UNIVERSITATEA DE MEDICINĂ, FARMACIE, ŞTIINŢE ŞI TEHNOLOGIE „GEORGE EMIL PALADE" DIN TÂRGU MUREŞ

Scientific and Technical Report
Summary

Stage III
Prototype development and integration based on multi-agent social network for predictive maintenance

Project code: COFUND-CHIST-ERA-SOON
Contract number: 101 / 17.04.2019

Project title (in Romanian):*Smart Device Social Network*
Project title (in English):*Social Network of Machines*
Project acronym:*SOON*

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1. The objectives of Stage III

1.1. Context. Preliminary aspects

This document aims to present a summary of the main activities and results related to Stage III of the project.

An important direction of evolution in Industry 4.0 is the integration of intelligent technologies in all spheres of industrial production. In the current conception, intelligent solutions, if implemented, can be found at the level of stand-alone, heterogeneous applications, which in most cases operate in isolation, without the possibility of efficient interconnection and cooperation in order to fulfill integrated multi-system functions. , even if they have a close physical location. The central motivation of the proposed research aims to develop a paradigm of easy interconnection of processes, data, things and people in a holistic paradigm that extends the concept behind the authentic Internet of "all things", with functions with certain degrees of intelligence.

In the present project, the proposed holistic paradigm is centered on a multi-agent framework that models machines, processes but also the people who operate or monitor them. Although automation has taken over many of the functions of human operators, their presence is still essential from the point of view of technical expertise, which from a project perspective is one of the sources of knowledge used by software agencies along with other data sources used by algorithms. deep learning and extraction of details and features, in order to provide new, essential information, otherwise difficult to extract 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 different profile of the three industrial partners involved ensures the generality of the project approach from the perspective of the types of industrial manufacturing processes considered. Finally, we intend to demonstrate that the introduction of Industry 4.0-specific principles, combined with recent developments in machine learning, along with the application of an architecture based on a multi-agent social system,

In Stage III of the project report, the consortium of three universities, a research institute of a national academy and three industrial companies with a distinct production profile (machine tool production, steel industry, recycling and plastics production) from different European 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 Switzerland de West (HES-SO) from 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);
- Company Tornos SA (Tornos) from Switzerland, industrial partner;
- MAT-obaly, s.r.o. (MAT) from Slovakia, industrial partner;
- ArcelorMittal (AMI3) from Spain, industrial partner.

1.2. Specific objectives related to Stage III

The overall objective of the SOON project is to investigate the impact of using smart autonomous social agents to optimize industrial production processes in the context of 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. Figure 1 shows the conceptual idea of the Smart Network Social Network.

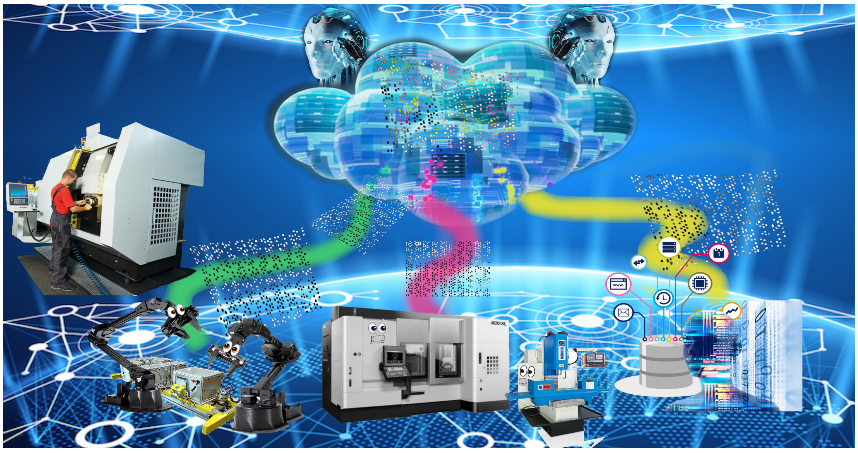

Figure 1. Conceptual representation of the Smart Device Social Network solution

The specific objectives of Stage III are the following:

- **Objective 1.**Research and development of predictive maintenance integration framework based on the proposed multi-agent paradigm. (achieved by Act. 3.1).
- **Objective 2.**Design and development of machine social network solution architecture modeled through the multi-agent system approach. (achieved by Act. 3.2)
- **Objective 3**. Research and design of predictive maintenance algorithms based on Artificial Intelligence (AI) techniques. (achieved by Act. 3.3)
- **Objective 4.**Design and implementation of the interface between smart devices (M2M) and the human-machine interface (UI). (achieved by Act. 3.4)
- **Objective 5.**Design and development of predictive maintenance solution evaluation plan. (achieved by Act. 3.5)
- **Objective 6.**Designing scenarios for evaluating and testing the performance of a pilot industrial solution. (achieved by Act. 3.6)
- **Objective 7.**Design, implementation of the module for predicting equipment failure and sensors with AI algorithms. (achieved by Act. 3.7)
- **Objective 8.** Project management and dissemination.

1.3. Specific activities of the current stage

In full compliance with the Project Implementation Plan, within Stage III, two categories of activities were implemented: some in progress from the previous stage, respectively some that started in this stage. The development of some of the activities will continue in the next stage.

Act. 3.1. Development of integration framework*(The activity of Act. 1.5. From Stage I, continued with the identifier of Act. 2.1. in Stage II, continued in this stage as well) [conf. implementation plan] [Successfully completed]*

Activity focused mainly on the elaboration of the requirements and design of the integration framework and at the same time on the implementation of the integration framework (in the project proposal, WP5: T5.2, T5.3).

Based on the analysis of the requirements and specifications established in the previous stage, the integration framework (framework) of the intelligent solution for predictive maintenance based on an innovative multi-agent paradigm was developed. The approach considered in the project is based on the defined predictive maintenance scenarios, specific to each industrial partner, taking into account a large number of factors such as heterogeneity, availability, real time and the amount of data purchased.

The developed solution starts from the idea of agile interconnection [Yli19] of the main intelligent processing modules, services, sources and data storage. In this sense, the aim was to define a universal interface exposed by the modules of interest, so as to allow the configuration of the solution according to the needs of the work scenario, the addition of additional modules of intelligent processing, continuous integration of new solutions in the existing functional context. lastly, the interaction with the human operator.

Act. 3.2. Model implementation and multi-agent social network solution architecture.*(Activity started in Stage II with the identifier Act. 2.4 .; continued in Stage III) [conf. implementation plan] [Successfully completed]*

Activity focused on the implementation of the model and architecture of the multi-agent social network solution (in the project proposal, WP3: T3.2).

The aim of this activity was to develop and refine innovative architecture based on an integrated intelligent cooperation structure in the form of a social network that brings together IIoT devices, machines, cloud processing solutions and human specialists. The main basis of this solution is the multi-agent system that can operate with different intelligent processing algorithms adapted to the place and field of use, algorithms that have a machine learning component based on the ontology proposed and developed in the project. In this regard, mention should be made of the work on developing and refining the standard structure of the profile of agents and the model of social relations between them.

Act. 3.3. Explore and design maintenance algorithms based on artificial intelligence (AI).*(Act. 1.3. Started in Stage I continued in Stage II with the identifier Act. 2.5 .; continued in Stage III) [conf. implementation plan] [successfully continued in Stage IV]*

Activity focused on the design of algorithms based on artificial intelligence techniques (in the project proposal, WP4: T4.1, T4.2).

One of the main themes of the project focuses on exploring, developing and improving the implementation of a predictive maintenance solution in the context of Industry 4.0 using models based on machine learning techniques. In this context, the activities carried out focused on i) predicting the failure of technical systems used in industrial production but also ii) identifying anomalies that could have as a source erroneous data caused by the failure of monitoring sensors.

Act. 3.4. Development of intelligent device interface solution and human-machine interface. *(started in Stage II with the identification of Act 2.6 .; continued in Stage III) [successfully, according to the implementation plan] [Completed]*

Activity focused on the design and implementation of the interface between smart devices (M2M) and human-machine interface (UI) (in the project proposal, WP5: T5.4).

An important component that ensures the successful implementation of the collaborative social structure is represented both by the communication interfaces between smart devices - machine to machine (M2M) and by the human-machine interface (UI).

The aim of this activity was to finalize the specifications and the implementation model of the agent-to-agent interface (A2A), respectively M2M, providing the framework for implementing and testing its functionality both within local facilities and interconnected with the experimental platform developed by the partner in Slovakia. .

Act 3.5. Testing and evaluation of integrated predictive maintenance solution.*(started in Stage II with the identifier Act. 2.7 .; continued in Stage III) [conf. implementation plan] [Successfully completed]*

Activity focused on the development and implementation of the evaluation plan (in the project proposal, WP6: T6.1).

In this activity it was proposed starting from the analysis performed in the previous stage the definition and adaptation of the performance indicators adopted in accordance with the particularities of the defined solutions of predictive maintenance. The aim was also to establish the procedures, testing scenarios and methodology for acquiring and processing the data obtained, respectively the validation criteria. In this activity it was proposed to carry out a series of preliminary tests to calibrate and validate the proposed approaches.

The next step is to carry out detailed testing and evaluation activities.

Act. 3.6. Testing and evaluation of developed industrial solution.*(activity started in Stage III) [conf. implementation plan] [successfully continued in Stage IV]*

Activity focused on testing and evaluation in industrial pilot implementations (WP6: T6.2).

Verification and validation in real experimental conditions is a stage in which a new solution is given the guarantee of transfer from the laboratory to the real environment. In order to facilitate the use of the solution in the real industrial environment, it was proposed to create a model of experimentation and testing with real characteristics: starting from real devices and machines and continuing with the relevant signal sources. This activity aimed to perform tests in accordance with a series of customized scenarios, considering different types of operating modes, different defects, with varying intensities and disturbances of different levels, respectively spatial orientation.

The data obtained in this activity are to be selected and organized so as to allow their inclusion in the open access data set of the project.

Act. 3.7. Implementation of algorithms for defect detection using AI techniques.*(activity started in Stage II with the identifier Act. 2.9 .; continued in Stage III) [according to the implementation plan] [successfully, continuation in Stage IV]*

Activity focused on the implementation of the module for predictive fault detection using Artificial Intelligence algorithms (in the project proposal, WP4: T4.3).

Within this activity, it was proposed to design and implement algorithms designed to identify the types of defects that may occur in the case of operational sensors and monitoring sensors for the implementation of the predictive maintenance solution of industrial production machines and equipment. The activity involved several directions such as: analysis and identification of process characteristics to be used as a data source for machine learning algorithms, which included a series of specific sub-activities that included the development and implementation of conditioning strategies, filtering, scientific visualization and labeling in the acquisitions made, implementation of algorithms, respectively testing, evaluation and formal validation.

Act. 3.8. Project management, publications and dissemination.*(Continuation of Act. 1.4 from Stage I; continued in Stage II with the identifier Act. 2.8; continued including in Stage III) [conf. implementation plan) [* successfully, continue in Stage IV]

Includes specific project management and dissemination activities (in the project proposal, WP1: T1.2, WP7: T7.1).

This activity aimed at accomplishing the tasks necessary to ensure project management, reporting activities, dissemination and increasing visibility. In order to ensure increased visibility, the aim was to update the Romanian and English bilingual web portal of the project related to the UMFST partner, respectively its population with the information specific to the current stage. Throughout the stage, the dissemination strategy was explored, developed and adapted taking into account the current pandemic context with the SARS-CoV-2 virus, the evolution and impact of which could not be estimated.

2. Synthesis of the achievements of Stage III

R.1. Specific activities for the implementation of the SOON proposal carried out in Stage III

Stage III included various research-development-testing-evaluation activities specific to the implementation of the project, described in section 1.3., Which were successfully carried out according to the implementation plan.

R.2. Collaboration with SOON project partners

Close collaboration was maintained with SOON project partners, both university and industrial. Video conferences were organized monthly for the regular meetings attended by all project partners. On these occasions, progress reports were presented by all partners. Meetings for bilateral discussions on topics of particular interest have been set up as needed.

R.3. Scientific and research collaboration between SOON and FIREMAN projects

The scientific collaboration between the SOON projects and the Framework for the Identification of Rare Events via Machine Learning and IoT Networks (FIREMAN), initiated in the first stage of the project, has been extended and continued during the current reporting period. The reference is the involvement in joint actions, such as the “FIREMAN and ee-IoT” Workshop, May 14, 2021 [Gli21]. The continuation of this collaboration was possible and motivated by the existing complementarity between the two projects, respectively by the vision regarding the obtaining in the field of research of some benefits from both sides.

R.4. Establishing the next edition of the Smart Technologies in Industry 4.0 Workshop

In Stage II of the SOON project, the projects SOON and FIREMAN organized the first edition of the International Smart Technologies in Industry 4.0 (RATIONALITY) [WebR] Workshop. The main contribution to the organization of the Workshop was made by the UMFST team through the role of host of the event and main organizer. The event took place online, the virtual location being on the Microsoft Teams platform of UMFST. The RATIONALITY workshop was publicized through various means of electronic communication, including social media. https://www.facebook.com/InterEng

At this stage it was established that the next date of the workshop will be in Phase IV of the project. This workshop will present scientific results and progress reports from both SOON and FIREMAN projects.

R.5. Dissemination, communication, participation in conferences

R.5.1. **Communication and dissemination of research results obtained in collaboration by**

project partners

The project entitled SOON: Social Network of Machines to Optimize Task Scheduling in Smart Manufacturing [Gho21] was collaboratively developed within the project, which included results obtained in collaboration by the UMFST team with the project partners. The paper presented at the prestigious 2021 IEEE 32nd Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) was held on 13-16 Sept. 2021 in Helsinki, Finland, being published by IEEE CS Press. PIMRC 2021 is a Core B classified conference.

***R.5.2.* Communications in workshops.**

The UMFST team together with the project partners participated in the conference: Joint FIREMAN and ee-IoT, Virtual Workshop 2021, May 14, 2021. On this occasion, the communication entitled: SOON Social Network of Machines a Solution for Smart Manufacturing was presented. was developed in collaboration by the UMFST research team and the research team of the Institute of Computer Science of the Slovak Academy of Sciences, partner in the SOON project, presenting recent research results. One of the aims of the presentation was to disseminate some preliminary results of the research obtained under the SOON project to be extended, disseminated and published.

R.5.3. Participation in the CHIST-ERA 2021 Seminars

The UMFST team participated in the CHIST-ERA Projects Seminar 2021, held online from April 12-14, 2021. A presentation was made by the SOON project on the progress report, in which it participated. and the UMFST team.

R.5.4. Participation in the competition for the promotion and dissemination of CHIST-ERA projects organized within the CHIST-ERA 2021 Seminars

On the occasion of this competition, a promotional video material was made to popularize the SOON project. The prepared material can be found both on the web portal of the SOON project by the UMFST team (https://soon.umfst.ro) and on the web portal CHIST-ERA (https://www.chistera.eu/ps2021-video-contest).

R.5.5.Participation of the UMFST team in the organization of an international conference

The UMFST team participated in the organization of the international conference Interdisciplinarity in Engineering (INTER-ENG 2021), October 7-8, 2021, an online event with the UMFST virtual location. The main announced theme of the conference, which also includes the particular theme of the SOON project, was: “Innovative aspects of Industry 4.0 concepts aimed at consolidating the digital future of production in companies”.

***R.5.6.*Updating the bilingual web portal**

The bilingual web portal (in Romanian and English) of the SOON project has been updated, presenting the relevant information regarding the project, specific to the current stage of development. Among other things, it includes a video material to popularize the SOON project for stakeholders.

R.6. Publications and awarding of research results

***R.6.1.* Social network of machines for optimizing task planning in intelligent manufacturing**

The article entitled "SOON: Social Network of Machines to Optimize Task Scheduling in Smart Manufacturing" [Gho21] presents the main results obtained in collaboration by the project partners. The aim of the research was to investigate the impact of using autonomous social agents to optimize production processes related to an industrial platform based on the concept of Industry 4.0. The paper was accepted for presentation at a CORE B classified conference and published in the conference volume.

Various aspects related to the design of optimal architectures of intelligent production systems in Industry 4.0 are current topics [Far20, Tru19]. In this context, [Gho21] presents the architecture of the SOON multi-agent system and the proposed methods aimed at optimizing task planning. Two different planning approaches are proposed. The first approach is based on a "bidding" paradigm in which the assignment of a task is decided based on the ability of a machine agent to bid for that task. The second approach is built on a network of agents in which agents learn to acquire and perform tasks cooperatively. Both solutions allow you to manage and synchronize communication between agents while performing tasks. To describe each approach, two cases of industrial use are illustrated: manufacturing processes in the steel industry and manufacturing processes of high-precision parts and subassemblies. Finally, in the agent network, agents are trained to use enhanced learning to maximize cumulative reward and optimize production planning. The obtained results demonstrate that learning by reinforcement allows the learning of the optimal behavior in various scenarios.

***R.6.2*. Black-box Performance Indicator for modeling the measurement of systems intelligence**

In [Jan18B] we conducted a comprehensive study of recent trends in the intelligence of agent-based systems. Various results [Jan19a, Jan19b] regarding the measurement of systems intelligence were obtained in the previous stages of project implementation.

The article entitled "Black-Box-Based Mathematical Modeling of Machine Intelligence" [Jan21] was awarded the PN-III-P1-1.1-PRECISI-2021-53997 prize. The magazine where the article was published is included in the list of WoS Q1 publications. The aim of the research was to develop a universal performance indicator [IP, En: Key Performance Indicator (KPI)] universal black box, called MetrIntPairII that can be used to measure the intelligence of systems in general and systems multi-agent cooperatives in particular. The published article is open access, thus allowing free access of researchers around the world and its use in research.

***R.6.3*. Exploratory analysis of factors to identify risk factors**

In the article [Dob21] a study was carried out on statistical methods of data analysis. The aim of the research was to obtain a preliminary synthesis on the future use of methods based on the analysis of predictive maintenance data in Industry 4.0. The article is published in open access mode in a BDI journal and can be accessed by researchers from all over the world.

Topics covered in the analysis include: exploratory factor analysis; establishing the optimal number of factors; correlation analysis; the Bartlett test, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy test, and more. Determining the optimal number of factors is a particularly difficult issue that has been addressed in numerous studies [Yun17, Cos05, Hay04, Pre13, Son08]. Determining an inadequate number of factors can lead to inaccurate or even erroneous results. Among the most commonly used methods in determining the number of factors is the Kaiser criterion [Kai58], the test called Cattell's Scree [Cat66]. Kaiser's criterion allows numerical evaluation to determine the number of factors. The Cattell's Scree test allows visual evaluation to determine the number of factors.

In the research carried out, a very important aspect was highlighted that must be taken into account in determining the number of factors, namely the minimum cumulative variance that must be explained by the extracted factors. At the same time, various tests and verifications are indicated that must be performed in order for the exploratory analysis of the factors to be correctly applied.

R.7. 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 (Figure 2, architecture left and a visual image of the infrastructure on the right). The test solution consists of an HPC unit, workstations, a communication network with high-speed and management equipment, and SBC systems connected via PoE as data concentrator systems from sensors via SoC solutions.

In Stage III, the pilot platform for testing and evaluating IIoT / IoE solutions for predictive maintenance was extended. The experimental stand allowed to obtain new data that were used in research in the current Stage, and their use will be planned in the next Stage of the project. The data will be available with free access in recognized sources allowing their use by all interested researchers.

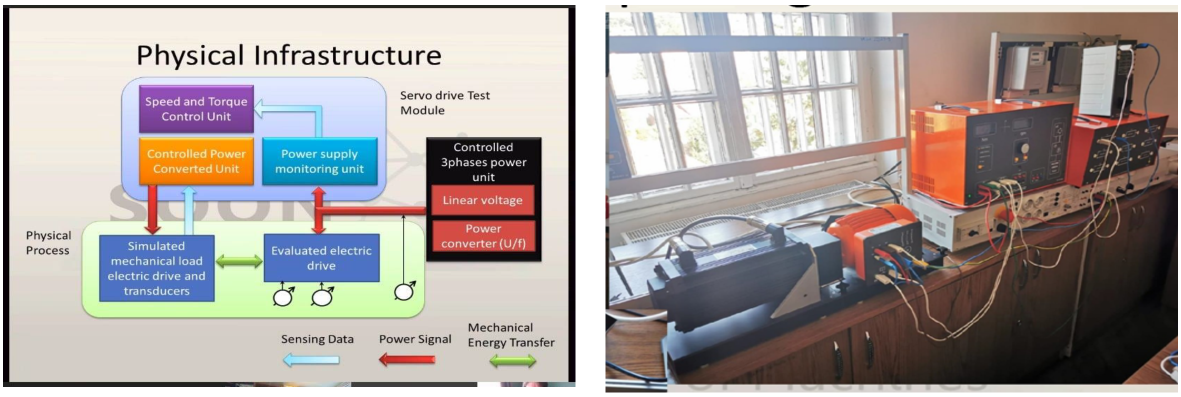

Figure 2. Pilot platform for testing and evaluating IIoT / IoE solutions for predictive maintenance.

3. Scientific and technical description

At this stage of reporting, as mentioned above, a number of highly complex activities have been addressed, both scientifically and applied. This section summarizes the activities carried out during the reporting period.

It was considered useful to structure this technical description in sections related to the main activities in order to provide an overview of the predictive maintenance solution based on the innovative holistic multiagent social system architecture, integrating machines, devices, operators, ontologies, knowledge, algorithms. real-time processing based on AI and big data.

3.1. Preliminary aspects

In the industrial area, the interest in solving predictive maintenance problems is very topical [Car19, Zon20]. In this project, in view of this aspect, it was proposed to investigate the feasibility of developing a solution based on a holistic paradigm based on social smart agents for predictive maintenance that includes both machines and human operators. Expert operators provide knowledge, but at the same time benefit from the support provided by agents in decision-making processes. This involves various algorithms for extracting values and characteristics, as well as deep learning algorithms in order to optimize industrial processes. A significant challenge of these algorithms is related to the large amounts of data, for example thousands of mega bytes in 24 hours, the heterogeneous character, given the diversity of acquired signals (vibrations, temperatures, energy consumption, etc.), they are provided by a wide variety of equipment and devices (supervision and monitoring systems, automatic control systems, robots). In many cases, real-time measurements are needed, but at the same time data from historical records, available in the form of time series, some of which are based on ERP systems, all of which lead to an increase in the complexity of the problem.

The developed solution is based on the specifications from the various industrial companies involved in the project. The overview of the architecture of the proposed solution is presented in Figure 3. The main design requirement is to ensure scalability, so as to allow the dynamic incorporation of entities such as physical machines and processes, devices, sensors and ICT infrastructures consisting of systems smart cloud processing, data concentrators and software for processing and analysis.

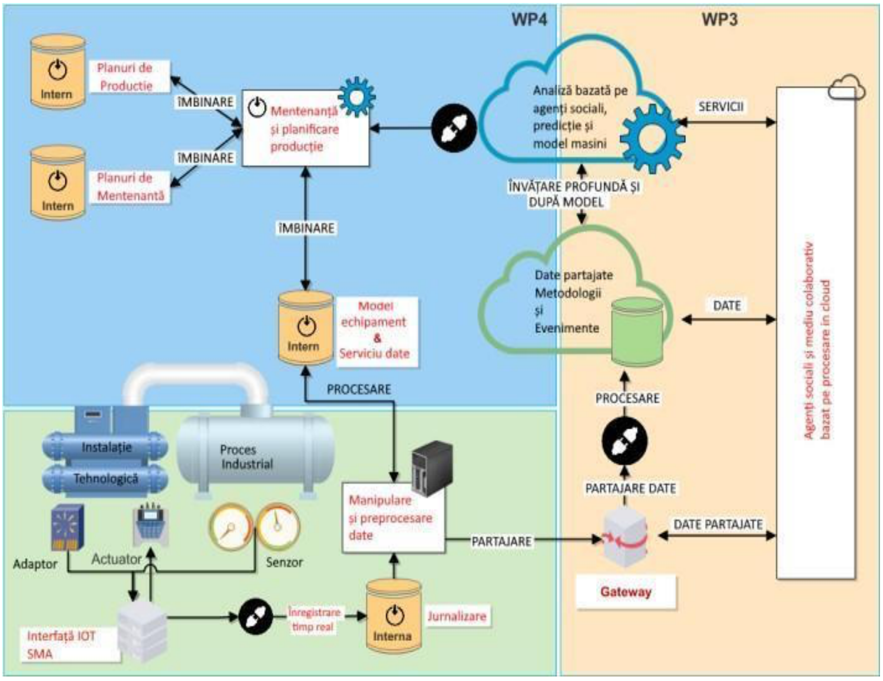

Figure 3. The proposed SOON solution for predictive maintenance.

3.2. Smart solution solution for predictive maintenance

One of the important objectives of the current phase was to develop a framework for integrating the main predictive maintenance functionalities proposed in the industry-specific scenarios considered in the project. Based on the analysis of the requirements and specifications established in the previous stage, the integration framework (framework) of the intelligent solution for predictive maintenance based on the paradigm of a multi-agent platform was developed.

The framework developed in the project started from the idea of the possibility of agile integration [Yli19] of the main modules, services, sources and data storage. The result has led to the definition of a universal interface that provides access to modules of interest, with the possibility of configuring the solution according to existing needs specified in the work scenario or with the possibility of adding new facilities, for example as in the case of modules. intelligent processing, continuous integration of new solutions in the existing functional context.

In order to ensure increased portability and extended compatibility, it was considered appropriate to adopt two integration methodologies, namely the use of standardized markup language descriptions and the use of established protocols, in this case MQ Telemetry Transport (MQTT) [MqtW].

Estimating the need for dynamic adaptation of the offered functions, in the proposed approach, a software agent type structure was adopted that supports real-time updating of its functional model, considered being either updating the parameters of the intelligent processing model or even the whole algorithm. The proposed model was tested using the experimental platform developed for modeling a predictive maintenance scenario for a variable speed drive machine equipped with monitoring sensors integrated in a high-resolution, high-speed data acquisition system. updated the fault recognition models (electrical, mechanical, etc.) resulting from real-time measurements.

A special aspect, mentioned in the Requirements Document of the proposed solution, followed throughout the project, was to consider in the foreground the role of the human operator. Thus, an extensible human operator interface model designed based on IoT technologies was designed and developed. In the demonstrator prototype, the human operator can interact with the multi-agent solution and can obtain information about the status, resources, system messages of the platform.

3.3. The model and architecture of the solution based on the paradigm of a multi-agent social network

An important task of this stage was the activity focused on the implementation of the model and the architecture of the multi-agent social network solution. Figure 4 contains an overview of the proposed solution for predictive maintenance in Industry 4.0, while illustrating the overall SOON architecture.

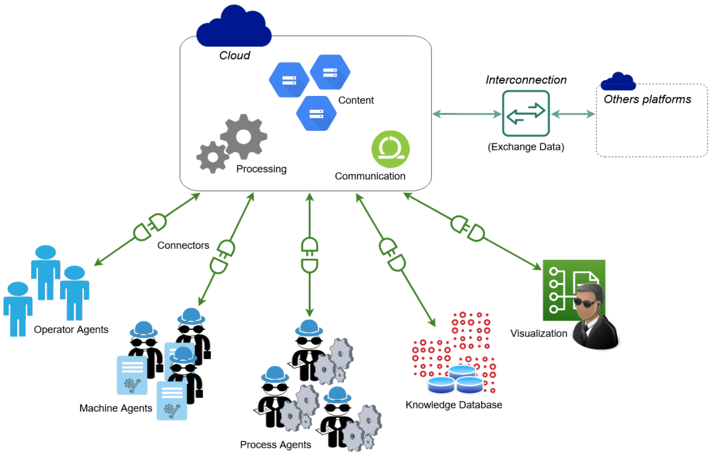

Figure 4. SOON general architecture

Developments based on the innovative approach introduced in this project have led to an integrative solution, considering as a basic model a smart cooperative structure, in the form of a social network, IoT devices, machines, cloud processing solutions and specialists humans.

The architecture developed and refined in this stage of the project is based on a multi-agent paradigm that includes a component of online machine learning and also the ontology proposed and developed within the project as well as a real-time adaptation function using cooperation algorithms. to identify optimal configurations to support decision issues related to the cases described in the predictive maintenance scenarios.

A significant result of this stage is the refined standard structure of the profile of agents and the model of social relations between them.

The updated version of the ontologies used by the multi-agent system has been designed to comprehensively describe an adaptive multilevel social context, extensive knowledge and mutual relations between agent-type entities.

The developed architecture is based on parameterizable models of agent profiles and social relations between them. The architecture exposes functionalities aimed at cooperation based on social relations for services such as help, assistance, friendship or follow-up, which can be extended according to the specifications of new requirements that could be proposed.

In particular, to ensure extended compatibility, the real-time collaborative system has been designed to implement a MQTT-based publishing-subscription interaction and cloud integration.

3.4. Development of predictive maintenance algorithms based on AI techniques

The project proposed to exploit one of the most important resources available in current industrial platforms, being here the data we have access to due to the availability of sensors, monitoring systems and even storage such as ERP solutions. However, the nature, complexity and amount of data available are an important barrier in the process of solving many problems often encountered in current industrial practice. One of the most important issues, considered as a topic of this project, is that of predictive maintenance, proposed to be explored from the perspective of AI.

The proposed and undertaken developments have focused on exploring, designing and improving the implementation of a predictive maintenance solution in the context of Industry 4.0 with the help of models based on machine learning techniques able to estimate with high accuracy the time of occurrence of technical systems. used in industrial production but also the identification of the type of defect at various levels of granularity - the detection of failure of a subassembly, component, module or that of sensor failure.

In order to develop the proposed algorithms, it was considered useful to use real data sources in order to easily transfer the results in the industrial environment. Thus, data provided by the demonstration stand were used, data associated with specific quantities of three-phase industrial electrical drives, in a first phase to predict the remaining useful operating time, respectively for the second objective, the identification of sensor failure. We mention that we started from the premise of the presence of non-compliant values, out of print, in the model of data collected in case of sensor failure. In this context, algorithms in the form of a prototype application that works integrated in the solutions based on social agents developed for the industrial partners were tested in real time. Thus, the foundations were laid for the development of a series of tools to provide the following functionalities: i) real-time detection of sensor failure and ii) fault diagnosis, classification, prediction and planning of the intervention. Among other things, various methods for identifying outliers have been tested, such as [Stef72, Zer03, Gru69, Dek05]: Grubbs, Chauvenet, and the IQR rule.

Algorithms developed, tested and evaluated to date include those based on different types of deep learning algorithms to identify the peculiarities of operation of simple electric drives or in operating configurations with variable parameters through dedicated power converters.

Another class of methods implemented, tested and experimentally evaluated are based on a series of regression algorithms, such as logistic regression [Dum22, Lan20]. Aspects such as the applicability of these methods for various types of data, the study of the prediction potential of variables, the regression model, etc. were investigated. Various statistical tests that could be adopted were analyzed, such as: Wald [Fea96], Hosmer and Lemeshow [Hos13] and others, necessary to verify the applicability of logistic regression (this aspect is often neglected or even misapplied in research). Aspects related to the quality of the classification were also studied in depth, allowing the comparison of the results obtained by logistic regression with results provided by other methods.

The results show that the solutions proposed by the accuracy of the answer provided can be used successfully in classification and recognition processes on both labeled and unlabeled entries. This allows these algorithms to be considered as the basis for the integrated predictive maintenance solution but also for the identification of sensor failure, at least if the available input data is represented by physical quantities, such as mechanical signals such as acceleration, positioning, vibration and electrical signals obtained from energy consumption sensors. The developments so far provide a basis for future extensions specific to the particularities and requirements manifested by the industrial partners.

At this stage, what is highlighted as a novelty aspect proposed in the project was addressed, namely the design and development of a predictive maintenance strategy, currently folded on solving the proposed scenario for the configuration of technical systems using variable speed drive systems. , a strategy that brings together the facilities offered by the deep learning-based modules used to process data from sensors in real time, as well as the decision-making algorithm based on the social network of machines.

In the last stage of the project, in collaboration with the project partners, it is planned to extend the proposed approach to a wider range of use cases present in the case of industrial partners.

3.5. Interface between machines and smart devices. Operator-machine interface

An important component that ensures the successful implementation of the collaborative social structure is represented both by the communication interfaces between smart devices - machine to machine (M2M) and by human-machine interaction (H2M).

At this stage, the specifications and implementation model of the agent-to-agent interface (A2A) and M2M were finalized, so that it was possible to implement and test its functionality both in local facilities and interconnected with the experimental platform developed by the partner in Slovakia. .

As the human operator is a key player in the operation of the solution, its inclusion in the provision of expertise, control, management and monitoring is possible only through the H2M and UI interface solution. This component designed and developed at this stage allows the human operator to flexibly configure and track operating parameters at the smart device level. At the moment, the prototype solution is available for access from computer systems as a web service and with the help of mobile devices, respectively.

If so far the development and implementation has been based on state-of-the-art technologies such as the Flutter Framework [Mui19], WebGL [Liu21] and Unity [Wod22] following functionality issues, in the next stage adjustments will be made to improve performance in the perspective of the resources used and the optimization of the operator interaction - the SOON platform of predictive maintenance.

3.6. Testing and evaluation of the integrated predictive maintenance solution

In order to evaluate by experimental testing the proposed solutions, starting from the analysis performed in the previous stage, the performance indicators adopted in accordance with the particularities of the defined solutions of predictive maintenance were established and defined. The procedures, test scenarios and methodology for acquiring and processing the data obtained were also established, along with the validation criteria.

In this activity it was proposed to carry out a series of preliminary tests to calibrate and validate the proposed approaches.

The next step is to carry out detailed testing and evaluation activities.

3.7. Testing and evaluation of the developed industrial solution

At this stage, improvements have been made to the experimental test platform, so that more parameters can be tracked in a wide variety of values at the time of writing.

With this configuration the verification and validation is closer to the real experimental conditions, which gives us the facilitation of the transfer of valid results from the laboratory environment to the real environment. In order to go through a small number of steps towards the implementation of our solution in the real industrial environment, we set out to create a model of experimentation and testing with characteristics close to industrial configurations: starting from real devices and machines, continuing with relevant signal sources.

Based on the development test cases and scenarios, a series of tests were performed that targeted different simple scenarios, considering different types of operating regimes, different defects and disturbances with varying intensities.

The data obtained are to be selected and organized in such a way as to allow their inclusion in the open data set of the project.

3.8. Implementation of algorithms for defect detection using AI techniques

Starting from the scenarios defined in the previous stage, during the current implementation phase, a series of algorithms were designed and implemented to identify the failure of operational sensors and monitoring sensors for the implementation of the predictive maintenance solution of industrial production machines and equipment. The activity involved several directions such as: analysis and identification of the characteristics of the processes to be used as a data source for deep learning algorithms, which included a series of specific sub-activities that included the development and implementation of conditioning, filtering, scientific visualization and labeling in the acquisitions made, implementation of algorithms, respectively testing, evaluation and formal validation.

In the process of designing and implementing the proposed algorithms, we focused on optimizing the operation of data acquisition, measurement and monitoring systems in order to correctly identify both the failure processes in the monitored processes and the sensor failure.

3.9. Multiagent social system: Specifications and architecture

The research, development, testing and validation framework focuses on the proposed system specifications and architecture, presented in Document 5.1. deliverable at the project level entitled “System and Architecture Specification”. The principles and an overview of this architecture was published in the paper [Gho21].

4. Stage results

Section 2 briefly presented the summary of the stage and the main results: R.1, R.2, R.3, R.4, R.5 (R5.1, R5.2, R5.3, R5.4, R5. 5, R5.6), R.6 (R6.1., R6.2., R6.3), R.7. All the expected results were successfully fulfilled, specifying the way to achieve the achievements. Also presented were some specific scientific results obtained that were actually published.

R.1 .: Section 1.2. presents the specific objectives of the stage. The activities required to achieve the objectives are described in section 1.3. The specific activities for the implementation of the SOON proposal in Stage III were successfully carried out according to the updated implementation plan. The continued implementation of the proposed solution will be based on an agile methodology [Yli19] due to the complexity of the proposal.

R.2 .: At all monthly project meetings with the project partners, the UMFST team made presentations in the form of progress reports. (see R.4. in section 2)

R.3 .: see R.4. from section 2.

R.5 (R5.1, R5.2, R5.3, R5.4, R5.5, R5.6): are detailed in section 2.

R.6. (R6.1., R6.2., R6.3): were briefly presented in section 2. The actual results obtained, the method of capitalization by publication (in publications that have actually appeared and have already been indexed), the value of the publications were specified. The following publications may be briefly mentioned:

A publication in an open access BDI magazine.

An article published in the volume of a conference rated B according to the CORE Classification of conferences.

An open access article published in a red zone magazine, the article being awarded.

We specify that in all the previous stages there were articles published, among others, in magazines in the red zone, which were also awarded. The proposed dissemination strategy for the next stage includes the creation of a new series of representative publications.

R.7 .: The pilot platform for testing and evaluating IIoT / IoE solutions for predictive maintenance has been successfully expanded. It consists of an experimental stand with the role of physical model of some classes of industrial processes whose operation is based on three-phase electric drives with variable speed. A strong point is that the stand can be configured to run different scenarios needed to obtain diversified data similar to real systems in the industry. The developed research infrastructure allows the generation of a large amount and diversity of data, whose processing is suitable to be performed with AI algorithms [Car19, Yan18, Zon20] (prediction, classification, machine learning, etc.).

5. Conclusions regarding Stage III of project implementation

In Stage III, various research results were obtained, some of which were published in the form of articles and / or presented at conferences. This report summarizes the results obtained presented in three articles, R.6.1 [Gho21], R.6.2 [Jan21], R.6.3 [Dob21] which were actually published and indexed. The summary of the current RST summarizes the results included in the three articles. Various researches and developments are currently underway, on the basis of which the aim is to consolidate the results obtained in Stage IV, respectively to obtain new results that can be exploited through communications at conferences and articles published in journals.

The scientific collaboration started in Stage I with the members of the FIREMAN team has been continued and developed in this last period. The most important points of this collaboration, besides the technical and scientific ones, were materialized in the participation in the virtual Workshop “FIREMAN and ee-IOT 2021” - May 14, 2021, respectively the preparations for the organization in the next period (Stage IV) of the the second edition of the Smart Technologies in Industry 4.0 (RATIONALITY) International Workshop, an event coordinated and organized by the UMFST team.

The UMFST team improved and developed the configuration of the pilot platform for testing and evaluating IIoT / IoE solutions for predictive maintenance through new computing resources, sensors and test configurations to facilitate research undertaken by generating data in various scenarios useful for proposed developments related to methods and algorithms. based on artificial intelligence techniques. The expansion of the research infrastructure continued at this stage as well. Part of the research infrastructure is available on the ERRIS Platform - uefiscdi.gov.ro: Center on High-Performance Computations https://eeris.eu/ERIF-2100-000H-7254

In order to communicate the results to the industrial, economic and academic stakeholders, the

UMFST team participated in the organizing activities, and in the scientific sections of the International Conference Interdisciplinarity in Engineering, 7-8 Oct. 2021.

Establishment of a new general direction of research and expertise of a UMFST Research Center: The SOON project was a source of inspiration for the reshaping of the Center for Advanced Research in Information Technology (CCATI) at UMFST University, by including specific research directions related to Industry 4.0 and intelligent manufacturing. The name of the Center itself is being changed, namely Artificial Intelligence, Data Science and Intelligent Engineering Research Center (Artemis).

Acquisition by the university of a state-of-the-art Industry 4.0 laboratory: The project is the source of inspiration for the development with the help of an investment supported from the university revenues of a state-of-the-art Industry 4.0 laboratory. All these endowments constitute an experimental testing platform for education, research and development dedicated to I4.0. It integrates a variety of technologies, from industrial control equipment, industrial sensors to IIoT devices and communications infrastructure.

6. Brief report on mobility and dissemination and / or training activity

Participation in seminars, mobility and working visits

The special conditions caused by the pandemic situation persisted during the period related to the activities of the third stage, however the objectives and specific activities proposed for this reporting stage were successfully achieved. This situation did not allow for certain types of planned activities such as international mobility, working visits, on-site participation in conferences. However, the online media have allowed us to maintain a close collaboration with all SOON project partners. Monthly online meetings were organized within the project with the participation of all project partners complemented by extraordinary small bilateral meetings with different partners in order to solve common goals.

Online entries: This reporting period included two conference participations and two workshops: IEEE 32nd Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Sept. 13-16. 2021, Helsinki, Finland (classified CORE Conference Ranking B), 15th Int. Conf. Interdisciplinarity in Engineering INTER-ENG 2021, Târgu Mureș, 7-8 oct. 2021, CHIST-ERA 2021 Seminars and “FIREMAN and ee-IOT 2021” Workshop - May 14, 2021, Lappeenranta Univ. of Technology, Finland.

Participation in the CHIST-ERA 2021 Seminars

It was possible to participate in the CHIST-ERA 2021 Seminars, held over several days, in online format. The SOON project team participated during the three days of development in all general sections and those dedicated to ongoing projects. Here was the opportunity to present the stage of the evolution of the project implementation, as well as the results obtained.

Participation in the Competition for the promotion and dissemination of CHIST-ERA 2021 projects

During the event, the SOON team participated through a video presentation multimedia material in the “CHIST-ERA Projects Seminar 2021 video contest” contest (https://www.chistera.eu/ps2021-video-contest) for the popularization of CHIST projects. It was in progress to the general public. 11 – SOON, Posted on Mon, 04/12/2021 - 11:17 Social Network of Machines.

Research collaboration between SOON and FIREMAN projects

The scientific collaboration between the SOON and FIREMAN projects was continued during this period, the motivation being the complementarity and some common research areas existing between the two projects, which suggest beneficial advantages in research on both sides.

Participation in the FIREMAN and ee-IOT 2021 Workshop

In light of the collaboration developed with the CHIST-ERA FIREMAN project team, the SOON project team was invited to the event with international participation “FIREMAN and ee-IOT 2021” where the stage of the evolutions of the two projects was presented, and within the main program, from the SOON project where A. Gligor and E. Gatial presented the work “Soon Social Network Of Machines A Solution For Smart Manufacturing” which was highly appreciated by the audience.

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