ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership

MANTIS

Cyber Physical System based Proactive Collaborative Maintenance

D1.2 Consolidated State-of-the-Art of Sensor-based Proactive Maintenance

Work Package	WP1 - Service platform architecture requirement definition. Scenarios and use cases descriptions
Version	2.5
Contractual Date of Delivery	30/04/2016
Actual Date of Delivery	?/?/201&
Dissemination Level	Public
Responsible	Erkki Jantunen
Contributors	Tom Tourwé (SIR), Elena Tsiporkova (SIR), Mathias Verbeke (SIR), Tom Ruette (SIR), Leena Parkkila (LUAS), Tom Maris (ILIAS), Antti Niemelä (LUAS), Franc Novak (JSI), Anton Biasizzo (JSI), Gregor Papa (JSI), Arja Kotkansalo (LUAS), Karel De Brabandere (3E), Daniel Brettschneider (M2X), Mikel Anasagasti (MONDRAGON), Lidia Godoy (ACCIONA), Rafael Socorro

	(ACCIONA), Raquel García (ACCIONA), Aitzol Iturrospe (MGEP), Mikel Viguera (FARR), Juha Valtonen (LUAS), Daniel Vladušič (XLAB), Pál Varga (AITIA), Csaba Hegedűs (AITIA), István Moldován (BME), Riku Salokangas (VTT), Bence Petho (AITIA), pela Poklukar (JSI), Quinten Marcelis (ILIAS)
Reviewers	Urko Zurutuza (MGEP)

The MANTIS consortium consists of:

Num.	Short Name	Legal Name	Role	Country
1	MGEP	Mondragon Goi Eskola Politeknikoa J.M.A. S.Coop.	CO	ES
2	MONDRAGON	Mondragon Corporacion Cooperativa S.Coop.	BEN	ES
3	IKERLAN	Ikerlan S.Coop.	BEN	ES
4	TEKNIKER	Fundacion Tekniker	BEN	ES
5	FARR	Fagor Arrasate S.Coop.	BEN	ES
5.1	KONIKER	Koniker S.Coop.	TP	ES
6	GOIZPER	Goizper S.Coop.	BEN	ES
7	ACCIONA	Acciona Infraestructuras S.A.	BEN	ES
8	MSI	Mondragon Sistemas De Informacion S.Coop.	BEN	ES
9	VTT	Teknologian Tutkimuskeskus VTT Oy	BEN	FI
10	LUAS	Lapin Ammattikorkeakoulu Oy	BEN	FI
11	NOME	Nome Oy	BEN	FI
12	FORTUM	Fortum Power And Heat Oy	BEN	FI
13	SQ	Solteq Oyj	BEN	FI
14	WAPICE	Wapice Oy	BEN	FI
15	AAU	Aalborg Universitet	BEN	DK
16	DANFOSS	Danfoss A/S	BEN	DK
17	UNIV	Universal Foundation A/S	BEN	DK
18	HGE	Hg Electric A/S	BEN	DK
19	VESTAS	Vestas Wind Systems A/S	BEN	DK
20	SIRRIS	Sirris Het Collectief Centrum Van De Technologische Industrie	BEN	BE
21	ILIAS	Ilias Solutions Nv	BEN	BE
22	ATLAS	Atlas Copco Airpower Nv	BEN	BE
23	3E	3e Nv	BEN	BE
24	PCL	Philips Consumer Lifestyle B.V.	BEN	NL
25	PHC	Philips Medical Systems Nederland B.V.	BEN	NL
26	PHILIPS	Philips Electronics Nederland B.V.	BEN	NL
27	S&T	Science and Technology B.V.	BEN	NL
28	TU/E	Technische Universiteit Eindhoven	BEN	NL
29	RUG	Rijksuniversiteit Groningen	BEN	NL
30	UNINOVA	UNINOVA - Instituto de Desenvolvimento de Novas Tecnologias	BEN	PT
31	ISEP	Instituto Superior de Engenharia do Porto	BEN	PT
32	INESC	Instituto de Engenharia de Sistemas e Computadores do Porto	BEN	PT
33	ADIRA	ADIRA - Metal Forming Solutions S.A.	BEN	PT
34	ASTS	Ansaldo STS S.p.A.	BEN	IT
35	CINI	Consorzio Interuniversitario Nazionale per l'Informatica	BEN	IT
36	AIT	Austrial Institute of Technology GmbH	BEN	AT
37	HBM	Hottinger Baldwni Messtechnik GmbH	BEN	AT
38	INNOTEC	Innovative Technology and Science Limited	BEN	UK
39	AITIA	AITIA International Inc.	BEN	HU
40	BME	Budaperst University of Technology and Economics	BEN	HU
41	JSI	Josef Stefan Institute	BEN	SI
42	XLAB	XLAB d.o.o.	BEN	SI
43	FHG	Fraunhofer Institute for Experimental Software Engineering IESE	BEN	DE
44	M2X	M2Xpert GmbH & Co KG	BEN	DE
45	STILL	STILL GMBH	BEN	DE
46	BOSCH	Robert Bosch GMbH	BEN	DE
47	LIEBHERR	Liebherr-Hydraulikbagger GmbH	BEN	DE

Document Revisions & Quality Assurance

Revisions:

Version	Date	By	Overview
1.1	02.03.2016	Istv□n Moldov□n (BME)	Appendix 23 created
1.2	29.03.2016	Leena Parkkila (LUAS)	Appendix 19 updated
1.3	30.03.2016	Tom Ruette (SIR)	Appendix 15 updated
1.4	01.04.2016	Istv□n Moldov□n (BME)	Appendix 8,11,14 updated
1.5	04.04.2016	Istv□n Moldov□n (BME)	Appendix 9,10,12 updated
1.6	12.04.2016	Leena Parkkila (LUAS)	Appendix 21 updated
1.7	18.04.2016	□pela Poklukar (JSI)	Appendix 6 updated
1.8	19.04.2016	Lidia Godoy (ACCIONA)	Appendix 7 updated
1.9	20.04.2016	Bence Petho (AITIA)	Appendix 2 updated
2.0	22.04.2016	Riku Salokangas (VTT)	Appendix 22 updated
2.1	25.04.2016	Arja Kotkansalo (LUAS)	Appendix 20 updated
2.2	27.04.2016	Quinten Marcelis (ILIAS)	Appendix 16,17 updated
2.3	29.04.2016	Karel De Brabandere (3E)	Appendix 13 updated
2.4	02.05.2016	P□l Varga (AITIA)	Appendix 1,3 updated
2.5	02.05.2016	Riku Salokangas (VTT)	Revised version

Abstract

This deliverable report presents a revised summary of Preliminary State-of-the-Art of Sensor-based Proactive Maintenance reports which are listed as appendices of this report. There are two completely new appendices added to the report, Appendix 22 and Appendix 23. Appendix 22 presents some potentially valuable standards related to the project and Appendix 23 terminology that has been used. Appendices 4 and 5 have remained the same, so they have not been added to this deliverable. In addition appendix 18 has been modified into the appendices 16 and 17. In this report only the titles of the appendices and copy of their abstract is given.

Table of Contents

1 Introduction

In this deliverable report a revised summary of Preliminary State-of-the-Art of Sensor-based Proactive Maintenance reports is given. All the reports are listed as appendices of this report. There are two completely new appendices added to the report, Appendix 22 and Appendix 23. Appendix 22 presents some potentially valuable standards related to the project and Appendix 23 terminology that has been used. All the appendices have been reviewed and references to standards have been added to them. In this report only the titles of the appendices and copy of their abstract is given. The numbering of appendices follows the structure of the project i.e. first are listed the appendices related to work package two and then those related to work package three and so on.

2 Individual State of the Art reports

2.1 Current ways to integrate different information sources

The MANTIS projects aims to consolidate and aggregate data from several data sources, e.g. textual logs. These logs are mainly generated for human reading (structured sentences) and they are sometimes hard to process into query-able forms. This appendix aims to describe the State of the Art approaches of log parsing and processing technologies. Later in this document four different integration techniques are introduced. Some of these techniques are mainly used in business solutions. Different integrations related to maintenance work are usually achieved by manual integration or by some middleware solution.

2.2 Existing platform architectures and overall designs

The purpose of this document is to give a state-of-the-art report on proactive maintenance platform architectures. There are several system management frameworks already available in the telecommunications and more broadly in the ICT sector, as the main competitive edge for network operators is the impeccable network they can provide. These approaches and frameworks (mainly created by/for network operators) might also be useful analogues when defining and designing MANTIS elements, as they have been tested in practice and refined over time.

In this document we will present the reference model created by ITU-T and is under constant research ever since. This service model, system management aspects and framework has been also widely validated and implemented.

2.3 Interoperability and properties of existing systems

This appendix describes a number of existing standards and frameworks for interoperability.

PLCS describes a data-model standard for Product Life-Cycle Support. It could be considered as solution for interoperability between different (generations of) CAD, PLM, ERM, CMM tools used within a network of organizations that contribute to a cloud based proactive collaborative maintenance system.

PMML has a similar ambition to be a solution for interoperability by defining a standard for exchange of predictive models between different tools of different vendors.

IEEE Standards Coordinating Committee 20, Diagnostic and Maintenance Control Subcommittee is responsible for two standards that might be of interest. Artificial Intelligence Exchange (AI-ESTATE) and Software Interface to Maintenance Information Collection and Analysis (SIMICA).

Finally, we present a standard from the military on the Generic Vehicle Architecture. As interoperability is an important requirement within the military, this standard deals with many aspects of a vehicle's architecture. The chapter on the Health and Usage Monitoring System is of particular interest, as it describes what data needs to be collected at a minimum for exchange with a CMMS.

2.4 New sensor technology

This appendix provides an overview of new sensor technology, highlighting the specific features of this technology and their advances in this field. Currently there exists a tendency to technology miniaturization, an example of these are Micro Electro Mechanical System sensors (MEMS) that consist of miniature devices which are able to sense, generate a signal and process it. Furthermore, it is essential to mention the wireless connection sensors, bidirectional data flow and the ability to contactless sensing of some devices for several applications. These are the main characteristics which new sensor technology is focused.

In order to obtain more comprehensive understanding of this technology, the document presents an example of new sensor implemented in a real scenario such. This section shows the necessary elements which forming a sensor node (also named mote) and some parameters to measure with this technology in a production plant. Finally, sensing strategies in manufacturing processes are described, explaining how the sensors based on process monitoring systems work.

2.5 Power solutions for sensors

This appendix summarizes a general overview in Power Solutions for Wireless Sensors. We propose a wireless technology based on passive wireless sensors and analyse their advantages comparing with other power supply solutions. We discuss some solutions and give basic examples of this technology applied in different industrial domains.

A short antenna design and communications overview is also provided to analyse different solutions for different structures.

2.6 Security approach to prevent unauthorized access to sensors via test bus

Testing of complex electronic systems is a difficult problem. One of the popular solutions in practice is the application of JTAG test bus also defined as IEEE Std 1149.1. JTAG infrastructure consists of scan chains, which enable easy test access to system internal logic. Industrial applications of boundary scan technology are today supported by a variety of sophisticated electronic design automation (EDA) tools, which simplify boundary scan infrastructure insertion as well as test generation and application. Most automated test equipment manufacturers have included IEEE 1149.1 support into test systems, which are commonly used during production testing as well as system maintenance. In many cases, maintenance of systems with JTAG infrastructure is performed remotely via internet. In this way, the maintenance costs can be reduced but on the other hand, the access to system□s internal logic represents potential security vulnerability. In the following, we briefly describe the security threats and proposed countermeasures. Next, we propose a low cost solution based on the JTAG bus locking mechanism. The original solution, proposed in 2006, will be customized to different requirements as regards employed technology, level of security and hardware overhead. Developed solutions will be scalable to meet the needs of different partners. Deliverables will include VHDL description of the locking mechanism, test bench and working prototype on a FPGA device.

2.7 Wireless communication

This appendix provides an overview of Wireless Communication focussing on wireless sensor network based on standards, the possibility that it offers and benefits of using this type of communication.

2.8 Algorithms for anomaly detection, failure prognosis and remaining useful life

This appendix provides an overview of algorithms for anomaly detection, failure prognosis and the prediction of remaining useful life. Anomaly detection is the identification of those items, events or observations, which do not conform to an expected pattern or other items in a dataset. In the context of MANTIS, the focus will be on detecting anomalies in time series of sensors monitoring physical systems and the networked environment they operate in. Subsequently, maintenance-decision support regarding the anomalous system can be offered. In essence, it is relevant to operators to determine the cause, i.e. fault diagnostics, and the remaining useful life (RUL) of the anomalous system, i.e. fault prognosis, in order to optimally plan maintenance.

2.9 Algorithms used to optimize maintenance strategies

In appendix 9, maintenance strategies and algorithms related to maintenance optimization are introduced and explained. Various maintenance strategies and their advantages and disadvantages are also discussed. As a specific use case, we show the strategies used in telecommunication network maintenance, and we show how the used maintenance strategies relate to the models presented.

Maintenance strategy optimization is one of the approaches that MANTIS can provide and improve upon.

2.10 Algorithms used to predict, identify, estimate and alert of failures before they occur

This appendix gives an overview on algorithms used to predict, identify, estimate and alert of failures before they occur. The method proposed by the MANTIS infrastructure must be able to initially identify failures which lead to system down and then predict them by analysing real-time sensor data or other quality issues that can be related to worn out tools. Some tools and methods are discussed for this, among them Root Cause Analysis (RCA) being the most common basic technique and different algorithms are researched to be able to do RCA on real-time. MANTIS operators must trust the system to help and guide them, thus it is also important that the alert system be properly configured, for this eMaintenance guidelines will be contemplated. Furthermore, so-called Health Management Systems as used in aerospace applications are described that take a system-wide view on the process of predicting and diagnosing system faults.

2.11 Data unification and semantic reasoning for integration of data from heterogeneous sources

Data unification is concerned with combining data from different types, levels and sources in such a way that they are made compatible and comparable, and thus useful for further processing. This is particularly relevant in the multi-stream context considered in MANTIS. Furthermore, there are also differences in the interpretation of the meaning of data, i.e., semantic heterogeneity. Semantic models deal with this issue by offering of way of formally representing knowledge about a particular domain, thereby defining a controlled vocabulary. Subsequently, using semantic reasoners, the ontological constructs can be employed to infer additional knowledge. This appendix offers an overview of current approaches for data unification, and semantic modelling and reasoning.

2.12 Existing practices to optimize maintenance decisions in different levels

This appendix contains a description of some of the existing practices in maintenance optimization in various plants and different plant levels and in different type of industries, ranging from process industry to IT. Existing optimization practices require the use of a wide array of different information sources and different tools and a centralized solution for decision support is lacking in most organizations.

2.13 Fault detection and identification in PV systems

Vast amount of data is recorded at photovoltaic (PV) plants through the real-time monitoring system. Current use is mainly restricted to basic failure detection and the reporting of system performance. Proactive maintenance of PV plants is highly desirable but requires a more advanced utilization of the monitored data.

Current state-of-the-art of FDI techniques of PV systems rely mostly on limit checking of directly measured or derived variables. Several other approaches for FDI of PV systems, often using more advanced machine learning techniques, have been proposed in literature, but their practical applicability in the field is limited. Only recently, some advanced machine learning techniques have been attempted in the field in order to predict faults.

The residuals used in FDI can be generated using various methods. In the analytical redundancy-based or model-based approach, the residuals are generated based on an explicit mathematical model of the system. The explicit mathematical model of a PV system is derived using data from type tests, from off-line field tests or from operational data.

The PV health scan methodology has recently been explored at 3E for the systematic analysis of operational data in an efficient way, identifying how design choices and O&M practices lead to inferior or superior performance in the field.

2.14 High-performance stream-based processing

In MANTIS, computations need to be performed on a continuous unbounded stream of data. In this appendix, we will discuss state-of-the-art approaches for scalable stream-processing. A stream processor has a prominent role in a state-of-the-art IoT architecture as a highly scalable component to route data towards or get data from online learning algorithms, various data stores (e.g., in-memory caches, (distributed) storage for batch processing/archiving, non-production environments, etc.), and the data integration layer (e.g., lookup technical parameters, push/read from ERP/CRM systems, etc.). Stream processors also excel at basic on-the-fly filtering, pattern detection and data aggregation.

Online (incremental) learning allows to learn from these data streams as they come in, which has the advantage that the models can output a hypothesis at any time during processing, instead of only after all data is processed. However, over time some of the assumptions underlying machine learning theory can be violated, which is referred to as concept drift. A number of practical approaches to deal with this will be discussed as well.

2.15 Modelling techniques for high-frequency time-series data

In this appendix, a number of modelling techniques for high-frequency time-series data will be described.

The first set of methods is situated in the domain of data stream mining, focusing finding (frequent) patterns of events in the data stream and predicting upcoming events.

Second, cluster analysis techniques estimate the similarity between objects and propose a categorization into k clusters.

A third set of methods is related to time-varying system identification, which tries to identify the system behind a series of states in which the system is varying over time due to an unobserved scheduling parameter.

In Section 4, probabilistic modeling techniques are discussed, which describe the data that can be observed from a system, using probability theory to express the uncertainty resulting from noise and missing data; issues that are often inherent when working with sensor data. Subsequently, probabilistic reasoning can be used to infer additional knowledge and make predictions.

Finally, we present a reminder about statistical analysis on time series data that might be useful for detecting various types of very long term tendencies. These methods are mainly used in econometrics and financial analysis, but could be relevant to issues that arise in MANTIS.

2.16 Existing devices and interface types related to HMI

This appendix provides an overview of existing devices and interface types related to HMI. Interface section of this document focuses on natural user interfaces (NUI) where interaction is done with human abilities such as touch, vision, voice and motion. In these few years, touch has become a very popular interaction method especially in mobile devices. Devices section introduces common everyday mobile devices which are still rarely used in industry compared to the stationary PCs. Especially maintenance workers would greatly benefit from these mobile devices and of their ability to bring lots of helpful technical information to the field in a small package.

Later sections have two example cases where HMI of a pultrusion line and a press machine are presented.

2.17 Existing scenarios of maintenance related Human Machine Interaction (HMI)

This appendix contains a description of existing scenarios of maintenance related Human Machine Interaction (HMI). The objectives are to describe the basics of the HMI design and especially to describe the approach for scenario based and context aware HMI design. The goal is also to give a practical examples of different scenarios that maintenance people are conducting during their everyday work. In each scenario is also a description of commonly used devices that maintenance people are using when communicating with the machine or system. The idea is to give an overall picture of when and how maintenance people are interacting with the machines and systems and through which kind of interfaces.

As a result and conclusion can be said that technology today offers multiple choices and solutions for different kind of devices that can be used to support everyday maintenance work. There are many different devices and types for interfaces available that maintenance people can use to interact with the machine and systems. There are also a portable devices that make it possible to connect with the machine or system directly from the field. However, often the most common way to interact between human and machine is through PC or laptop in the office or in the control room. Interfaces are often machine or system specific.

The results are largely based on previous research projects and experiences from the Finnish process industry. Certain industrial sectors are more advanced in using new technology concerning devices or interfaces between human and machines or system. However, the process or manufacturing industry seems to be more conservative when it comes to embracing new technologies.

2.18 Existing visualization techniques

Appendix 18 has been modified into the appendices 16 and 17.

2.19 Different stake holders and value chains involved in PMM

This document focuses on the different stakeholders and value chains involved in proactive monitoring and maintenance (PMM). This appendix offer an overview of internal and external stakeholders and value chains in overall maintenance process in process industry. To achieve high availability, reliability and quality of production processes, each phase of the overall maintenance process has to work internally and seamlessly in conjunction with the other phases. Maintenance process is highly dependent on external stakeholders. Good information flow and knowledge exchange are extremely important in overall maintenance process and it involves everyone. Seamless collaboration between different stakeholders (internal and external) and manufacturing company is essential to achieve competitive advantage in global competitive arena.

2.20 Economic evaluation of the current business models of each value chain

This report describes the existing business models between different value chains involved in maintenance process and assesses the economic impact of these different models. Equipment manufacturers have increased their maintenance services for companies in recent years. They are now not only manufacturing and selling machines, but also offering long-term maintenance contracts, which are signed at the same time when machines are sold. In some cases, equipment manufacturers are not selling machines, but for example produced tons. Equipment life-cycle management has gained more and more attention in recent years. Manufacturing companies have outsourced their maintenance activities and focused in their core business and at the same time equipment manufacturers have increased their after-sales and maintenance services. In many equipment manufacturing companies the overall revenue consists of 60% of manufacturing and 40% of selling life-cycle services.

Development of maintenance business models have happened from internal maintenance towards outsources maintenance. In addition internal maintenance are moving from centralized model towards decentralized model. However, both of these changes are happening at the same time. Companies are outsourcing their internal maintenance activities and also moving remaining internal activities from centralized models to decentralized ones. Usually this means, that production companies are outsourcing equipment level maintenance activities to equipment manufacturers, low level maintenance tasks e.g. during the production shutdown to maintenance subcontractors and special maintenance activities to service providers like condition monitoring requiring special skills and equipment. In addition, some of the remaining internal activities are moved from centralized maintenance organization under the production organisations e.g. low-level maintenance and condition monitoring. Still, not all activities are outsources and moved from centralized maintenance organisations to operators. Some of the activities are seen beneficial to keep in own internal maintenance organisation. Even if the whole internal maintenance actions are outsources, some of the maintenance activities are kept under the production organisation.

2.21 Existing business models related to Proactive Monitoring and Maintenance (PMM)

This appendix 21 analyses existing business models related to Proactive Monitoring and Maintenance (PMM). All business models have the common goal to reduce costs or improve effectiveness. Thereby, a competitive advantage will be gained or maintained.

The business models are divided into three parts. First, there are internal business models, where a company performs maintenance with its own resources in a centralised or decentralised way. Second, maintenance can be partially outsourced. Different levels of outsourcing exist: outsourcing of equipment or system maintenance, outsourcing of low level maintenance during e.g. a scheduled shutdown and outsourcing of maintenance which requires special knowledge. Third, maintenance can be totally outsourced to other companies.

All business models are analysed and also their advantages and disadvantages are shown. Additionally, different approaches to proactive monitoring maintenance are described.

In conclusion, a company has to analyse its own goals and requirements to select the right business model, regarding maintenance. Also maintenance activities performance effectiveness have to be measured and right indicators must be chosen according to the chosen maintenance strategy.

2.22 Some Potentially Valuable Standards

This report presents a short list of standards that are considered potentially valuable for carrying out research work in Mantis project. It has been collected mainly by searching with certain key words that represent the technologies used In Mantis project. The standards are tabulated in different ways in order to make it easier to find them based on the subject or area of interest of the reader. Obviously, there is great variation in how valuable each of the standards is from the point of view of Mantis project. It can be assumed that the ISO standards focused on condition monitoring, diagnosis, and prognosis are of highest value and so are also the IEEE standards focused on programming. However, the report also lists standards which might be focused on one industrial sector or the discussed technology is only used by a marginal number of partners but hopefully it is still of value to the whole consortium.

2.23 Terminology

This document collects the most important terms used in documents in order to provide a common understanding of the terminology used.

3 Conclusions

In this report the list of individual State of the Art reports have been presented together with their abstracts. There are two completely new appendices added to the report, Appendix 22 and Appendix 23. Appendix 22 presents some potentially valuable standards related to the project and Appendix 23 terminology that has been used. All the appendices have been reviewed and references to standards have been added to them. Appendices 4 and 5 have remained the same, so they have not been added to this deliverable. In addition appendix 18 has been modified into the appendices 16 and 17.

4 Appendices

Appendix No	State of the Art report title
1	Current ways to integrate different information sources
2	Existing platform architectures and overall designs
3	Interoperability and properties of existing systems
6	Security approach to prevent unauthorized access to sensors via test bus
7	Wireless communication
8	Algorithms for anomaly detection, failure prognosis and remaining useful life
9	Algorithms used to optimize maintenance strategies
10	Algorithms used to predict, identify, estimate and alert of failures before they occur
11	Data unification and semantic reasoning for integration of data from heterogeneous sources
12	Existing practices to optimize maintenance decisions in different levels
13	Fault detection and identification in PV systems
14	High-performance stream-based processing
15	Modelling techniques for high-frequency time-series data
16	Existing devices and interface types related to HMI
17	Existing scenarios of maintenance related Human Machine Interaction (HMI)
19	Different stake holders and value chains involved in PMM
20	Economic evaluation of the current business models of each value chain
21	Existing business models related to Proactive Monitoring and Maintenance (PMM)
22	Some Potentially Valuable Standards
23	Terminology