high volume data provided by the machine.

Most of the data provided are time series (e. g. temperature over time, axis movement and position...), some are relational data (e. g. material characteristics, control result, product ID...). Time series and relational data must be stored in different database system : relational database like *PostgreSQL* or *MySQL* or time series databases like *InfluxDB*. Both are probably required by DNAMIC project.

Machine should not save data directly into the database for scalability and robustness reasons : any change in the database hosting would need to update all the machines, a very short loss of availability in the IT infrastructure (network, servers...) could cause a data loss. These are the main reasons it is advised to use a broker, like *MQTT Mosquito* or *Apache Kafka*, between the machines and the databases. Choice has been made to use *Apache Kafka* in DNAMIC project because of the better scalability functions provided.

Communication between machines and broker should be based on OPC UA protocol, as for Control software. Other protocols supported by the broker could also be used.

Validation of this data pipeline has been made in another project (HE-Arc Micro Lean Lab) with the following data requirements :

- Up to 5 machines
- Each machine generates up to 50 time series signals at a sampling rate of 1 kHz
- Each machine generates up to 10 time series signals at a sampling rate of 1 Hz

Because of the characteristics of the machines (high speed milling), these requirements are higher than expected in DNAMIC project (slower process).

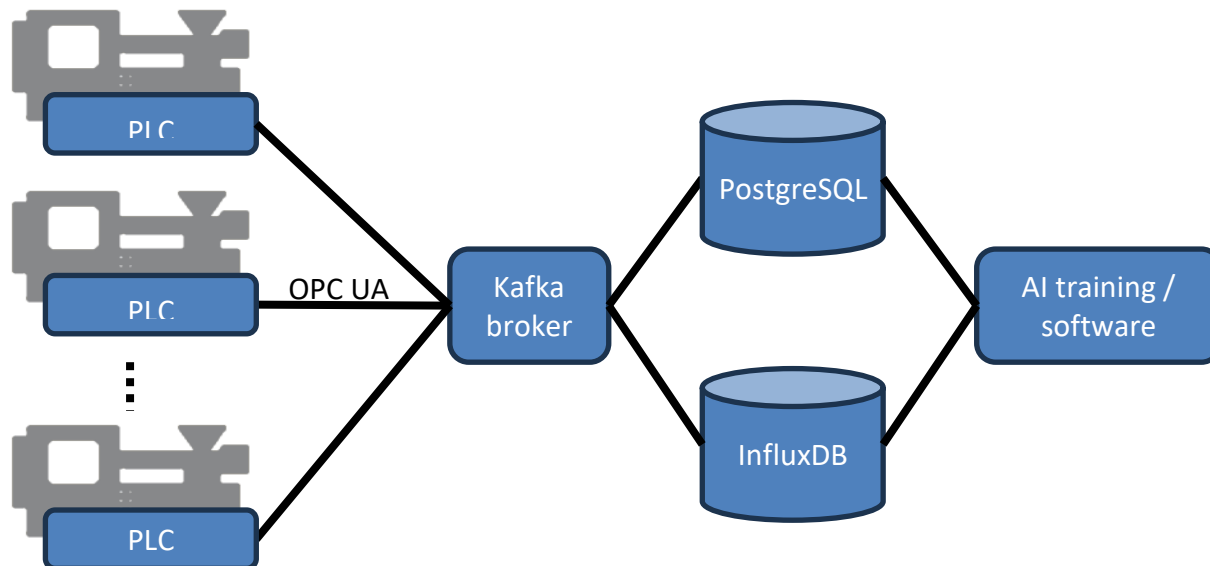


Figure 11 : Interaction diagram of high-volume data pipeline

4. CONCLUSIONS

The communication standard and software interface presented in this document has been presented to all partners of the project during the consortium meeting in February 2024. No major concern has been raised during the first discussions. But it is required and planned to study all this in more detail during the next few months to ensure that all aspects, constraints and requirements of the DNAMIC project are correctly considered.

5. REFERENCES

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