A step forward on Intelligent Factories: A Smart Sensor-oriented approach

Gil Gonçalves, João Reis, Rui Pinto
Institute for Systems and Robotics
Faculty of Engineering of University of Porto
Porto, Portugal

Marco Alves
FreedomGrow
Matosinhos, Portugal

***Abstract* — Sensors always played a significant role on the industrial domain, since monitoring the current machine's process state is notoriously an advantage for shop-floor analysis, and consequently, to rapidly take action according to the production system demands [3, 6, 7, 8]. The I-RAMP3 European Project explores exactly these demands, and proposes new approaches to efficiently address some of the nowadays difficulties of the European Industry.**

The Smart Sensor technology is explored in the I-RAMP3 Project using the NETwork-enabled DEVice (NETDEV) concept, as a logical entity for equipment encapsulation with high level of communication capabilities and intelligent functionalities. Therefore, not only how the NETDEV concept is implemented, but also how to use sensors is explored in the present paper, being means of UPnP Technology, for communication extensibility, and PlugSense Framework for easy sensor integration and complexity addition.

Moreover, the importance of sensors based on the context of the I-RAMP3 is explored, discussing some trends and possible steps to be taken in conventional production towards the next generation of Smart Manufacturing Systems.

Keywords — Smart Factories; Sensors and Actuators, Factory Automation, Sensor Networks, Plug'n'Play

I. INTRODUCTION

I-RAMP3, Intelligent Reconfigurable Machines for Smart Plug&Produce Production, is an ongoing project under the wing of the Seventh Framework Programme of the European Commission. Twelve partners from all Europe, including Germany, Portugal, Netherlands, Hungary, France and Greece are putting together efforts to create solutions to improve the European Industry competitiveness with innovative concepts towards smart manufacturing systems, converting the conventional product equipment into intelligent agent-based production devices known as NETDEVs (NETwork-enabled DEVices). The main responsibility of these components lies in equipping the manufacturing equipment - both complex machines, as industrial PCs or PLC, and sensors & actuators - with standardized communication skills, along with intelligent functionalities for inter-device negotiation and process optimization. Hence, the main goals of the project are to reduce the production costs and increase the manufacturing efficiency, by enabling fast and optimized ramp-up making use of the plug&produce concept.

The lack of processing and memory capabilities associated with sensors used on the shop-floor to sense the environmental conditions is an obstacle for the today's industry towards first, easily integrate new sensors or replace old ones, and secondly to add additional complexity to support communication skills among other shop-floor components and increase the intelligence of sensors [3], fostering individual and collaborative capabilities, putting side by side high capacity devices, as PLCs, with low capacity devices, as sensors and actuators. This barrier leveraged the exploration of new approaches related with intelligent sensors on I-RAMP3 Project, as they will assume a significant role in the next industrial generation [3].

Furthermore, this communication uniformity and leveled shop-floor equipment capability is the foundation towards the next generation of Smart Factories. The capability of each shop-floor equipment describing himself and announcing to other similar entities will be also explored on behalf of this project, and represent a major advantage for reducing efforts not only the early stages of a production system, like the ramp-up phase, but also on the management side where important maintenance decisions need to be taken, like scheduled maintenance and unscheduled maintenance phases. All the afore mentioned production phases compose the moving core of the I-RAMP3 Project, being the focus and guidance towards all the innovative technological developments. Moreover, the UPnP Technology is being explored to easily develop the communication capabilities of each shop-floor equipment, and more specifically for the sensor part, the PlugSense Framework is used to easily integrate sensors in a configured network, and provide well-structured architecture to support and explore the concept of intelligent sensors.

The paper is organized in three more sections. The first one, Section II, refers the importance of sensor use as both individual and collective entity, depicting advantages and benefits, as well as some possible new trends. Section III starts talking about the technologies used to implement all the sensor complexity by means of NETDEV concept, and then details about the I-RAMP3 architecture, as well as main data structures for information flow are presented. Finally, in Section IV, some conclusions about the project implementation and industry response are exposed, along with some possible next steps within the I-RAMP3.

II. Sensor networks on industry

Monitoring the execution of a certain shop-floor equipment and sensing the environmental conditions that surround it, is undeniably an advantage for the manufacturers in which concerns about diagnosis and shop-floor analysis. Assuming that all collected information from shop-floor is important and can be correlated using pattern recognition techniques and other mechanisms, the use of additional sensing capabilities on the shop-floor level can represent an enrichment and improvement on both equipment, production and process level, and therefore, a competitive advantage can be achieved, compared with other approaches that don't support the use of sensors on the shop-floor level [3, 6, 7, 8].

The present section aims to depict some new ideas arising from new and innovative concepts being explored in the I-RAMP3 European Project, and to foresee some possible next technological steps based on this project. The first sub-section is mostly concerned about the added value that a single sensor can bring to the industrial domain, while the second one is more focused on how a set of sensors, all related together, can be used towards a more efficient and effective production system.

A. *Sensor Significance*

Nowadays, the importance of sensors is increasing drastically in the industrial domain, moving from a plain control approach, in which only information regarding the machine process execution is important, to an additional monitoring one, allowing the acquisition of environmental information, complementing the controlling process. This information is significantly important for the study of the machine's behavior and operation, and therefore, for the applicability of techniques capable of diagnosing and prescribe solutions for problems found in the shop-floor. This kind of sensor-oriented approach is opening doors towards the use of, e.g. Statistical Process Monitoring (SPM) in the industrial world [12, 13], use of Soft Sensors for data fusion and heterogeneous data correlations [15], fostering the future of smart factories, in which the sensor components will have a higher importance for process optimization and production automation [12].

An example of sensor's direct applicability on a shop-floor process optimization is on metrology systems, where the environmental conditions can drastically change the results on the machines' execution. On the Automotive industry, where metrology systems are used to, e.g. detect surface imperfection on the vehicle body parts, the luminosity conditions variation can lead to false positive results, consequently decreasing the machines performance and invalidate the quality of a certain product. Therefore, sensors can be used to automatically recalibrate a system according to certain conditions, moving from, normally a manual and costly configuration, to a fully automated and reliable parameterization of the metrology system.

Another example of a possible usage of sensors on the machine execution assistance is on the Welding industry, where efforts are being applied to evaluate and automatically infer the quality of a certain resistance spot welding using spectrometer devices, evaluating the light properties of an electromagnetic spectrum. With this type of sensor-based approach, the additional information provided by sensors can reduce the number of destructive tests normally made on this kind of field, and ultimately improve both efficiency and effectiveness.

As explored in the I-RAMP3 project, one of the main improving points on the today's industrial field is related with fast ramp-up of a production system, where several manual calibration iterations need to be made until a certain machine is correctly configured and parameterized to operate according to well defined quality boundaries. Also, the previous overview about the sensor significance is pertinent in the sense of other production process phases like scheduled maintenance and unscheduled maintenance, also explored by the I-RAMP3 Project. These two latter phases are more closely related with the monitoring approach described earlier in this paper, where additional information about the machine operation is used to detect machine's drift or wear-out. For example, an additional thermal sensor can be used to measure an engine's temperature, allowing the analysis of its behavior and diagnosing if it will fail, and consequently, if any maintenance needs to be scheduled or it needs to immediately stop [12]. It can also be possible to foresee if the equipment's engine can be differently parameterized, allowing to continue the execution, lowering its performance and schedule maintenance in the further future, minimizing production stopping costs.

B. *Centric Sensor System*

In the previous sub-section was explored the individual sensor potentialities regarding the shop-floor configuration and execution. However, a higher level of complexity can be also explored as a step forward to the smart factories approach. This higher level is related with the benefits of Wireless Sensor Networks (WSN) [8], where a set of sensors is integrated to sense different types of environmental conditions (like temperature, humidity, vibration, sound, pressure, presence, and so forth), moving to a collaborative and information aggregation approach. There are nowadays a variety of WSN applications on the industrial field [9, 10, 11]. The emphasis of this specific approach is not related with the study of network connectivity, like flooding or routing techniques used to improve the network reliability and node fault-tolerant [12]. Contrarily, regarding the industrial domain, the Industrial WSN (IWSN) approach can be explored in a more data-oriented way, considering the huge amount of data that can be collected from the production system, and all the techniques that can be applied to process it, inferring high quality information [15].

The easy integration approach leveraged by the I-RAMP3, along with the NETDEV concept – based on a previous European Project called XPRESS [4], aims to equip sensors and actuators with standardized communication capabilities and intelligent functionalities, being the first step towards this centric sensor system, capable to provide the foundation for data analysis techniques usage. Despite data mining techniques being out of the scope the I-RAMP3, the proposed logical entity NETDEV, along with the project's physical architecture, are capable enough of supporting not only the use most of the useful data mining techniques, but also the standardized communication of the data resulting from the use of those techniques. This way, the path is paved towards a more automatic, autonomously and wise use of available industrial equipment on production systems.

When using sensors for monitoring purposes where the sensing frequency is high, reliability is always a concerning point. Therefore, an advantage of wireless sensor networks on the industrial domain is related with cross-sensor data validation [14]. This means that a specific sensor information can be validated by a set of similar sensors near it. For example, if a set of close temperature sensors is being used, and one of them provides a sensing value way too different from the others, it could be an indicator of unreliable information, and consequently, the need of sensor replaced, always taking into account a certain probability. This approach is associated with the self-healing concept, not in the sense of connectivity sensor networks, but providing feedback on the network reliability and prescribing a solution to solve the detected problem.

From all the I-RAMP3 Project consortium feedback, knowing when a machine drifts or detecting a wear-out is a major difficulty on the today's industry. Most of the times, the information that a machine itself can provide is not enough to feed data analysis algorithms to guarantee a reliable conclusion about a possible machine malfunction. Therefore, using the additional information provided by a set of sensors for monitoring purposes, forming a sensor network, can be correlated with the machine's process information, and then, use data analysis techniques, like pattern recognition, to foresee any problem that was previously analyzed and diagnosed.

III. SMART SENSOR COMPONENT

In order to make all devices on the network able to communicate with each other, they must be in the same level of understanding. Sensors are low capacity devices, due to their lack of processing and memory capabilities, unlike complex machines with high capacity devices, such as industrial PCs or PLCs.

Therefore, there's a necessity for all the devices being encapsulated by logical entities known as NETDEVs (NETwork-enabled DEVices), allowing the exchange of information between all the equipment on the shop-floor during the ongoing operation phases.

The next sections present an approach for the sensor integration, along with an explanation of how the communication process is performed and strategies for sensor's data reliability and validation.

A. *Sensor Integration*

NETDEVs are standard logical entities that encapsulate all kind of devices on the shop-floor, such as sensors & actuators and complex machines, incorporating intelligence in the devices, extending their functionalities and communication capabilities. These intelligent entities can adapt themselves to varying production conditions, agreeing between them the best configuration to use, by means of well-structured communication skills.

Hence, when referring to sensors and actuators, there are two main obstacles with this approach. First, it's very important to easily integrate, in a generic and standardized way, several types of sensors from different vendors on the same common network. Secondly, every sensor or actuator encapsulated by a NETDEV must make himself visible in the network to all the other NETDEVs, using multicast messaging, letting everyone know the services that a specific device provides, like a sensor that can measure temperature and humidity, or looking for someone who can assist in certain task execution, using discovery services, e.g. a welding machine that needs measurements for process monitoring. In addition, NETDEVs must have Plug&Produce capabilities, for a better maintainability and reusability of sensors and actuators, and production equipment.

Framed in the I-RAMP3 project, the encapsulation of the devices in the network and the easy integration of sensors and actuators is made using the PlugSense Framework [1]. Moreover, the discovery, presentation and overall communication of NETDEVs on the network is done using the UPnP technology [2].

1) *Technology*

a) PlugSense Framework

The PlugSense Framework is a development tool that assists developers creating software and monitoring solutions based on wireless sensor networks. Basically, it is a systematization of a set of necessary operations to create this kind of monitoring solutions. The automation of these processes allows the developers to minimize configuration time, focusing on the final applications, not concerning about communication protocols, development of web services and databases and other tasks that require hard programming skills. The main features available with the PlugSense Framework are project creation and management, sensors' management, user and entity profile administration, as well as configuration of an intuitive graphical user interface.

There are some software monitoring solutions in the market that were made with PlugSense Framework, as software tool. One example of these solutions is KeepCare, which consists on a monitoring solution for Healthcare Management [1].

Regarding the physical architecture associated with the generated projects using the PlugSense Framework, they're distributed in four main modules: Universal Gateway (UG), PlugSense Server, PlugSense Database and PlugSense App (Fig. 1). The first, Universal Gateway, is a local application responsible for the data reception from the sensors, converting raw data into human understandable information, and organize it into a proprietary XML-based format, called PlugSenseML. As a way promoting flexibility, several Universal Gateways can be instantiated, allowing the integration of sensors in a wider space, not impairing the connectivity of the network.

Additionally, this application is capable of interpreting different protocols such as Bluetooth, ZigBee or Generic RF.

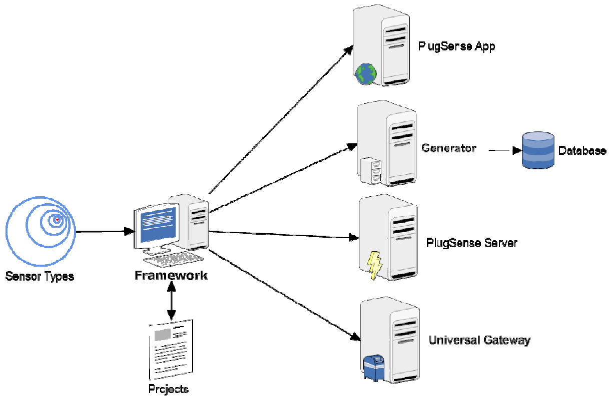

Fig. 1 – Wireless Sensor Network Project with PlugSense Framework

PlugSense Server is a Web Service that processes the information coming from the Universal Gateway, using well-defined workflows and event triggers. PlugSense Database consists on a SQL Server database that stores all the system data. The fourth component is the PlugSense App, which consists on a website for end-users to see the activity of the sensor network in real time.

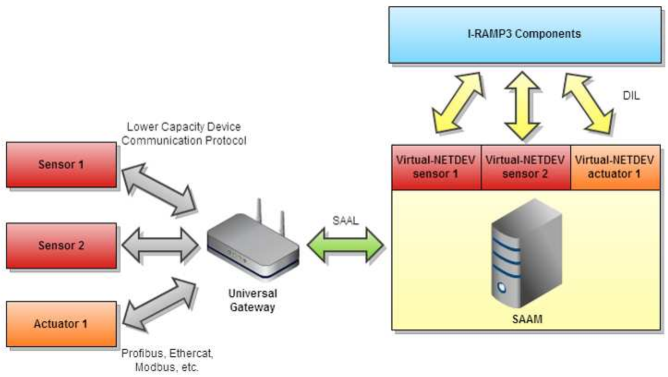

Fig. 2 - Sensor & Actuator I-RAMP3 Architecture

With PlugSense Framework, developers can easily create projects for monitoring a sensor network, using the already integrated drivers from various sensor manufacturers, as well as integrate new sensors, following a well-organized set of steps. This platform is built in C# programming language with Microsoft .NET Framework 4.0, using the following main technologies: ASP.NET; ASP.NET MVC; IIS; SQL Server.

b) UPnP

The UPnP technology is promoted by the UPnP Forum, an industry initiative supported by more than 700 companies, including Intel Corporation, Microsoft Corporation, Motorola, Nokia Corporation, Philips Electronics, Pioneer and Sony Electronics. The main goal of this initiative is to develop standards and protocols with the purpose of enabling a robust connectivity between devices in a networked environment [2].

The UPnP technology allows networked devices to discover each other on the network and communicate between them using technologies such as TCP/IP, UDP and XML. The main components of UPnP are Devices, Control Points and Services. Devices are entities that provide Services and Control Points are entities that request Services. Services include actions and a list of variables that model the state of the service at run time.

2) Physical Architecture

As previously explained, a major importance and visibility is being given to the WSN on the I-RAMP3, and therefore, all the functionalities of easy integration and easy encapsulation, by means of NETDEV concept, need to be provided. Based on the PlugSense Framework physical architecture, Fig. 2 presents the main entities needed to fulfil the afore mentioned functionalities.

From Fig. 2, it can be seen that the Universal Gateway is been used to convert the sensor's raw data into a well-structured XML-based format, now called Sensor & Actuator Abstraction Language (SAAL), and then the Sensor & Actuator Abstraction Middleware (SAAM), which is an adaptation of PlugSense Server, is responsible to interpret the received sensor data, and act accordingly. This is the entity where all the complexity and intelligence associated to the sensors should be defined. One main feature of the SAAM is to dynamically create Sensor & Actuator NETDEVs according the ones available on Universal Gateway. Finally, SAAM component is responsible to communicate with the other NETDEVs available on the network, using a higher communication language called Device Integration Language (DIL).

Due to insufficient processing and memory capabilities, sensors and actuators need a Universal Gateway to easily interpret the information from sensors with specific protocols from different vendors. Universal Gateway is also very important on the I-RAMP3 project, because it provides a simple environment to integrate new sensor types and it allows to have several wireless technologies on a single application.

Regarding the communication with SAAM, Universal Gateway uses the structure of SAAL to receive any command that needs to be executed in the sensor level, and send information about sensors and actuators. It is able to specify all the different types of measurements a sensor can provide, or any information provided by actuators and send them to SAAM. Universal Gateway receives structured and known commands from SAAM, e.g. to start or terminate sending information about the environment, or even to reconfigure certain sensors and actuators, if physically allowed. SAAM also communicates with the Universal Gateway, executing any actuator's command or asking for some new configuration on the Sensor & Actuator level.

This kind of communication allows a full integration of any type of sensor or actuator that might be integrated in the network. This allows SAAM to create a Sensor & Actuator NETDEV for each integrated component using Universal Gateway, and provide a set of services that enables the fulfilment of all the specified requirements for the sensor level.

As previously explained, SAAM was made based on PlugSense Server, and therefore, some adaptations were made in order to fulfil the requirements of I-RAMP3 project. The main changes are related with sensors' creation and data receiving. When a new sensor starts sending data to the Universal Gateway, this application will convert this data and forward it to the SAAM, by means of SAAL. Here, it is created a new sensor representation as well as a new NETDEV for this sensor. SAAM will always update the state of the Sensor & Actuator NETDEV, so other I-RAMP3 components can have access to its current state, current state variable values and other pertinent information regarding the device.

Taking in account Fig. 3, it can be seen that SAAM is the bridge between Sensor & Actuator NETDEVs (specific technology to encapsulate sensors and actuators) and all the remaining I-RAMP3 components, being able to communicate via DIL and SAAL.

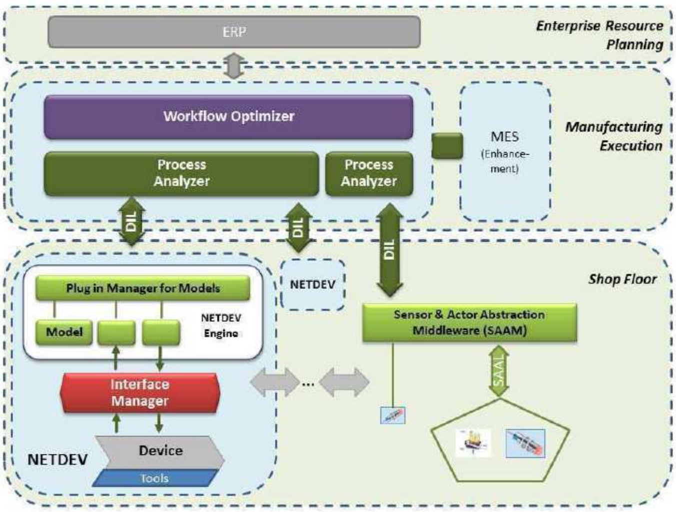

Fig. 3 – I-RAMP3 Architecture

Basically, SAAM is in the middle of the two greatest worlds of I-RAMP3 on the equipment level. It bridges the high capacity devices like Welding Machines or Metrology Systems, and the lower capacity devices like Sensor Motes that collect temperature or humidity information, among other types of measurements. All the information that needs to be exchanged with all sensors and actuators passes through SAAL, and all the communication with other I-RAMP3 components, is made using DIL, causing it to be the center of two different realities, with very different well-defined requirements, suitable for each context.

B. Communication Process

Sensor & Actuator Abstraction Language (SAAL) was built based on an already existing language called PlugSenseML, which provides means to communicate via UG to the SAAM. The PlugSenseML is a language that makes part of PlugSense Framework and is used by PlugSense Server to communicate with UG. Since this technology was used for sensor integration on I-RAMP3 project, which makes totally sense to take advantage of the already well-implemented and tested language, being used as a baseline for the SAAL requirements. Hence, the format used was the Extensible Markup Language (XML), which is a very well established format for document encoding, and has the advantage of being possible to be understood by both human and machine.

1) Generic Structure from UG to SAAM

The generic structure developed for the communication from the UG to SAAM is totally based on PlugSenseML, but nevertheless, the full comprehension of the existing structure was necessary and adaptations were made to fulfil all SAAL requirements.

As can be seen on the schema from Fig. 4, the information exchanged is a simple and easy to understand structure that contemplates the sensor or actuator data. It is based on an external tag named Message, in which the device information is contained, and a set of tags that represent the data to be exchanged. The attributes used in this structure are described as: *ID* – Unique identifier of the device; *DeviceType* – Textual field that describes the device type; *Data* – Device data to be exchanged from UG to SAAM; *Timestamp* – Time of occurrence with the following structure: dd-mm-yyyy hh:mm:ss.

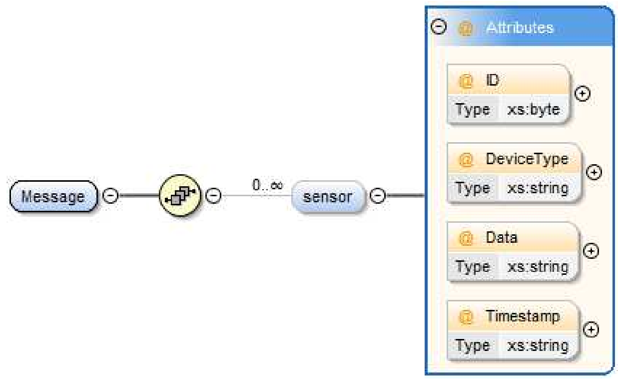

Fig. 4 - Generic XML Schema of communication from UG to SAAM

From the received data from devices, UG has the main responsibility to generate this structure and fill it accordingly, and send it to SAAM. Basically, UG generates as many device tags it needs to encapsulate that raw data, and disseminates it with the same frequency as the corresponding sensors and actuators.

2) Generic Structure from SAAM to UG

The presented generic structure was specifically developed for the I-RAMP3 project, and it can be analyzed from two different perspectives. One of them is basically the request of a pre-defined command execution, depicted on the schema of Fig. 5, and the other one is a request of a concrete command execution that requires the specification of additional information, presented in Fig. 6.

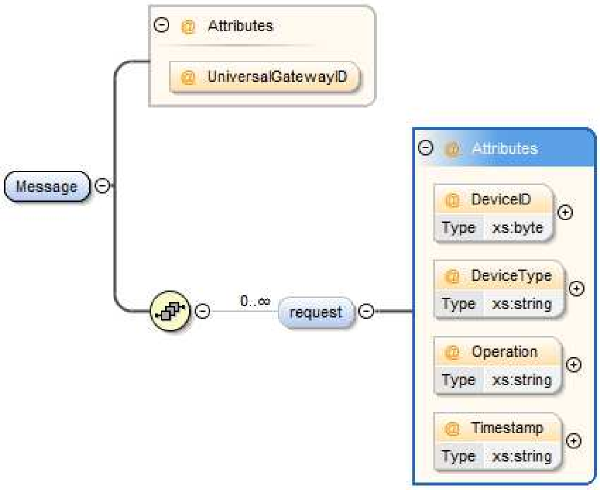

Fig. 5 - Generic XML Schema of communication from SAAM to UG (Pre-defined Commands)

As can be seen from Fig. 5, there are two levels of tags that need to be specified to correctly implement the XML structure and communicate from SAAM to the UG. The *Message* tag has only one attribute named *UniversalGatewayID*, used to define the correct UG to communicate with. This attribute needs to be defined, since, like it was previously explained, it might be possible that several UGs will be connected to only one SAAM, which in turn means that the UG location information should be known and defined when sent to the correct UG instance. In an actual implementation, the SAAM may omit the *UniveralGatewayID* when the message is directly sent to the designated UG, but nevertheless the *ID* has to be known by the SAAM (for example in a lookup table). Additionally, keeping the *ID* in the message is helpful for logging and auditing purposes. Regarding the *request* tag, it can be seen that this structure is where the information for the command execution needs to be specified. The schema of Fig. 5 only takes into consideration the services *Initiate Operation*, *Terminate Operation* and *Device Deregistration (External Request)* specified on Table 1.

Table 1 - Possible values for the *Operation* attribute

ID	Description
0	Initiate Operation
1	Terminate Operation
2	Configuration
3	Deregistration

Basically, each command is one *request* tag, and it should match the services presented in the following sections, where all the required information will be explained. All the tag's attributes have the following meaning: *DeviceID* – Unique identifier of the device; *DeviceType* – Textual field that describes the device type; *Operation* – Identifier of the command to be executed. All the possible values are presented in Table 1; *Timestamp* – Time of occurrence with the following structure: dd-mm-yyyy hh:mm:ss.

The schema from Fig. 6 has a similar structure to the sample from Fig. 5, but it has additional tags that aim for the parameterization of a device. These additional tags can only be used when *Operation* parameter is *Configuration* (ID number 2). The *optionalAttribute* tag is basically a pair of *name* and *value* attributes, in which a description of the parameter can be specified, along with the intended value for the device parameterization. SAAM can generate as many *optionalAttribute* tags as needed, respecting a maximum of possible parameters to be configured on the sensor or actuator, and a minimum of one, not allowing the specification of two or more tags with the same *name* attribute. This way, sensors and actuators can be easily and simply parameterized, like the frequency of sensor measuring or even from which sensor, integrated in a Sensor Mote, SAAM needs to receive information from.

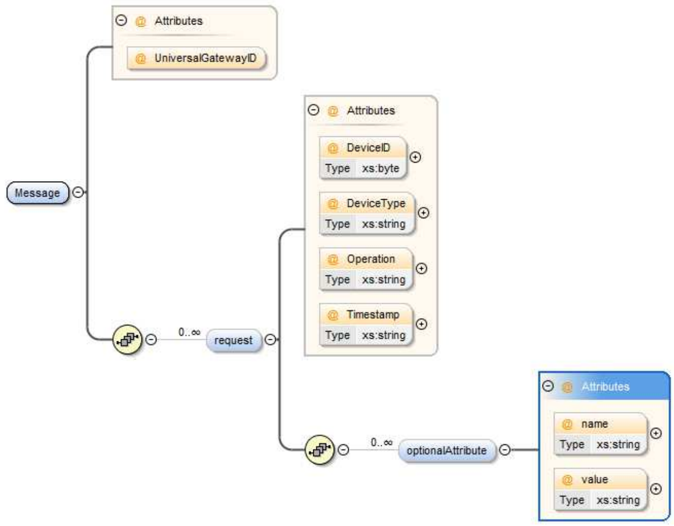

Fig. 6 - Generic XML Schema of communication from SAAM to UG (Custom Commands)

3) Communication with other NETDEVs using DIL

The communication with other NETDEVs, representing other I-RAMP3 components, is made via DIL (Device Integration Language) and is presented on Fig. 3. DIL implements four different types and each one can be exchanged inside the environment between the NETDEVs. The four types are: NETDEV Self-Description (NSD); Task Description Document (TDD); Task Fulfilment Document (TFD); Quality Result Document (QRD).

The NSD is describing the capabilities of a NETDEV, in other words, the range of tasks, which can be performed by the

NETDEV. The tasks may be defined as goals and conditions or as bare process parameter values. The task range gives the possible range of goals and conditions or parameter values, which can be realized and accepted by the NETDEV. Additionally, NSD can be adapted, when self-diagnosis finds restrictions.

The TDD describes the information defining a requested task as roughly specified on NSD. It determines one of the possible goals or parameter values, which have to be reached by the NETDEV. If it is a continuous task (for instance detection of irregular signal values) or if it is a repetitive task, the period of the task execution or the number of task repetitions is given.

The TFD is a document-type acknowledge to the TDD, reflecting the settings with respect to the requested goals or parameters. The TFD also has a second purpose: It is used to inform the other NETDEVs about the actual settings and let them decide if they can cooperate with the NETDEV under the present circumstances or if they have to wait until they can set them otherwise via a new TDD.

The QRD describes the result achieved after process execution, which can be the description of the end state or of the quality achieved after the process. In a continuous or repetitive process, the QRD is issued only at the end of all scheduled repetitions or time period and is giving a summary of the total repetitive or continuous process.

C. Smart Sensors

As previously detailed in this section, the intelligence of a sensor is reached using the NETDEV implementation that already provides communication capabilities and additional functionalities to understand and be understood by similar devices in the network, providing automatic and easy configuration services associated with the equipment shop-floor execution. Regarding the I-RAMP3 project, the behavior expected by the NETDEVs on the network is implemented by the UPnP technology. When a sensor is encapsulated as a NETDEV, he joins the network and immediately advertises its capabilities to all the available NETDEVs that need the services provided by the sensors. Furthermore, in a network of NETDEVs, sensors are implemented using UPnP Devices and complex machines using UPnP Control Points.

The services requested are mainly about measuring environmental conditions, such as temperature, humidity, light, pressure, presence and so forth. The variables that model a sensor service should provide are, consequently, the resulting measurements. These measurements are retrieved by the NETDEVs who require the service at runtime. This will allow the NETDEV to take action on-the-fly, depending on the existing conditions that can affect the quality of the resulting product of an ongoing task.

Despite the complexity that a NETDEV can implement on the SAAM level, there are other ways to explore the *Smart Sensor* concept. As explained in the section II, one of the advantages of having a network of intelligent devices (NETDEVs as sensors) that can communicate and easily collect information from, several data analysis can be applied towards a more efficient and effective way of using the information.

It is been, so far, explored in the I-RAMP3 project the creation of virtual entities that have the capability to process information and provide higher quality results, based on sensor data, using the NETDEV concept. Since one of the major advantage of the NETDEV is the standardized communication by means of SAAL and DIL publishing services that can be, therefore, consumed by other NETDEV entities, additional complexity can be easily implemented. A simple case, but not less important, is the aggregation and processing of data of several sensors, creating this way a hierarchy, and provide a quality measure that allows others to operate dependently on this value. An example of this aggregation and processing service is the use of a virtual NETDEV that collects luminosity values from several luminosity sensors, and then calculate the mean value between all the values, compares the mean with a previously defined threshold, and communicates the resulting information to a metrology system, also implemented by means of a NETDEV. This qualitative data is an easy and effective way of dynamically changing the parameterization of processing algorithms used to analyze images provided by cameras. Since the information exchange between components is an automatic process, this parameterization can occur as much as needed, ensuring the optimal metrology system configuration e.g. during a whole day on an open room, or even if a manufacturer displace the metrology system to a different environment with different luminosity conditions. Therefore, this system automatic calibration can decrease the ramp-up phase of production system setup, and also rapidly react to changes on product requirements. Additionally, this kind of functionality explored in the I-RAMP3 Project avoids flooding the communication between real equipment on the shop-floor, and also store only the pertinent information, minimizing the database usage.

As afore mentioned, the previous example is very simple but can provide very good results on the shop-floor, only slightly increasing the complexity of the whole system. Taking advantage of the NETDEV implementation on both complex machines and sensors & actuators, the use of virtual NETDEVs and the hierarchical formation can be the basis for a direct and easy use of data analysis techniques on the industrial domain, allowing machine diagnosis and predictive maintenance concepts a step closer to a flexible and uniform use.

IV. Conclusions

From all the experiments made so far related with WSN, the proposed sensor integration architecture seems yet reliable, capable of efficiently and effectively support inter-component communication, and also flexible enough to easily integrate new types of sensors, not previously defined in the sensor production system solution. The developed NETDEV concept is perfectly suitable for the sensor and actuators domain, enabling those components to be at the same level of understanding and complexity as PLCs and industrial PCs.

Therefore, the benefits of using a network of intelligent sensors can start to be drawn from now. I-RAMP3 Project provides mainly the foundation towards the simple integration of more complex techniques for supporting the shop-floor. This kind of support is based on machine's condition monitoring information, since is from these raw data that equipment process state can be inferred, and therefore data analysis techniques as diagnosis mechanisms for drift and wear-out detections are suitable to be integrated.

Nevertheless, the obstacles associated with the proposed I-RAMP3 Smart Sensor solution need also to be pointed out. One of the main restrictions about the possibility of increasing the complexity of a simple sensor device, is intimately related with the processing and memory of the physical device that is used to implement the SAAM. If high capabilities are required, the costs associated with a Smart Sensor implementation is also very high, being the opposite verified if there's no need for high processing and memory in the SAAM level. Since the I-RAMP3 is an R&D Project, its purpose it not to study the hardware requirements to implement the proposed solution, but to ensure it works in an effective and reliable way.

Another restriction is related with the mapping of what a NETDEV should provide to the network, and the service implementation it must follow. With higher quality information based on sensor data, it may be difficult to first, create the service in the most efficient way – using UPnP Service state variables – and secondly, to update the service in ongoing operations. The adaptation on-the-fly of a service is not supported, compelling the system to instantiate new NETDEVs and consequently, to stop the production system's process execution.

Taking into account the specifications of the I-RAMP3 project on the present paper along with its latest developments, the future work related with sensors and actuators can be identified. A more intense sensor applicability on industrial systems for monitoring purposes is definitely a step that needs to be taken. Nowadays, this necessity is not yet unconsciously turned out into a dependency, so more case studies and practical implementation of this proposed technology needs to be explored towards a more generic and wide approach, and ultimately leading to standardization

V. Acknowledgments

This research was supported by project I-RAMP^3 (FoF.NMP.2012-3) – Intelligent Network Devices for fast Ramp-up – funded by the European Commission under the Seventh Framework Programme for Research and Technological Development.

VI. References

[1] R. Sousa, M. Alves and G. Gonçalves, "Health care Management with KeepCare," *Medetel - Global Telemedicine and eHealth Updates Knowledge Resources*, vol. 6, pp. 148-153, 2013.

[2] U. Forum, "UPnP™ Device Architecture 1.1," 2008.

[3] V. C. Gungor and G. P. Hancke, "Industrial Wireless Sensor Networks: Challenges, Design Principles, and Technical Approaches," *IEEE Transactions on Industrial Electronics,* vol. 56, no. 10, pp. 4258-4265, 2009.

[4] M. Peschl, N. Link, M. Hoffmeister, G. Gonçalves and F. Almeida, "Designing and implementation of an intelligent manufacturing system," *Journal of Industrial Engineering and Management* , vol. 4, no. 4, pp. 718-745, 2011.

[5] V. C. Gungor and F. C. Lambert, "A survey on communication networks for electric system automation," *Computer Networks,* vol. 50, pp. 877-897, 2006.

[6] D. Dzung, C. Apneseth, J. Endresen and J. Frey, "Design and implementation of a real-time wireless sensor/actuator communication system," in *IEEE Conference on Emerging Technology and Factory Automation,* Catania, Italy, 2005.

[7] K. S. Low, W. N. N. Win and J. E. Meng, "Wireless sensor networks for industrial environments," in *International Conference on Computational Intelligence for Modelling, Control and Automation,* Vienna, 2005.

[8] G. Zhao, "Wireless Sensor Networks for Industrial Process Monitoring and Control: A Survey," *Network Protocols and Algorithms,* vol. 3, no. 1, pp. 46-63, 2011.

[9] Schneider. [Online]. Available: http://www2.schneider-electric.com/sites/corporate/en/products-services/former-brands/scada-cmi/telemetry-portal.page.

[10] Honeywell. [Online]. Available: https://www.honeywellprocess.com/en-US/explore/products/wireless/pages/default.aspx.

[11] Emerson. [Online]. Available: http://www2.emersonprocess.com/en-US/plantweb/wireless/products/Pages/Wireless-Products.aspx.

[12] S. J. Qin, "Survey on data-driven industrial process monitoring and diagnosis," *Annual Reviews in Control,* vol. 36, no. 2, pp. 220-234, 2012.

[13] S. J. Quin, "Statistical process monitoring: basics and beyond," *Journal of Chemometrics,* vol. 17, no. 8-9, pp. 480-502, 2003.

[14] A. Duchesnea, G. Heyen, P. Mack and B. Kalitventzef, "Combined use of Model based Data Validation and Data driven Techniques for Process Monitoring," in *17th European Symposium on Computer Aided Process Engineering,* Bucharest, 2007.

[15] P. Kadlec, B. Gabrys and S. Strandt, "Data-driven Soft Sensors in the process industry," *Computers and Chemical Engineering,* vol. 33, no. 4, pp. 795-814, 2009.