SOON
Social Network of Machines

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Summary Scientific and Technical Report
SSTR

Stage II
Year 2020

Definition and design of a multi-agent system for predictive detection of defects

Project Code: ***COFUND-CHIST-ERA-SOON***
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Project Title: *Social Network of Machines*
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University of Medicine, Pharmacy, Science and Technology
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UMFST team SOON webpage: *https://soon.umfst.ro*
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1. The objectives of Stage II: the year 2020

1.1. Context. Preliminary aspects

This document summarizes the main activities and results related to Stage II of the project. One of the novelties brought by Industry 4.0 is the adoption of "smart" technologies at all levels of industrial production. In current state-of-the-art approaches, intelligence, if implemented, is located at the individual level, and intelligent heterogeneous entities often cannot communicate and cooperate effectively even if they have a close location. The main motivation of our research lies in the fact that if we want to create an authentic Internet of “everything” that brings together processes, data, things and people, then all these entities must be connected and follows a shared and easy-to-follow paradigm.

In this project, we propose a holistic multi-agent paradigm that includes systems and people. The presence of human operators is essential, as a source of technical expertise, which will be transmitted to software agents, and they through access to numerous data sources, through deep learning algorithms and extraction of details and features, will provide new, essential information, otherwise difficult to obtain for human operators. Agencies will make decisions based on the data collected, following the fusion and analysis of large heterogeneous amounts of data produced in real time by sensors (vibration, temperature, etc.), automation and information systems (such as planning systems) and supervision of enterprise resources), respectively by human operators.

The main goal of the project is to identify and propose innovative solutions for optimizing manufacturing processes through intelligent predictive maintenance methods. The way to solve this problem in the SOON project starts from a set of predictive maintenance scenarios established in collaboration with three industrial companies (from Slovakia, Spain and Switzerland). The choice of these three industrial partners, with a completely different industrial profile, was based on increasing the generality of our approach and proving the adequacy for a greater diversity of industrial manufacturing processes. We intend to demonstrate that the introduction of Industry 4.0-specific principles, combined with recent improvements in machine learning, and the application of an architecture based on a multi-agent social system can ultimately lead to significant innovation in optimizing and modeling industrial processes.

In the second stage of project reporting, the consortium consisted of three universities, a research institute of an academy and three industrial companies with distinct production profile (machine tool production, steel industry and recycling and plastics production) from different countries focused on creating the framework for implementing the SOON proposal.

The SOON project implementation consortium is composed of the following entities:

- University of Applied Sciences and Arts Western Switzerland (HES-SO) in Switzerland, project coordinator;
- Slovak Academy of Sciences (SAV) in Slovakia;
- University of Oviedo (UNIOVI) in Spain;
- "George Emil Palade" University of Medicine, Pharmacy, Science and Technology from Târgu Mureș (UMFST);
- Tornos SA (Tornos) from Switzerland, industrial partner;
- MAT-obaly, s.r.o. (MAT) from Slovakia, industrial partner;
- ArcelorMittal (AMI3) from Spain, industrial partner.

Nomenclature of acronyms and abbreviations

ABT Asynchronous Backtracking
AP Production Automatization
CPPS Cyber Physical Production System
CRM Customer Relationship Management
CSP Constraint Satisfaction Problem
DDS Distributed Data Storage Communication Interface
ERP Enterprise Resource Planning
HPC High-Performance Computing
HSM Hot Strip Mill
IA Artificial Intelligence
ICPS Internet Cyber Physical System
IIC Industrial Internet Consortium
IIoT Industrial Internet of Things
IIRA Industrial Internet Reference Architecture
IoE Internet of Everything
IPA Information Pyramid Architectures
KD Knowledge database
KE Knowledge exchange
LTS Long-term Storage
OAI Operator-Agent Interface
OEE Overall Equipment Effectiveness
PdM Predictive Maintenance
PLC Programmable Logic Controller
RAMI Reference Architecture Model Industry 4.0
RDE Raw Data Exchange
RUL Remaining useful lifetime of a tool
RWM Rod Wire Mill

SBC Single-Board Computer
SCM Supply Chain Management
SMA Multi-agent System
SoC System-on-a-Chip
TEEP Total Effective Equipment Performance
TIC Information and communication technology
VI Visualization Instruments

1.2. The objectives for 2020

The overall objective of the SOON project is to investigate the impact of using intelligent autonomous social agents to optimize industrial production processes within Industry 4.0 from the perspective of maintaining nominal parameters and avoiding interruptions by applying appropriate predictive maintenance measures. The proposed solution consists mainly in anticipating and early detection of the occurrence of faults, identifying the nature of faults, respectively their location.

The specific objective of stage I, with the realization fully planned in this stage, has been successfully achieved. It consisted mainly in identifying the particular needs of the industrial environment represented through industrial partners and the requirements related to the tools that will be developed in this project, respectively that will respond to the challenges in terms of the concept of Industry 4.0.

The specific objectives of stage II are the following:

- Requirements analysis, specifications synthesis and design of the architecture of social agents and the cooperative multi-agent system that includes machines, sensors, along with human operators in order to implement the cyber-physical system solution to ensure predictive maintenance; design and development of ontologies related to the solution proposed by the project; designing the integration framework; smart device interface design and human-machine interface.
- Implementation of the test and evaluation platform for IIoT/IoE solutions for predictive maintenance.
- Dealing with various aspects related to the data that will be available in the project. Issues related to: data description and data integration.
- Designing the main scenarios of predictive maintenance. Design, testing and evaluation of predictive maintenance algorithms, mainly focused on fault detection using AI techniques;
- Organizing an efficient project management. Updating the results dissemination strategy and communicating with interested stakeholders. All this meant taking into account the current pandemic context with the SARS-CoV-2 virus.

1.3. The specific activities of the stage

In **full compliance with the Project Implementation Plan**, within Stage II, two categories of activities were implemented: some ongoing in Stage I, respectively some that started in this stage.

Act 2.1 Development of the integration framework [Continuation of Act 1.5. from Stage I; will continue in Stage III] (accomplished according the realization plan).

The activities related to the requirements analysis task and the design of the integration framework involved the preparation of the integration specifications in accordance with the predictive maintenance scenarios. The synthesized requirements depend in a large degree on the scenarios implemented, the machines available and the increased variety of data available. Among the fundamental principles on which the proposed solution is based are scalability and extensibility, which will ensure the independence of the proposed solution from the order of magnitude of the industrial platform.

The particular tasks related to the integration of the different software modules result from the work packages, WP3 and WP4. For the development of the prototype of the system are considered state-of-the-art platforms aimed at managing distributed processing, which allows advanced functionalities for IoT integration, large volume data management, feature extraction and machine learning.

The particular tasks of this activity include experimenting and evaluating the FIWARE platform with various integrated modules, such as Orion Context Broker, Cygnus, and NoSQL data storage MongoDB and InfluxDB for time series.

Act 2.2. ***Specification of data integration model. [activity started in Stage II] (accomplished according the realization plan).***

This activity includes, among other things, identifying data sources for established scenarios, designing an infrastructure that supports Big Data, and establishing how data is processed and stored. One aspect covered is to obtain a description of the data model that will be implemented in a cloud-like infrastructure, such as Microsoft's Azure and/or Apache Storm Cluster, the adoption of which is being evaluated.

Act 2.3. ***Designing the architecture of social agents. [Continuation of Act 1.2. from Stage I] (accomplished according the realization plan)***

The activity consisted in starting the design of the ontology and architecture of the multi-agent system taking into account the role and mapping of agents (machine level, production section, factory, company), targeted performance, capabilities, equipment condition (fault history, current status, etc.) and social skills.

Act 2.4. ***Implementation of model and architecture of multi-agent social network solution. [activity started in Stage II; continuing in Stage III] (accomplished according the realization plan)***

This activity consists in designing the profiles of the agents and the social relations between the agents. For example, as social relations can be mentioned those of: help, assistance, friendship, pursuit, etc. The activity refers to the design of the way the social network of cars is created, how communication and evolution are achieved (for example, a new car is added or removed from the production flow), defining the roles that agents have to take over, their interaction and identifying hierarchical relationships. Among other things, it involved designing a real-time cloud-based collaboration environment.

Act 2.5. ***Exploring and designing maintenance algorithms based on artificial intelligence (AI). [Continuation of Act 1.3. from Stage I; will continue in Stage III] (accomplished according the realization plan)***

The analysis was started and the predictive maintenance scenarios were specified through exploratory analyzes with industrial partners to identify the most significant cases of failure with an emphasis on predicting the duration of outages due to failures and prediction of sensor failure.

There are different types of data that will be used, in a first phase the time series are targeted. Based on them, various regression methods (linear, nonlinear, multiple linear and adaptive) and recurrent neural networks were studied and tested, following to what extent they correspond to the needs. Numerous classification methods have also been studied and tested. The activity will continue in Stage III. The algorithms that will eventually be designed will be implemented, tested and evaluated, for example, by applying cross-validation. The acquisition of data necessary for the testing and evaluation of algorithms is a phase of this activity.

Act 2.6. ***Development of intelligent device interface and human-machine interface. [activity started in Stage II; continuing in Stage III] (accomplished according the realization plan).***

This work focuses in particular on the definition and implementation of user interfaces (UI) to ensure safe and efficient interoperability with sensors, between machines, agents and human operators. In this context, it is essential to take into account the heterogeneity of the data.

Act 2.7. ***Testing and evaluation of integrated predictive maintenance solution. [activity started in Stage II; continuing in Stage III] (accomplished according the realization plan).***

At this stage, an analysis was performed based on a comprehensive bibliographic study on Key Performance Indicators (KPI) that can be used for example to measure productivity and efficiency in production processes. The overall Equipment Efficiency (OEE) and the Total Equipment Efficiency (TEEP) were studied, among others. Both OEE and TEEP are widely used indicators.

Act 2.8. P*roject management and dissemination [Continuation of Act 1.4 of Stage I; will continue in Stage III] (accomplished according the realization plan).*

This activity consisted in accomplishing the tasks necessary to ensure project management, reporting, dissemination and visibility activities. A step in order to ensure visibility consisted in updating the web portal of the project related to the partner in the country, respectively its population with information specific to the current stage. A study was carried out on the development and planning of the dissemination strategy throughout the project, taking into account the current pandemic context with the Covid-19 virus, the evolution and consequences of which cannot be estimated.

Act 2.9. Implementation of algorithms for defect detection using AI techniques. [activity started in Stage II; continuing in Stage III] (accomplished according the realization plan).

This activity aims to design and implement algorithms for automatic fault detection. It aims in a first stage, the preparation of data for machine learning. This process depending on the characteristics of the data may involve, among others, conditioning, filtering, scientific visualization and labeling. The process is followed by testing, evaluation and validation. The main purpose of this activity is to find the answer to the hypothesis: whether the automatic detection of sensor failures improves the overall performance measured using KPI.

2. Summary of Stage II

2.1. Specific activities for the implementation of the SOON proposal carried out in Stage II

Stage II included various project implementation activities (presented in section 1.3.) that were successfully carried out according to the implementation plan. The UMFST team has invested a great effort in the task of successfully developing the IT architecture of the proposed SOON solution.

2.2. Collaboration with SOON project partners

A close collaboration was maintained with the SOON project partners, both those from the university environment and the industrial ones. General video conferences were organized monthly, attended by all project partners. On these occasions, progress reports were presented by all partners. Depending on the needs, bilateral discussion meetings were established on topics of particular interest.

2.3. Scientific and research collaboration between SOON and FIREMAN projects

The scientific collaboration between the SOON and Framework for the Identification of Rare Events via Machine Learning and IoT Networks (FIREMAN) projects, initiated in the first stage of the project, has been strengthened. This collaboration will be continued and deepened in the Third Stage of project implementation. Bilateral meetings will be organized between the two projects. When necessary, meetings will be established focused on certain topics of discussion (private research, exchange of expertise) to that interested working groups will participate. The general motivation of this collaboration consists in the existing complementarity between the two projects, which suggests obtaining in the field of research some benefits from both parties.

2.4. Smart Technologies in Industry 4.0 International Workshop (RATIONALITY)

The SOON and FIREMAN projects organized in the framework of the 14th edition of the International Conference Interdisciplinarity in Engineering (INTER-ENG 2020, https://inter-eng.umfst.ro/2020, https://www.facebook.com/InterEng) the 1st International Workshop on Smart Technologies in Industry 4.0 (RATIONALITY), which took place on October 10, 2020.

(https://inter-eng.umfst.ro/2020/index.php?page=workshop&action=rationality).

The general topic of the 2020 Inter-Eng conference was "Europe's future is digital: a broad vision of the Industry 4.0 concept beyond direct manufacturing in the company". Particular topic addressed: "Integration of Industry 4.0 concepts in the production environment which form a complete value chain from providers to customers and all enterprise's business functions and services".

The initiative and the main contribution to the organization of the Workshop had the UMFST team through the role of host of the event and main organizer. The event was organized in a videoconference system on the Microsoft Teams platform, with the coordination and development center as follows:

Vitrual location: UMFST, Nicolae Iorga st. No. 1, Târgu Mureș, Mureș

Online: Room Workshop SOON - FIREMAN

https://inter-eng.umfst.ro/2020/index.php?page=workshop&action=rationality

The RATIONALITY workshop aims to bring together in the same forum researchers of European research projects funded under the CHIST-ERA program supported by the Future and Emerging Technologies (FET) program of the European Union through the ERA-NET Cofund funding system, HORIZON 2020.

At this edition of the workshop participated researchers involved in the implementation of the two CHIST-ERA projects, namely SOON and FIREMAN, by presenting the results of research obtained, respectively their progress reports. Open research issues that could involve knowledge transfer or even scientific collaboration were also discussed.

Finally, the possibilities and future opportunities for in-depth collaboration between the two projects were analyzed.

2.5. Dissemination, communication, participation to conferences

2.5.1. Communication of results and dissemination

For dissemination, during the RATIONALITY Workshop, the UMFST team made the presentation entitled: Physical Model for Electric Drive Equipped Production Unit Simulation with Edge Computing Based Monitoring Technology [Gli20a]. All authors of the presentation are members of the UMFST project implementation team. One of the objectives of the presentation was to disseminate partial results of the research obtained within the SOON project, to be extended with results of further research, and finally disseminated and published.

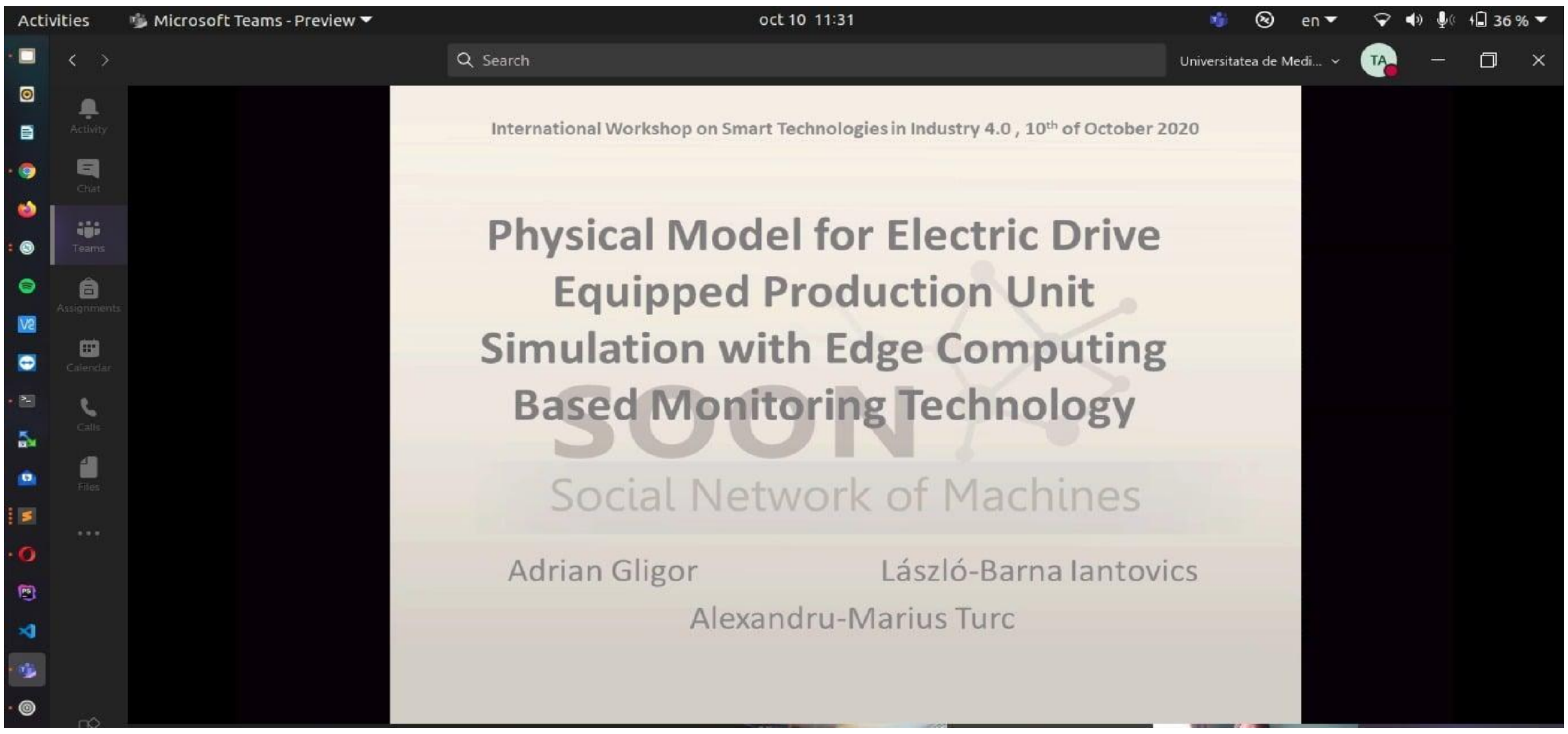

Fig. 1. Presentation [Gli20a] made by the UMFST team at the RATIONALITY Workshop

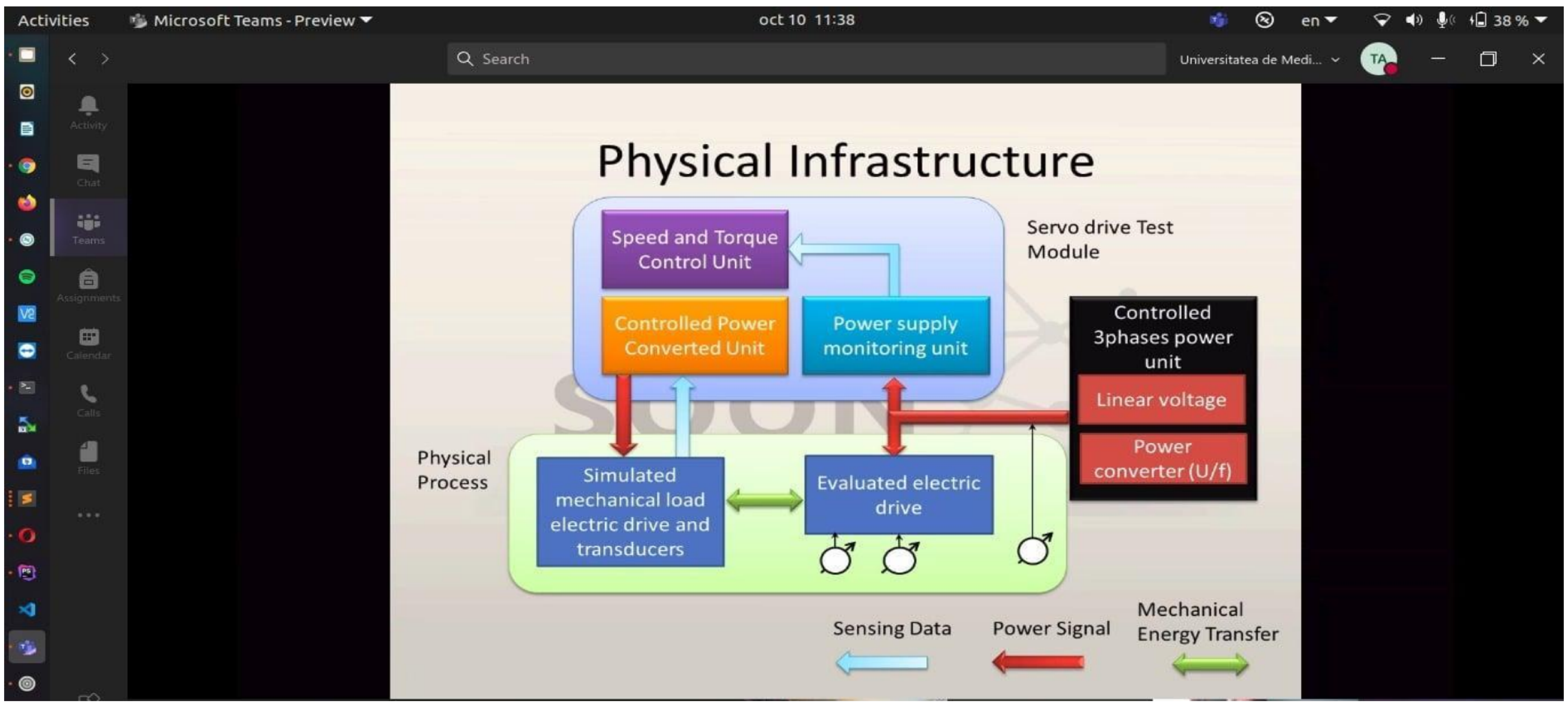

Fig. 2. Presentation [Gli20a] made by the UMFST team at the RATIONALITY Workshop

The UMFST team also performed a communication, consisting of a presentation made in the Progress Report of the SOON project that took place in section II, presenting the results obtained to the members of the SOON and FIREMAN projects and the other participants.

The bilingual web portal (Romanian and English) of the SOON project was updated, presenting relevant information about the project, specific to the current stage of the implementation, including the objectives and results obtained by the UMFST team, as well as the summary of the stage in Romanian and English.

2.5.2. Published publications

In the second stage of the project a series of obtained results were published in a top journal, the reference [Vla20] from the list of bibliographical references. The publications specific to the first stage were presented in the Stage I report.

2.6. Pilot platform for testing and evaluating IIoT/IoE solutions for predictive maintenance

In Stage I, the development of a Pilot Platform for testing and evaluating IIoT/IoE solutions for predictive maintenance was started, then continued in Stage II. Based on the budget for 2019 planned for this purpose, processing equipment, communications and field devices (SBC and SoC) were purchased and integrated into a pilot platform for testing solutions that will be designed to implement the necessary algorithms in the paradigm proposed by predictive maintenance, modeling the real production systems related to the industrial environment specific to the industrial partners. The test solution consists of an HPC unit, two workstations, a communication network with a high-speed communication node and management, and ten SBC systems connected via PoE as data concentrator systems from sensors via SoC solutions.

The experimental stand built has the role of physical model of some classes of industrial processes whose operation is based on three-phase electric motor with variable speed. The stand can be configured to run different scenarios needed to obtain diversified data similar to real industry systems. The developed infrastructure allows the generation of a large amount and diversity of data, which will be considered inputs for AI algorithms (prediction, classification, machine learning, etc.) to be developed within the project.

Fig. 3. Experimental stand for data acquisition

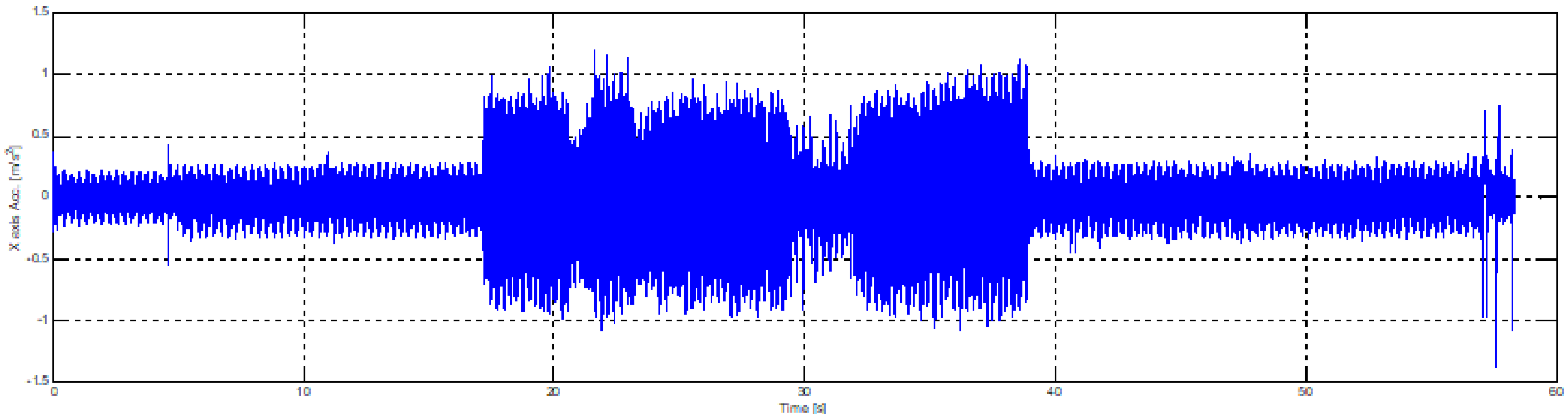

Fig. 4. Data sample obtained from the test platform

In the second stage, the acquisitions included storage media for SBC solutions, various sensors for the acquisition of signals from industrial processes and a high-performance workstation.

Fig. 5. Workstation purchased in 2020

3. Scientific and technical description

3.1. Preliminary aspects

In this project we propose for investigation the efficiency of a solution based on a holistic paradigm consisting on social intelligent agents who are associated with machines as well as human operators. Expert human operators will provide knowledge, but at the same time will benefit from the results of processing by agents, which can be used in decision-making processes. This involves, among other things, the implementation of various algorithms for extracting values and characteristics, respectively deep learning algorithms in order to optimize the operation of the analyzed industrial processes. Many algorithms will be used to solve problems associated with predictive maintenance. They have to use large amounts of heterogeneous data provided by a wide variety of equipment and devices (sensors, automatic control systems, robots), but which will have to compete in solving real-time complex predictive maintenance tasks. Along with real-time measurements, the data sources used will also consist of historical records, available in the form of time series, some of which are based on ERP systems.

The developed solution will be based on the specifications from all industrial companies involved in the project with industrial activity in different fields and profiles. The general vision on which the proposed architecture is based is presented in Fig. 6. The main design requirement is to ensure scalability so that it can dynamically incorporate entities such as physical machines and processes, devices, sensors and ICT infrastructure consisting of intelligent cloud processing systems, data concentrators and processing software and analysis.

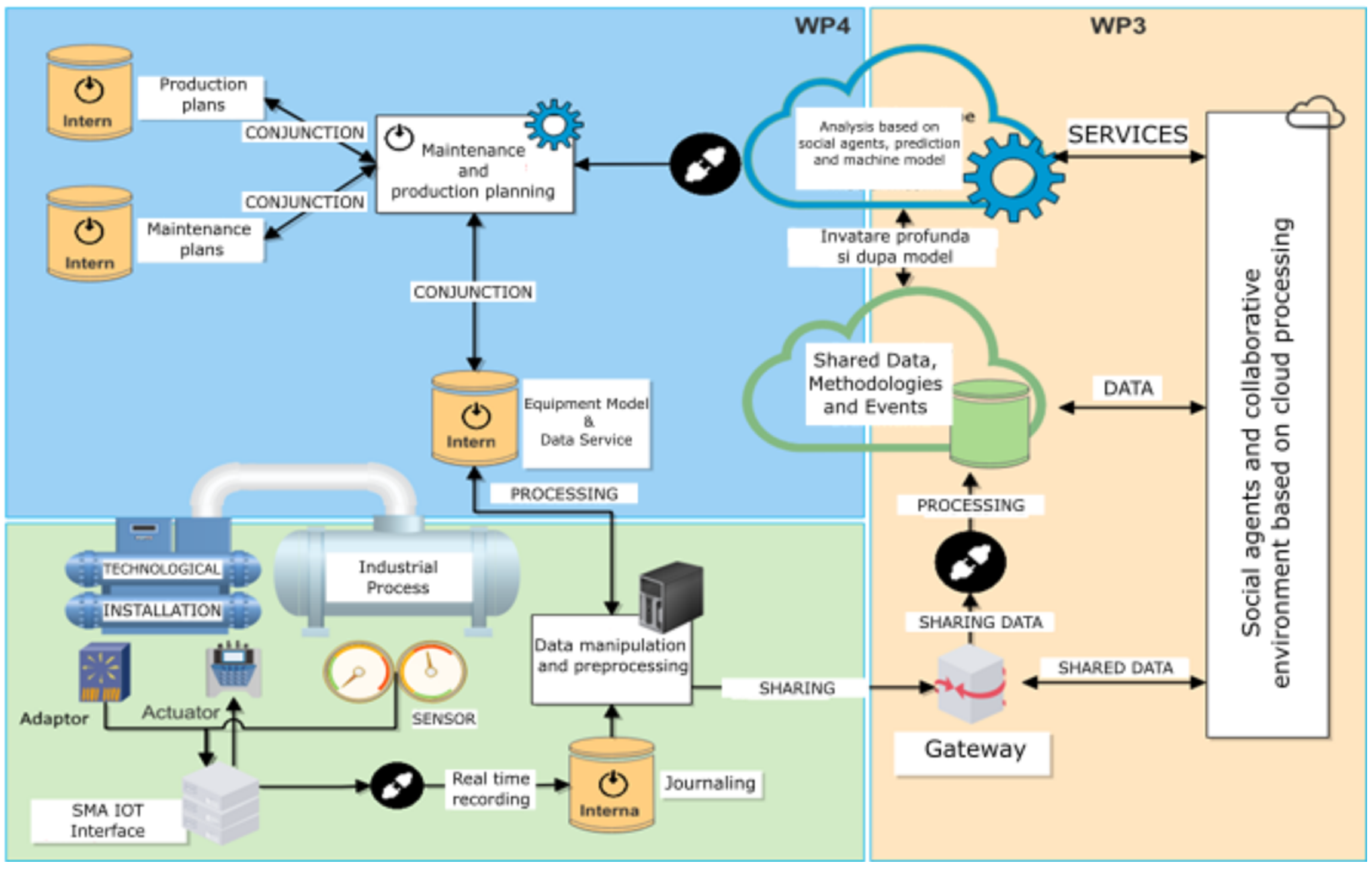

Fig. 6. The proposed SOON solution for predictive maintenance.

3.2. *Industrial specifications data integration model*

This chapter briefly describes the data models used to store all data from various sources for each of the scenarios that have been defined in collaboration with industry partners (Tornos, MAT-obaly and ArcelorMittal).

3.2.1. Data sources of industrial partners

The main data source considered includes: historical data from ERP, records on the operation of machines and machine tools, data from loggers, real-time data from sensors and recording devices.

3.2.2. Identifying the data sources of each scenario

The scientific and technical report in the subchapter of the same name "Identifying the data sources of each scenario" presents in detail each use case from the identified scenarios. For each use case, the main data sources are identified.

3.2.3. Description of the data storage model

Below are the storage models for data sources. The data is expected to be stored using technologies compatible with available solutions, currently accepted and used on a large-scale.

Proposed generic data model

Starting from the available data and the analyzed scenarios, a specific data model was designed, necessary for the unified representation of the data in the SOON solution.

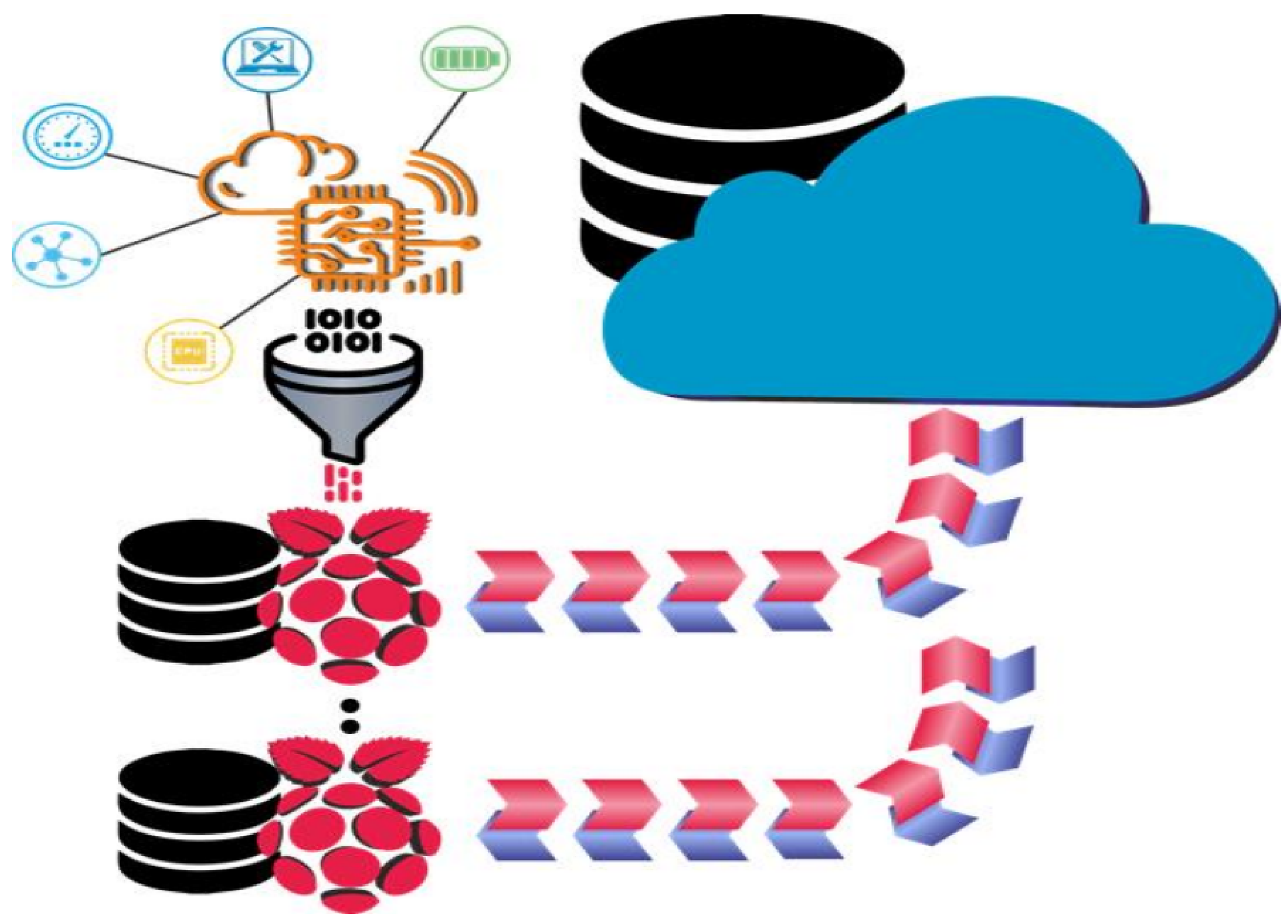

Fig. 7. Overview of the storage model

In this Data Acquisition Model, data acquired from sensors is sent through Data Acquisition Board to Agents (located on Raspberry pi). These agents collect acquired sensor data to local edge level database , after that some data are sent to the cloud , where is retained in a distributed database .

3.3. Synthesis of predictive maintenance scenarios

Annex 7 of the Scientific and Technical Report, contains a detailed description of this subchapter, while presenting a bibliographic study (see e.g. [Car19, Zon20, Yan18]) performed on predictive maintenance. The purpose of this subchapter is to formalize the predictive maintenance scenarios that will be addressed in the SOON project. The scenarios presented in this document are not limited to the prediction of failures, but also include the actions that social agents (operators and machines) must perform after the occurrence of an incident or is predicted a defect.

In the following, we present the summaries of the PdM scenarios of the SOON project.

Scenario 1: Intelligent maintenance of wire rollers

This scenario refers to the maintenance of the production line of a wire assortment, which is the raw material used to make products that require high quality standards like tires, springs, parts for making threaded joints, etc.

The quality of the finished product is determined by a series of subassemblies used in the manufacturing process, in the case of the present scenario, of interest are the rolls of the rolling boxes. The problem to be solved in this case is to determine the optimal set of rollers (in terms of size, material, positioning, service life) given the availability of a large number of rollers, in this case a few thousand, which changes interest rates after a period of use, becoming useful for other use assumptions than those provided at their entry into the system.

Solving this problem is traditionally impractical, which is why an IT based decision support solution or even autonomous operation on the choice and replacement of roles can provide an adequate result, given the large number of input variables of the problem, including here the dimensional aspects, usage history, evidence of wear, qualitative features, reconditioning operations, available stocks, aspects related to the movement and storage of rollers, etc.

Three different approaches are proposed for this scenario.

1. The problem can be formulated as a constraint satisfaction problem and solved as such.
2. The second approach will be based on a cooperative multi-agent system that follows a series of auction protocols.
3. The third approach will be based on reinforcement learning methods.

Scenario 2: Prediction of tool wear

This is a PdM scenario aimed at predicting the current effectiveness of certain processing tools. Accentuated degradation of a tool can result in reduced productivity. The prediction may be based on predefined operations, performed at predefined intervals or according to the prescribed criteria and is intended to reduce the probability of uncontrolled production interruption. Therefore, preventive maintenance will take into account actual use or constraints on its use. This maintenance is based on extrapolated predictions of the analysis and evaluation of significant parameters related to tool degradation. By predicting the wear of a tool, it is possible to optimize the replacement process, thus determining the appropriate timing of this operation.

SOON's proposal is to use machine learning algorithms to predict the remaining useful life of the tools (RUL).

Scenario 3 - Automatic prediction of work orders

In a production shop floor, the parts are processed by different types of machines along the production line. To complete a part of a piece, several steps are usually required.

Each of these steps is performed by a machine configured to perform a specific desired action. In addition, the machines in the production line are heterogeneous and have different properties and characteristics, depending on the type of part they produce or the process in which they are involved. In a shop floor, all these actions are performed on different machines in parallel and transferred from one device to another. Thus, the higher the number of machines present in the shop floor, the more different variants there are for the production of the desired parts. Due to the variety of paths to follow, it is usually difficult to predict whether an order can be fulfilled in the desired time. Moreover, the production line may be completely interrupted in the event of a (predicted) failure of one or more machines in the technological flow.

The objective of the project is to identify reinforcement learning methods capable of performing the optimization of a complex production system in a shop floor. Using these optimization methods, we aim to identify new strategies for coordinating and planning production.

Scenario 4 - Intelligent support of maintenance decisions

After-sales service is an essential department for machine tool suppliers and their life cycle. A shorter repair time is quantified in a shorter restart time. In this respect, the greatest impact on production is caused by unplanned downtime.

This scenario aims to improve after-sales service when a malfunction occurs. In order to reduce the downtime of a car, it is important to be able to identify the occurrence of faults as early as possible or even make predictions about their occurrence.

We propose the creation of a knowledge base with the history of failures that took place. The main idea is to connect information with past and present incidents in a smart end user interface.

Scenario 5 - Automatic sensor fault detection

Modern industrial production is largely fully automated, relying on the quality of the data collected needed to control production processes. Automatic processing uses the data provided by the various sensors installed along the production lines. Therefore, the quality of this data is essential to achieve high operational standards. There are industrial environments in which the sensors cannot operate in adequate conditions due to factors such as: dirt, vibrations, high temperatures, etc. Redundant sensor installation is sometimes not feasible.

The main purpose of rolling is to obtain metal strip at a certain thickness. The rolling conditions determine the variation of the thickness along the processing flow. Ensuring the right conditions allow the control of the thickness required by the customer. The thickness of the band evolves along the technological flow and is monitored by several sensors without redundancy, which makes very difficult to verify the quality of the measurements. The data provided by the sensors could be affected by various noises or disturbances.

The validation of thickness measurements throughout the rolling process will be based on the coherence between the actual values and their estimation, therefore the modeling of the measurements provided by the sensors is essential. We need to get several models to estimate the value of the thickness at a certain point in the process. The project approach involves constructing predictive models capable of estimating the measured value of a thickness sensor at a specific position in the production process (e.g., finishing station output), using as input the measurements of sensors of the same type located at other stages, along the processing line and combining other process parameters and information from human agents.

Within the project, two prediction algorithms were proposed: the first, which is based on the data measured at the output of the roughing plant and other production variables (temperature, chemical composition of steel, etc.), and the second using as data input measurements obtained from the winding machine together with other production variables.

Scenario 6 - Using electricity consumption data to predict outages

Monitoring of energy consumption is now common, mainly due to the need to maintain careful control over costs and has been facilitated by the development of intelligent metering systems. In the vast majority of situations, the data is examined only visually by operations managers in an ad-hoc manner. The desired situation would be to have implemented an automatic way of monitoring and alerting related to the individual consumption of the equipment and to evaluate in real-time the sudden changes of the consumption characteristics.

Along with the monitoring of energy consumption, data on faults and interruptions are also recorded. By discovering the dependencies between electricity consumption and outages, the problems in the technological flow due to electric drives can be identified, and possibly predicted.

Scenario 7 - Detection of electrical drive failures

Until recent time, there is mainly an empirical control over the state of the electric drives, which are inspected by the operators of the installations, verifications that are essentially only a passive control mechanism. Failure of an electric motor can lead to serious production interruptions. Therefore, it would be extremely important to have ways to monitor each electric drive and to predict various problems that may arise, in order to repair or replace parts of the drive system, or in terms of planning the complete replacement of the entire system.

The main objective is to minimize repair / maintenance periods. Ideally, maintenance periods match the maintenance of other equipment in the factory or fall within the period in which the production line is configured for different types of production.

The approach for detecting faults in an electrical drive will be based on analytical methods for detecting anomalies in the data collected during their operation. Every major drive in a production line should be equipped with sensors that monitor operational and environmental data. This data is centralized and, in addition, is transferred to the agents running their models for processing and fault detection. Each agent shall periodically estimate the likelihood of failure and, if the damage to the electric drive becomes imminent in a short time, warn the factory engineers to plan the maintenance of the electric drive. The analytical model must be able to detect false-positive indications, as even the sensors may malfunction during operation. To identify defective sensors, one solution is to have several temperature sensors installed on one drive to provide the values of interest.

Scenario 8 - Modeling and simulation of shop floor configuration

Making decisions about the location of machines in a shop floor can help optimize manufacturing processes. Various AI techniques can be used, including virtual simulation tools for such purposes.

Simulation based on modeling the configuration of a shop floor must provide the following functionalities:

- virtual modeling at shop floor level (current and potential scenarios);
- simulating a real setting or performing a reconfiguration at the shop floor level;
- “what would” simulations related to the reconfiguration of the resource (machines, materials, equipment, human resources) in the shop floor;
- generating data for agent-based predictive maintenance;
- making digital copies (Digital Twin): evolving digital models based on the history of operations to analyze and optimize process performance.

A use case refers to the modeling of the configuration of a shop floor for the optimal location of the machines, in order to obtain the highest possible efficiency of the manufacturing processes. Different batches of orders will be used to test various machine locations at the shop floor level, synchronize manufacturing activity and logistic optimization of the production flow. Optimal planning generation will involve the a priori use of simulation tools. Different car placement options will be tested in either online or offline mode. In addition to machines and operators, this simulation will take into account other components of the production cycle, such as transport, buffer stocks or internal means of transport.

The digital models of a shop floor can provide an almost real-time connection between the physical and digital worlds. The operational data collected can be used to understand and eliminate common operational inadequacies. The optimal allocation of operations on machines can be achieved through such a model. Machine learning techniques can be used to learn the current operating settings of machines and to predict the order completion period.

3.4. Specifications and multiagent social system architecture

The proposed system specifications and architecture have been developed in Document 5.1. deliverable at project level entitled "System and Architecture Specification". The proposed architecture is conceived in the context of two generic reference architectures: RAMI 4.0 [Deu16] and IIRA [Ind17], architectures often encountered in the I4.0 approaches [Far20, Tru19].

3.4.1. Preliminary aspects

A standardized predictive maintenance system for Industry 4.0 ecosystems is a new approach, complementary to automated production (AP) systems, that integrates at the systemic level various entities such as devices, tools, processes, agents, sensors and services, which together contributes to achieving the objectives of the production system in question. To manage the complexity and diversity of such systems, an architecture dedicated to them is the most appropriate tool for description.

The designed SOON architecture is distinguished by the fact that it incorporates the concepts proposed in the project, starting from the industrial requirements identified in the activities undertaken in WP2 and summarized in the deliverable D2.1 at project level in Stage I. Even if the proposed architecture is addressed directly to the context encountered in the project, it by its degree of generality can be easily adopted in any industrial system that satisfies the conceptual principles of Industry 4.0 and Smart Industry.

The following introductory subchapters of the current subchapter 3.4 are described in the Annex 8 of the Scientific and Technical Report:

- *SOON architecture in the context of reference architectures;*
- *Specific requirements for IT architectures for Industry 4.0;*
- *Challenges and perspectives on designing an architecture for Industry 4.0;*
- *Conclusions and observations regarding the development of the architecture of a predictive maintenance solution in the context of Industry 4.0.*

3.4.2. Proposed SOON architecture

The project aims to address and solve in an innovative way the specific requirements of industrial manufacturing systems that include processes, machines, sensors and human operators, through an approach based on a social network of agents. Specifically, the project focuses on proposing a general solution that meets the challenges of predictive maintenance, automatic detection of sensor failure and optimization of production flows. Fig. 8 illustrates the proposed general architecture, in which the entities involved are modeled as components of a social network.

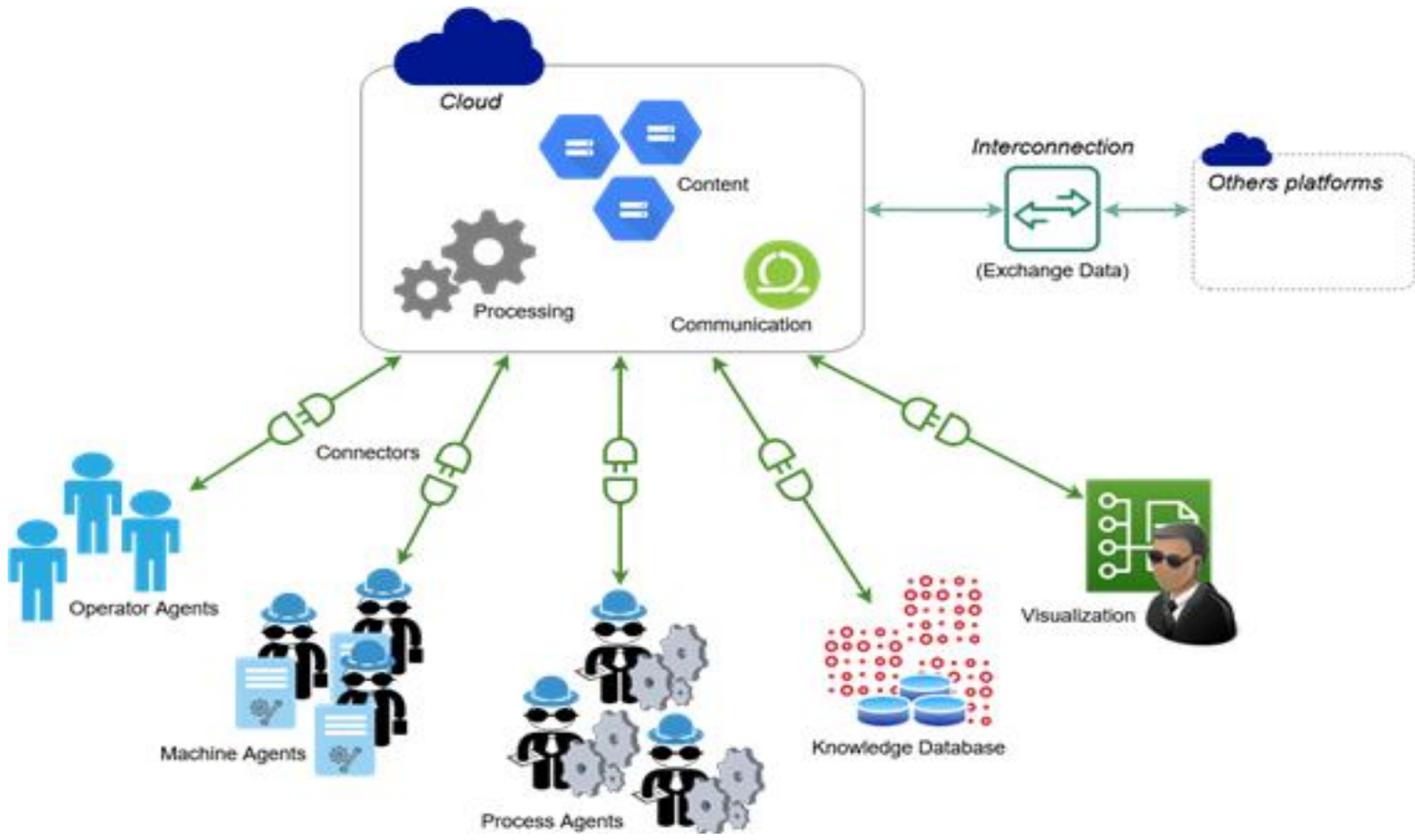

Fig. 8. SOON general architecture

The SOON architecture is focused on the following basic roles of agents:

- *Operator agent*: this role is assigned to the human specialists responsible for operating a machine / group of machines / equipment or an entire shop floor;
- *Machine agent*: seen as an entity represented by a standalone software agent (a software module, which functionally has agent properties), which is attached to a device (having sensors and actuators), a machine or machine in the real world. A machine agent "observes" the functioning and evolution of the physical system. He is endowed with a social behavior by relating to other agents;
- *Process agent*: is similar to the machine agent, being instead associated with a supervised process or flow.

Other main components within SOON are represented by:

- *Knowledge database* (KD): which stores various data, information, knowledge and ontologies relevant in the context of the social network of agents. For example, KD will store data and information about past faults and related maintenance. Thus, the agents will "interrogate" KD to obtain the reference to the most appropriate action to be taken in case of a malfunction or its prediction;
- *Visualization instruments* (VI): are used by operators or supervisors to obtain useful information from the system. Based on current research, it was concluded that it is very important to visually represent the data helping human operators to make further decisions.

Within the proposed architecture, the connectors represent the software interface solution that ensures the interconnection of heterogeneous components in order to ensure communication within the system. The cloud component includes functionalities in addition to those performed by social agents. We consider that it includes methods of processing, analysis and storage of data based on distributed processing technologies in the network. In principle, each production system can rely on its own cloud services that can be interconnected with other similar or related clouds for the transfer of data, information and knowledge.

3.4.3. Information flow in the SOON system

The implementation of the main functionalities of the SOON solution depends on the properties of the raw data from industrial processes that are based on machines and devices equipped with sensors and also on computer systems used in production. Figure 9 shows the flow of information within the SOON framework. The flow of information consists of the following: data is generated by different data sources, then processed to obtain relevant information, on the basis of which agents make informed decisions and initiate various actions.

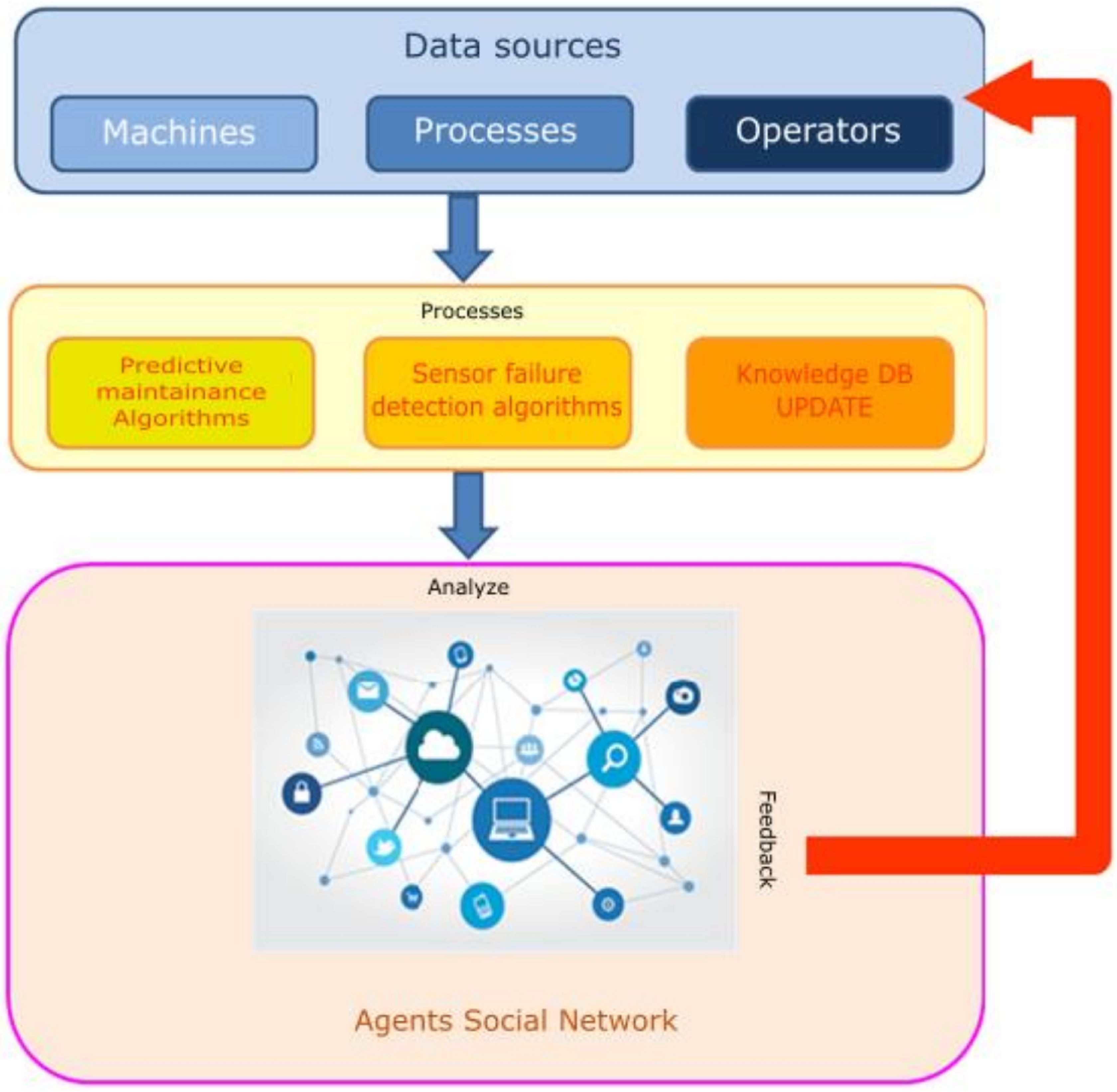

Fig. 9. Information flow in the SOON approach

Data sources: Within SOON, data is generated mainly by three types of heterogeneous data sources: machines, processes and operators.

- *Machines*: in an Industry 4.0 context, machines are usually equipped with sensors, computing capabilities and can keep track of the history of activities performed;
- *Processes*: information about a process allows obtaining an overview of the industrial process. In this category, we consider all available information from Enterprise Resource Planning System (ERP), Customer Relationship Management System (CRM) and Supply Chain Management System (SCM).

- Operators: human operators interact with the system leading to the generation of additional data and information. Often, only a small part of the data and information provided by operators is visible to the information system.

Data processing: The data generated in the previous step are processed in order to obtain information and knowledge about the monitored system.

3.4.4. The architecture of the multiagent system - The conceptual model

The conceptual multiagent system architecture highlights the general framework of the proposed social network model of the SOON solution, which incorporates SMA, advanced algorithms for predictive maintenance, automatic detection of sensor failure and optimal production planning in the context of Industry 4.0 involved in the project. The main requirements are extensibility and scalability, and it is necessary to integrate all the entities involved in a global solution. The SOON solution implemented based on the architecture will include new technologies, and various innovative methods to improve the decision-making processes regarding the maintenance and the different aspects of the management of the production processes.

The perspective illustrated in Fig. 10 of the Conceptual Model of System Architecture is based on a high-level description, which highlights the abstract structure of the SOON system, proposed for integration into a single paradigm that includes data, cloud and distributed processing systems (edge computing) with human operators involved in production systems.

The proposed architecture is organized starting from the storage of data from primary data sources, such as human operators, industrial processes of different subsystems and some data stored in the cloud from existing computer systems. Storage locations will be local (for example, on SBC systems) and accessed locally, and in the cloud through available APIs that allow cloud interoperability. The technologies proposed to be integrated include: human-type systems - cyber-physical system, cloud-based collaborative environment and the level of distributed processing systems.

The cloud-based collaboration environment is designed to provide real-time data exchange between human operators, distributed processing systems, processes and services such as intelligent algorithm-based processing, machine learning solutions, data aggregation and models. An important role in the SOON solution is represented by the level of distributed processing (edge computing) which consists in data acquisition, pre-processing and data storage, along with specific functionalities. The design of the multi-agent social system is coordinated by the academic partner in Slovakia in the form of the deliverable identified at project level as D3.2 Multi-agent social network and cloud-based collaborative environment architecture Environment Architecture Document).

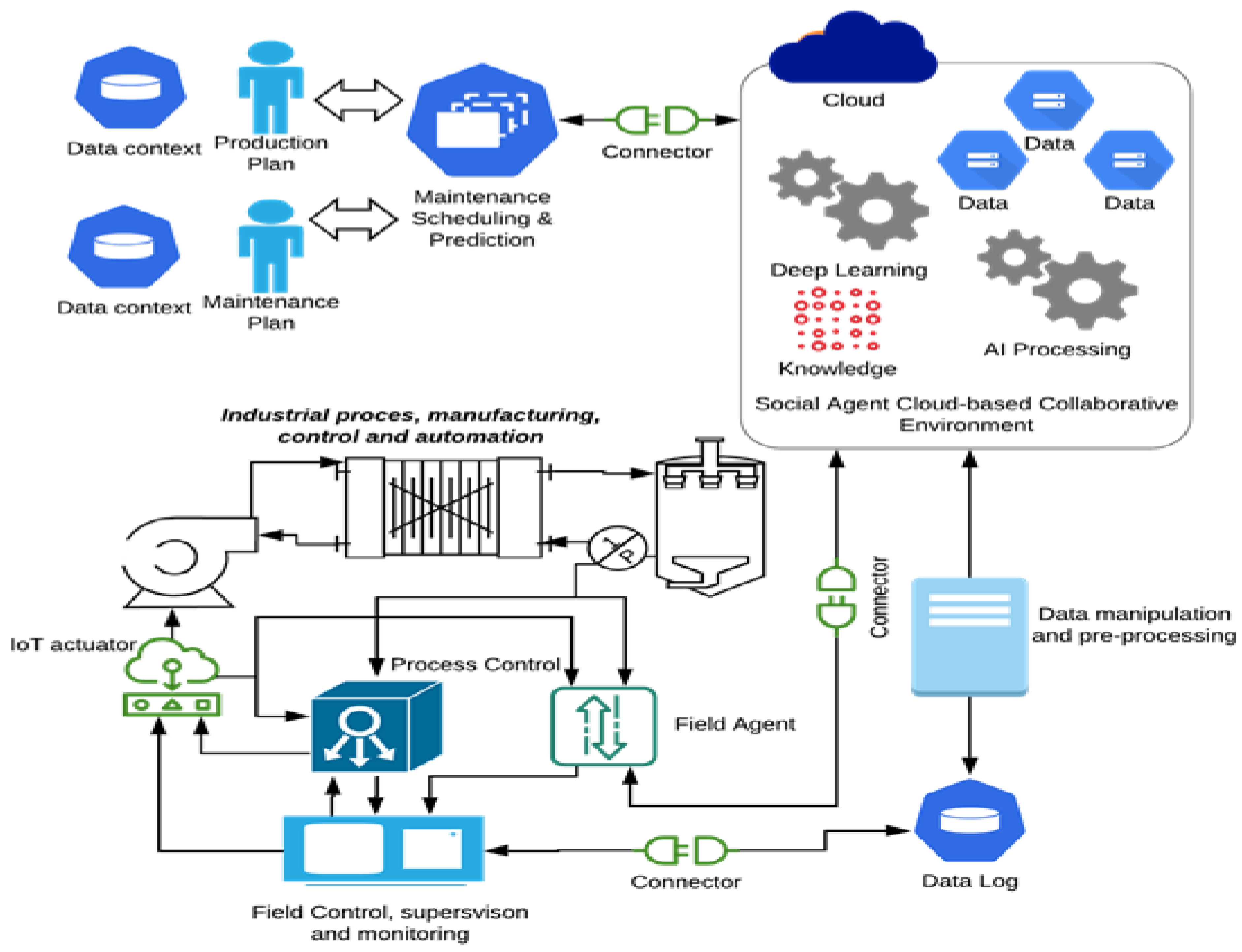

Fig. 10. The conceptual model of system architecture

The conceptual model developed highlights, in addition to the mentioned aspects, the data flow and the functional relationship in the proposed SOON solution. In the case of the presented conceptual model, a series of relationships are highlighted, which mainly follow three directions: machine / sensor / actuator - agents or distributed processing components - cloud and operator - collaborative environment based on social agents integrated in the cloud, as possible the highlight in Figure 11.

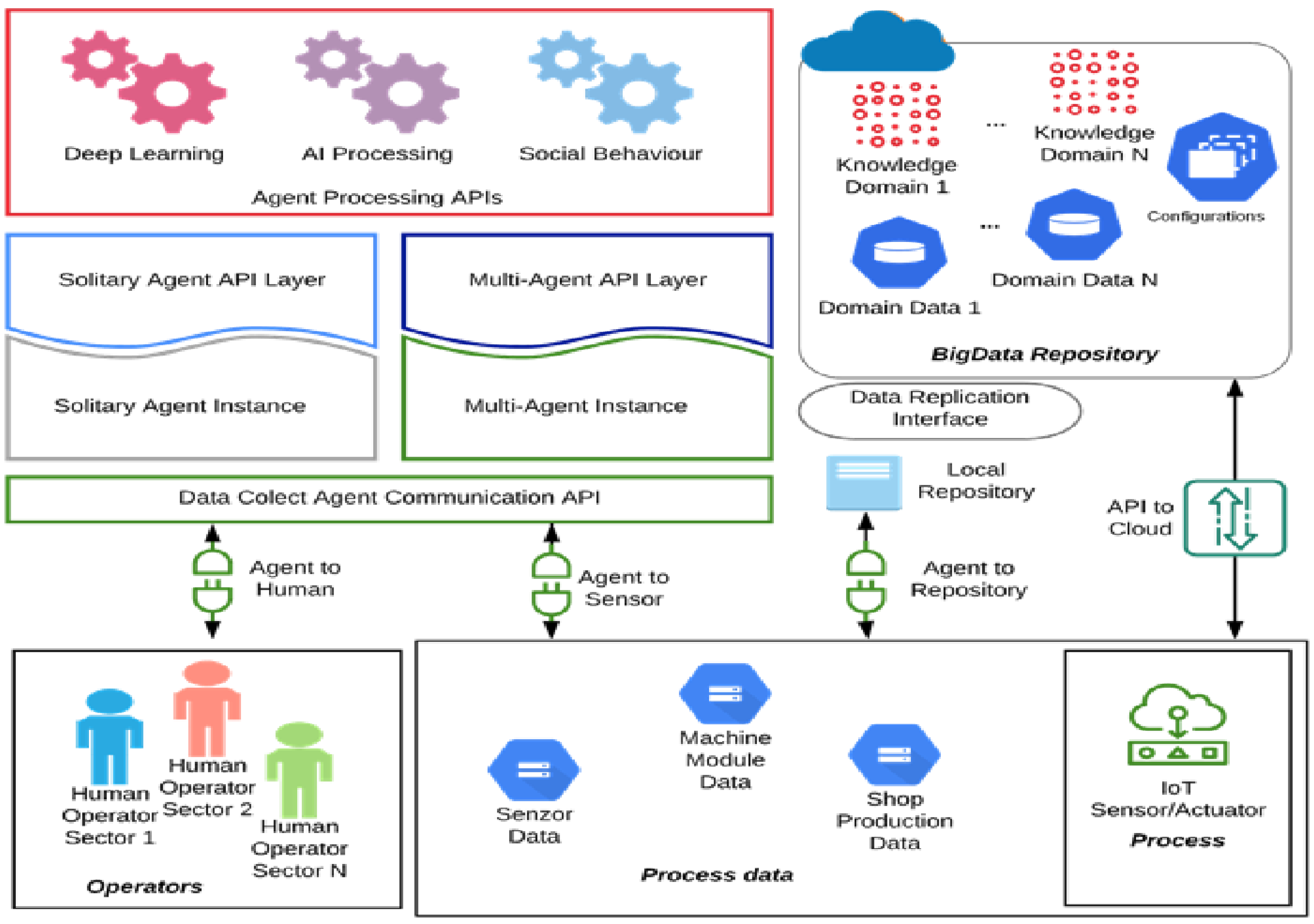

Fig. 11. The structure of the agent system structure

The proposed solution allows the integration in a multi-agent system architecture based on a social framework of heterogeneous and hybrid elements such as agents, sensors, machines, processes, optimization components, cloud-based services, human operators, etc. In this context, an API with various interfaces for each required data stream with open specifications can cover the proposed requirement.

3.4.5. Generic agent architecture

The main entity involved in providing problem solving based on the social network model includes processing units represented by social software agents. A social software agent, hereinafter referred to as an agent, depending on the field in which it operates, must make optimal decisions.

From the point of view of the specifics of the solved problems, the agents may have different specializations, for example monitoring and surveillance, operator, etc., as it was developed in the multi-agent social network presented in the document D3.2.

The proposed structure includes an integrated approach to predictive maintenance-specific processing, which requires data, related knowledge and communication interfaces for effective integration with physical systems (machines, sensors, processes), human operators, other social agents and computational processing modules, various edge computing technologies, databases and distributed processing services (e.g. cloud and fog).

The bibliographic study on the elaboration of ontologies included reference works [Kum19, Ram20]. In our approach, in the context of social agents, some of their knowledge and mutual relationships will be modeled using ontologies. Ontologies will integrate knowledge and data from use cases. The data needed to build the ontologies will be collected using a specific platform to be developed. The ontology generated, among others, will contain knowledge that underlies the agents' reasoning in relation to predictive maintenance.

3.4.6. Taxonomy of the SOON agents

The challenges identified in the industrial requirements impose specialized tasks to be solved, involving the use of agents designed to perform specific processing. In this context, as described in Fig. 12, agents belong to different classes. However, agents are assigned to solve dedicated tasks, but in essence they will share common characteristics, the most important being social behavior. Fig. 12 presents the SOON solution based on the proposal on the conceptual hierarchical approach of the agents. From the higher level derive hierarchically different agents with specialized purposes. This hierarchy can be analyzed from two points of view: of abstraction and from a functional perspective.

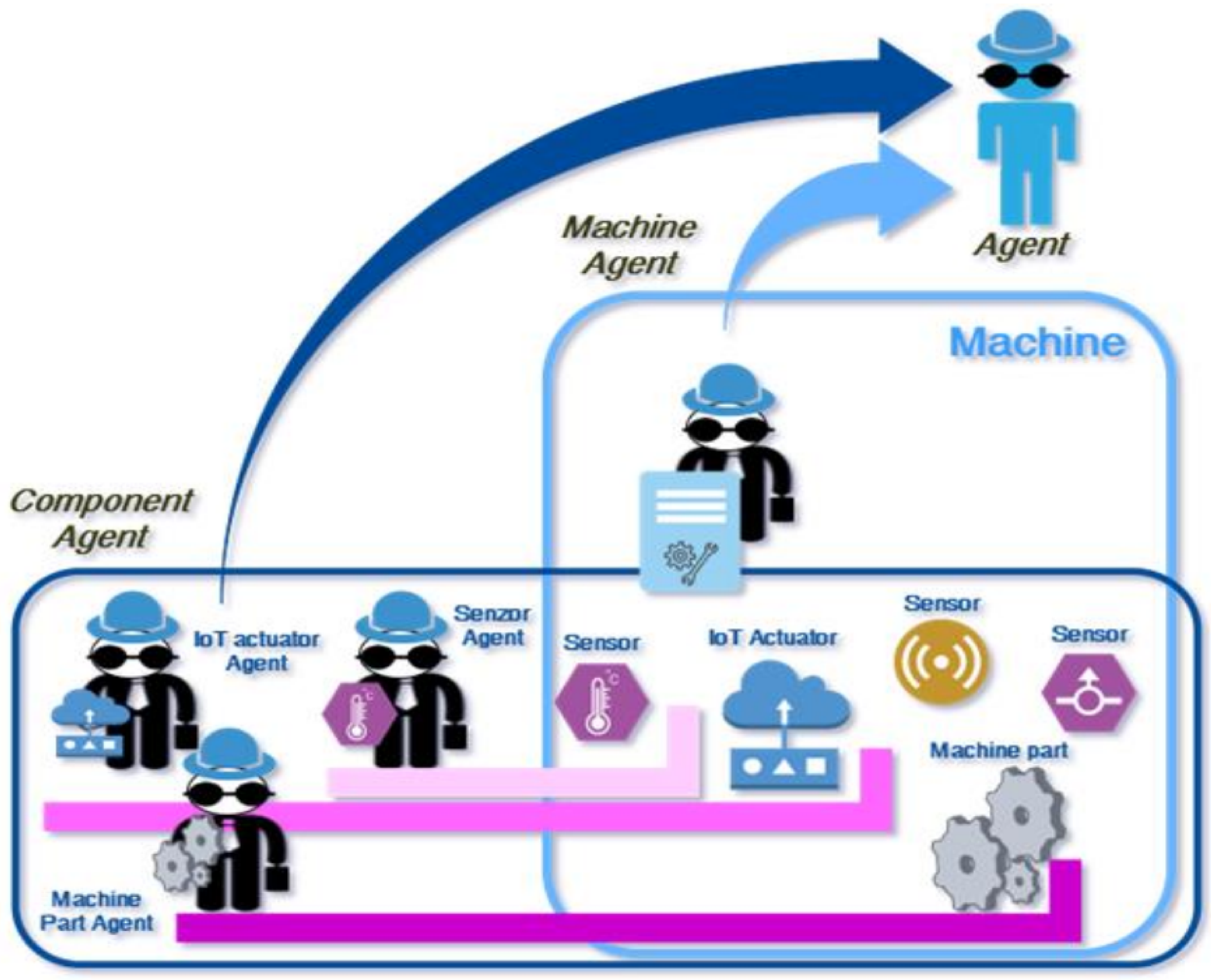

Fig. 12. Taxonomy of agents

More specifically, Fig. 12 presents the hierarchy of entities necessary for the implementation of the SOON solution, consisting of machines, components, sensors and process agents. It is also possible to see the approach on the two generalized classes proposed for agents, designated to describe the place in the SOON system at systemic level, namely: machine agent (e.g. machine, process), or field level agent, namely: component agent (e.g. sensor, machine part, actuator, IIoT component, etc.).

Component class agents are primarily designed to capture sensor states, interact with actuators, IIoT devices, and various machine / process monitored components. This interaction results in specific predictive maintenance tasks related to machine tools and components, which are often traditionally found in machines and production systems, e.g. lathe, electric drives, control units (such as PLCs) etc.

Machine-class agents (machine-type agents) are responsible for predictive intelligent maintenance functionalities at the level of machines or production lines (specific part related to the production process of products).

3.4.7. Conclusions regarding the proposed architecture

Recent literature shows that under the influence of industrial development, especially in the context of production systems and Industry 4.0, general architectures have been proposed, recognized by prestigious international organizations, which are presented at a conceptual level, without providing implementation details. In this sense, proposing and developing an appropriate architecture for the implementation of a predictive maintenance solution in the current context of adapting to the requirements of Industry 4.0, is a real necessity. Based on these circumstances, a system architecture was developed which was documented in the deliverable D5.1 at SOON project level, entitled En: “System and Architecture Specification”.

The developed architecture is an approach that involves a new paradigm of the manufacturing system seen as a social network that brings together a platform for solving problems related to predictive maintenance, people, agents, machines and state-of-the-art information technologies (multiagent solutions, big data, cloud processing, etc.). The scalable and open adopted structure ensures the incremental development of the solution and also the implementation in the cases of different identified industrial scenarios that are part of different types of industries.

In this subchapter were briefly presented some aspects related to the architecture designed at a general conceptual level, being presented the main specifications. Based on them, the multi-agent cooperative system will be implemented, which will include social agents, which will be used to solve some problems, focused on predictive maintenance within an industrial platform that conforms to an Industry 4.0 ecosystem. Software development will be based mainly on an agile software development [Yli19]. Which involves adaptive planning, evolutionary development, continuous improvement, which also encourages flexible adaptation to changes and new requirements that arise along the way.

3.5. Paradigms and predictive maintenance

This subchapter presents scientific results, also includes a bibliographic study, published in the form of an article, [Vla02] in the list of references.

3.5.1. Energy consumption an indicator of the state and efficiency of operation

Current production systems depend to a large extent on electricity, with estimates [Li16] showing that about half of world production is allocated to this sector. Obviously, it can be seen that many aspects, such as production costs or for example the impact on the environment due to these production systems, are directly related to electricity consumption. For this reason, the measurement, recording and analysis of energy consumption is of particular importance in the new context of Industry 4.0, representing the source of indicators that can be used to estimate and then optimize these production systems. Directly, the quantification and evaluation of energy consumption can be considered as a measure of the efficiency of production systems [Ma20]. Starting from this aspect, in the case of our research, it was considered that this indicator can be extended to assess the state and operating conditions of certain devices, assemblies, lines or production units, in order to establish predictive maintenance strategies. Starting from this approach, two main directions have been identified to follow: monitoring and evaluating energy consumption in order to correlate with failure events, respectively, integrating such a system considering the Industry 4.0 approach with the problems and challenges arising from it.

3.5.2. Predictive maintenance in terms of energy consumption

Assessing the condition of equipment, devices or machinery used in industry can be done directly and in real time by installing and reading sensors appropriate to each situation. Such an approach, however, raises a number of challenges, the solution of which is extremely complex and not infrequently and extremely expensive or in other situations, impractical or inefficient due to technical working conditions (difficult conditions such as high temperatures, environment with strong disturbances, improper operating environment, etc.). For this reason, not all situations allow direct monitoring in the field of the evolution of the systems of interest, therefore it remains at hand to assess these systems by indirect evaluation, starting from measurements or observations of accessible physical quantities or signals. Evaluation through electricity consumption is a possible approach, on the one hand due to the fact that in many situations it is already implemented, and on the other hand it is also useful as a primary source of data for other management subsystems.

In order to evaluate and demonstrate the viability of such an approach, an experimental stand was built and an applied research was carried out with the logistical support of a local economic agent which materialized through a research report published in the form of a scientific article [Vla20].

In [Vla20] we showed that by monitoring energy consumption, using sensors integrated in intelligent measurement solutions, we can evaluate the efficiency of operating technical systems and implicitly we can determine technical losses but especially non-technical ones, which allow the application of inexpensive and fast measures to reduce losses and reduce costs.

A remarkable result is the demonstration that by using the new algorithm based on the proposed optimization model and a modeling that has as a starting point the field measurements, one can effectively identify and locate the consumption points in the monitored network that present problems, and by extension to the issue of current research, consumer determination, which requires immediate intervention or future maintenance intervention. The optimization model (1) proposed in [Vla20] is particular to the analyzed system, but it can be extended by introducing appropriate modeling coefficients for any kind of system that can be abstracted informally in the form of a network that can track energy consumption.

3.5.3. Tracking energy consumption as a predictive maintenance solution in the context of Industry 4.0

The study was based on a structure that benefits from a conventional intelligent measurement system. In order to improve the performance of this system, it was proposed to implement IIoT and IoE type solutions that would transform the existing network into a smart network, by transforming its nodes into entities with a certain degree of autonomy. Reactive behavior and added communication skills, led to a social network that can be used to solve many problems presented in the paper [Vla19], such as automatic reconfiguration, identification of nodes where faults occur, self-diagnosis in case of operating anomalies.

In such a configuration, the algorithm in [Vla20] solves the problem for which it was designed in an efficient manner, identifying and eliminating connectivity problems specific to field sensors.

3.5.4. Identification of sensor failure and erroneous measurements

The main objective of the study focused on measuring energy consumption, but by adapting to the specifics of the proposed model, the solution is an appropriate approach for detecting sensor failure or erroneous data provided by them.

In the case of heterogeneous sensor networks, the proposed model must be adapted to each class of sensors, but by introducing an approach based on multiagent systems that have their own learning algorithms lead to the decentralization of the problem and to eliminate the mentioned shortcoming.

The results presented in [Vla19] are a basis for implementations within SOON, being a first step that demonstrates that an approach to technical systems based on models based on complex social networks can lead to promising results.

4. Conclusions

The emergence of the pandemic situation with the COVID-19 virus was a challenge from the perspective of project implementation, but all the proposed objectives and activities specific to the reported stage were successfully achieved. The pandemic did not allow for planning activities such as mobility, working visits, on-site participation in conferences. Among other things, participation in the Chist-Era 2020 Seminars was initially planned, but the event was canceled by the organizers. The collaboration with SOON project partners was very good. Monthly within the SOON project, video conferences are organized between all project partners. All this provides the necessary context for the further successful implementation of the project in the next stage.

The scientific collaboration with the FIREMAN project has been strengthened. Future collaborations have been established between the two projects in terms of research, exchange of expertise and experience, respectively various other activities. UMFST hosted the International Smart Technologies in Industry 4.0 (RATIONALITY) Workshop, organized at UMFST in collaboration with the support provided by the members of the two projects, SOON and FIREMAN. Thus it was possible to build a bridge between the two projects through the online event and to exchange ideas in a common platform.

The UMFST team expanded the pilot platform for testing and evaluating IIoT/IoE solutions for predictive maintenance that was started in the previous phase. The built experimental stand has the role of physical model of some classes of industrial processes. The stand can be configured to model and simulate different scenarios needed to obtain diversified data similar to real industry systems. Mainly, it will play an important role in Stage

III, where it will be used extremely intensively, in the processes of validation of intelligent predictive maintenance algorithms and testing the integration with cloud services of predictive maintenance solutions.

Four articles developed within the project and published in top journals were awarded in 2020. This year (May 2020) an article was published in an ISI journal with IF = 3,275, in the list of red journals (JCR list published in 2020).

In order to communicate the results to interested stakeholders from the industrial and academic environment, the UMFST team made two presentations at the RATIONALITY International Workshop.

Various researches are currently underway on the basis of which, in the next stage, it is expected to obtain results that can be exploited through conference communications, journal articles and possibly book chapters. The opportunity to attend conferences will be assessed according to the evolution of the pandemic.

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