Self-organising Smart Components in Advanced Manufacturing Systems

Rui Pinto, João Reis, Ricardo Silva, Vitor Sousa, Gil Gonçalves

Institute for Systems and Robotics
Faculty of Engineering of University of Porto
Porto, Portugal
e-mail: { rpinto, jpcreis, rps, vdsousa, gil }@fe.up.pt

Abstract—**Virtualization of shop-floor components as a way to foster easy access to machine information, collaboration among shop-floor components and task execution on demand are a few key aspects of the latest trends related to Intelligent Manufacturing. This concept is being explored in an ongoing European commission funded project called Intelligent Reconfigurable Machines for Smart Plug&Produce Production (I-RAMP[3]). The goal is to shorten the ramp-up phase time by making manufacturing systems self-aware and self-diagnosable, increasing the reliability and responsiveness of production systems, and ultimately improving the European industry competiveness. To achieve this goal, a device virtualization was developed for industrial equipment, such as machines and sensors, called NETwork-enabled DEVices (NETDEVs). As a technological background, PlugThings Framework was used for easy sensor integration, together with Universal Plug and Play (UPnP) Architecture for device virtualization, enabling standardized communication, dynamic sensor location, collaboration and diagnostics. The main purpose of the present paper is to describe how the collaboration between a virtualized sensors network was implemented, and pinpoint all the advantages that come out of this.**

Keywords—Wireless Sensor Networks; Intelligent Systems; Manufacturing Systems; Sensor Diagnostics and Validation; Sensor Location System.

I. INTRODUCTION

I-RAMP[3] [20] is an ongoing European Project funded by the Seventh Framework Program of the European Commission. This collaborative project involves both academic and industrial partners from Germany, Portugal, Netherlands, Hungary, France, and Greece. Therefore, the vision is to improve the European Industry competitiveness by developing technologies for smart manufacturing systems. To achieve it, the goal is to reduce the ramp-up phase of the shop floor equipment and manage efficiently the scheduled and unscheduled maintenance phases, increasing at the same time the efficiency of manufacturing. By virtualizing all shop-floor equipment into an agent-like system, standardized communication skills and a layer of intelligence for collaboration between complex machines, and sensors & actuators are introduced, improving also the plug'n'produce concept towards flexible smart factories. In this context, each agent is represented as a NETDEV, where three variations were considered: Sensor & Actuator (S&A) NETDEV; Device NETDEV; Process Analyzer NETDEV.

The S&A NETDEV is the entity responsible to encapsulate sensors and actuators deployed on the shop-floor, with the intent of monitoring the machines' conditions and the surrounding environment. The Device NETDEV represents the shop-floor machines, such as a Robotic Arm or a Linear Axis. The Process Analyzer NETDEV, in contrast to the previous entities, does not encapsulate a physical entity, being instead a virtual instance responsible to monitor machines' status and diagnose the sensor networks' condition. NETDEVs have a standardized way to communicate with each other using Device Integration Language (DIL), which is a proprietary task-driven language created in I-RAMP[3], in order to ease the quick delivery and reception of process information between all the virtualized shop-floor equipment. The transparency of discovering devices in the network and data exchange between them, using publish-subscribe services, is possible due to UPnP [21] as a base technology.

Sensor data is extremely important to monitor machines at the shop-floor level and its environmental surrounding conditions for condition-based monitoring, machine diagnosis and process adaptation to new requirements. The I-RAMP[3] technology allows Wireless Sensor Networks (WSNs) to become more flexible and agile, acquiring new capabilities that can enhance shop-floor operations, such as sensor group collaboration, which aims for providing to the machine aggregated information instead of quantitative data that normally comes in form of raw format. Additionally, it allows for dynamic sensor node location, used on sensor collaborations, to detect if sensor nodes are physically near to each other and to the machine, for the correct interpretation of data, and adaptation of its behavior accordingly.

In the past years, WSNs have become more explored and applied in several domains because of the latest advances on WSN communication protocols (such as ZigBee [22] and others) and more reliable and long-lasting hardware. This is mainly due to its feasibility of installation. WSNs are used when it is difficult to use wired solutions, either because of harsh location or a high number of sensors used. Also, they are used due to ease of maintenance and reduced costs of cabling [13]. Some of the advantages of WSN listed by Chen et al. [14] include its large coverage area, fast communication via Radio Frequency (RF), self-organisation throughout a direct communication between entities and ubiquitous information. As Ruiz-Garcia et al. [15] pinpoint, some of the WSN advantages can be seen in concrete structures or in the transportation sector, where a controlled environment needs to be monitored in real-time. Additionally, Evans [16] presents enablers and challenges, along with some contextual applicability of WSN in a manufacturing environment.

Specifically for the industrial domain, Ramamurthy et al. [13] developed a Smart Sensor Platform that applies the plug'n'play concept by means of hardware interface, payload,

communication between sensors and actuators, and ultimately allows for software update using 'over-the-air' programming (OTAP). Cao [17] explored a distributed approach to put closer sensors and actuators in a collaborative environment using WSNs. Chen et al. [14] push this approach forward considering the same approach, but taking into account all the industrial domain restrictions like real-time, functional safety, security, energy efficiency, and so forth. All these industrial restrictions and an overview about the industrial domain was explored and presented by Neumann [18]. In the recent past, Chen et al. [19] tackled the Optimal Controller Location (OCL) in the context of industrial environment.

The paper is composed of five more sections where all the details about the present work are specified. In Section II, an overall description about the I-RAMP^3 project is done, specifying the entities used and the communication processes. Section III talks about the sensor collaboration functionality where the communication protocols and sensor failing handling is presented. Section IV depicts the WSN location system used to locate the sensors on the shop-floor. In Section V, a discussion is made based on company personnel perspective of the system and all the functionalities developed, and, finally, in Section VI some conclusions are drawn and future prospects are presented.

II. INDUSTRIAL APPLICATION OF WIRELESS SENSOR NETWORK

Innovative concepts are being explored in I-RAMP^3 related to WSNs and their use in the industrial domain, implementing a higher level of complexity using entity virtualization. With the NETDEV concept, sensors and actuators will be equipped with standardized communication capabilities and intelligent functionalities such as self-awareness, self-diagnosis and self-organization, aiming for a smart sensor approach. Moreover, the system should be flexible enough to allow the integration of sensors from various manufactures, minimizing the efforts needed by automating this process. The PlugThings Framework [1] is used to integrate sensors on the system and encapsulate them into S&A NETDEVs. It is composed of 4 main modules: Universal Gateway (UG), PlugThings Server, PlugThings Database and PlugThings App.

As can be seen in Figure 1, each sensor node of the network communicates directly to the gateway node, where the received measurements are processed on the UG, converting raw data into readable form. These data is compiled into Extensible Markup Language (XML) based format files that are part of the Sensor & Actuator Abstraction Language (SAAL), which is used to communicate with Sensor & Actuator Abstraction Middleware (SAAM), where all the intelligence related to the sensors is implemented. When the SAAM detects that a new sensor node was connected to the network, the corresponding S&A NETDEV is created, making it transparent to all the entities on the network what tasks it can perform. Since a sensor node can have multiple sensors integrated, the corresponding S&A NETDEV will be able to perform different tasks related with the different sensor types of the sensor node. Basically, S&A NETDEVs will have one

functionality (execution task) to provide sensor information to other entities per integrated physical sensor in the sensor node. S&A NETDEVs can easily communicate with other NETDEVs on the network using DIL, such as Device NETDEVs that correspond to complex machines on the shop floor level, and the Process Analyzer NETDEV, which corresponds to a virtual instance that monitors sensor behavior while in a group collaboration.
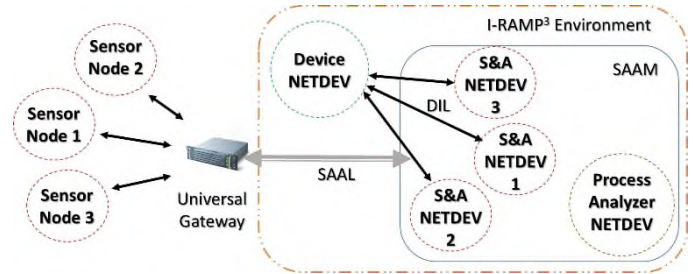

Figure 1. I-RAMP^3 Environment

A. Communication between NETDEVs

DIL is a proprietary language used exclusively to communicate between NETDEVs and it is composed of four main XML files: NETDEV Self-Description (NSD) describes the device capabilities in the form of a range of tasks that the NETDEV can perform, such as goals, conditions, process parameters values and also the physical location of the corresponding sensor node; Task Description Document (TDD) specifies information about a task to be requested, specifying the goals, conditions, process parameters and the period of the task execution or number of task repetitions; Quality Result Document (QRD) describes the result after one task repetition, specifying the quality that has to be achieved; Task Fulfillment Document (TFD) is used as an acknowledge document to the task under execution.
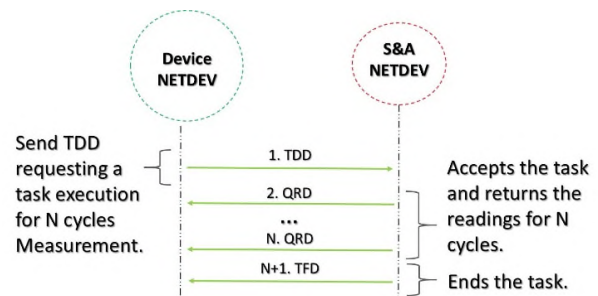

Figure 2. DIL Communication

As represented in Figure 2, DIL is used every time a NETDEV needs other NETDEVs to perform a task. Normally, Device NETDEVs request the S&A NETDEVs task executions for measurement of certain environmental variables, during a given number of cycles, by sending a TDD. If the S&A NETDEV is capable of performing such requested task, it will give a positive feedback via TFD, and answering with QRDs containing the measurement results, during the

number of cycles requested. If the S&A NETDEV is not capable of performing the task or it is already busy performing a task for other NETDEV, it will deny the task sending a denial TFD back to the Device NETDEV.

B. S&A NETDEV Task Execution

At this stage, S&A NETDEVs can execute two different tasks, both usually requested by a Device NETDEV: *Measurement* and *Group Formation*.

A *Measurement* task is used when the Device NETDEV needs the measurements of a single sensor node. Therefore, it should specify the desired type of sensor to receive the corresponding sensory data, the frequency of the readings, sensor accuracy, coverage radius of the sensor in spatial units (if applicable) and the number of cycles to execute the task.

A *Group Formation* task is requested when the Device NETDEV aims to collect several measurements at different locations, which means having multiple sensors executing the same task at the same time. In this specific task, the S&A NETDEV that receives the task is responsible to choose possible S&A NETDEVs candidates to join the group - based on the task parameterization and the sensor location - allowing for a more distributed approach in terms of collaboration, rather than a peer-to-peer-like solution, implying a communication with all the S&A NETDEVs from a group instead of only one. In terms of parameterization, beside the desired type of sensor to receive the specific data, frequency of measurements, sensor accuracy and the number of cycles to perform the task, the *Group Formation* parameterization must also specify the number of sensors intended in the group.

With this collaboration task, there are two main benefits from the task requester perspective. Assuming a Device NETDEV wants to collect and analyze data from multiple S&A NETDEVs, first, it avoids communicating with several S&A NETDEVs at the same time to collect data, since the responsibility to form a group is on the S&A NETDEV, and second, the S&A NETDEVs can process all sensor data and provide a statistical description, passing the data analysis complexity to the group side. This means that the requester does not need to know any statistical technique to process the data from multiple sensor entities on the network.

III. SENSOR & ACTUATOR NETDEV COLLABORATION

A. S&A NETDEV Group Formation

S&A NETDEV *Group Formation* is a methodology used to improve the communication performance and reduce complexity between Device NETDEVs and S&A NETDEVs while executing tasks with a sensor collaboration nature. On the shop floor level there can be thousands of sensors, and therefore, the flow of information can be very high when requesting tasks. The group formation methodology is a more distributed approach that allows S&A NETDEVs to provide a more aggregated information when the task requested from a Device NETDEV requires measurements from more than one sensor node. Instead of establishing communication with every S&A NETDEV required, the Device NETDEV will

have a single point of communication with one S&A NETDEV, which is responsible to form and manage a S&A NETDEVs group.

The main premise for the *Group Formation* is that every S&A NETDEV is capable of forming a group. When a Device NETDEV requests a S&A NETDEV to form a group with a certain number of sensors, this S&A NETDEV is responsible to search in the network (communicating via DIL) for available S&A NETDEVs that are capable of performing the same task and the corresponding sensor nodes are physically located in the same production area. If the requested number of S&A NETDEVs has joined the group, the S&A NETDEV responsible to form it becomes the group leader, called Super S&A NETDEV, and the group is formed. Internally in the group, each S&A NETDEV will collect measurements during the requested number of cycles and the Super S&A NETDEV is responsible, not only to gather all sensor data, but also process them to a more meaningful value, to be sent afterwards to the Device NETDEV. When task execution has ended, the Super S&A NETDEV will terminate the communication with the Device NETDEV and release the S&A NETDEVs from the group, which become available to execute other task requests.
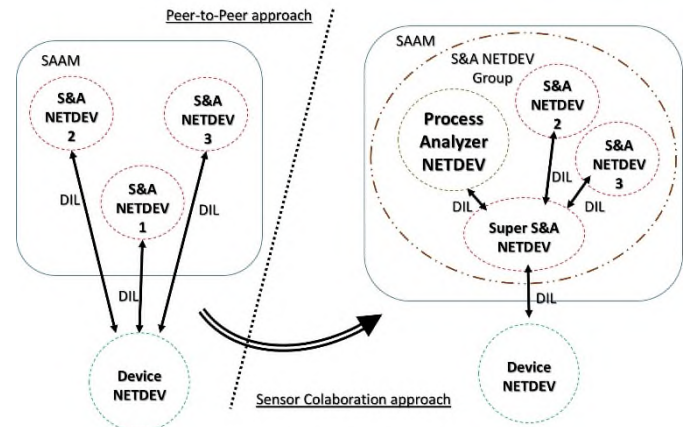

Figure 3. Group Formation Schema

An additional NETDEV entity represented in Figure 3 is the Process Analyzer NETDEV, which is created by the Super S&A NETDEV when the group is created. As previously mentioned, this entity is virtual, not representing any device on the shop-floor, and is responsible to apply the Spatial Correlation technique [11][12] to assess the condition of the group based on the sensor data generated. This entity collects the sensor data from each element of the group and identifies the most devious dataset by comparing the data sets from all group members. If the deviation is greater than a predefined threshold, then the sensor node is classified as probably malfunctioning, so the Process Analyzer reports to the Super S&A NETDEV, via DIL, the existing of a malfunctioning group member at that time so it can make a decision about the faulty sensor node(s) and maintain the group as consistent and reliable as possible.

B. S&A NETDEV Group Formation Fail

Having one single point of communication to interact with all S&A NETDEVs for a task execution is a good way to reduce complexity and increase the performance of communication. On the other hand, relying only on one single point of communication increases the vulnerability, in case the task execution fails on that point. Hence, there are two failing scenarios on a group: 1) The Super S&A NETDEV fails or 2) One or more S&A NETDEVs from the group fail.
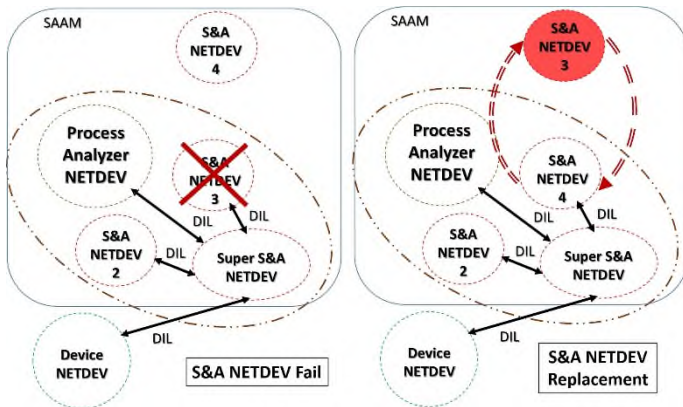

Figure 4.   Group Formation - S&A NETDEV Failure

If the Super S&A NETDEV fails, the single point of communication supporting the interaction between the Device NETDEV and S&A NETDEVs from the group is lost. There will be no more conditions to continue with the task execution, so the task stops and the group is disaggregated. In the termination process, the Super S&A NETDEV is responsible to change the process state of the remaining group members, so they can stop executing the measurement tasks for the group, becoming available to perform new tasks upon request from other NETDEVs.

If a S&A NETDEV from the group is failing, the Super S&A NETDEV is still working correctly, so the group isn't in danger of collapsing and the communication with the Device NETDEV is not affected. In this case, the Super S&A NETDEV is responsible to replace the failing S&A NETDEV for a new one able to join in. While the replacement process occurs, the collected data from the group will be less accurate, because the results sent to the Device NETDEV don't contemplate all the requested NETDEVs, due to a temporary deficit of one S&A NETDEV. Figure 4 depicts the process when the S&A NETDEV 3 fails and is replaced by S&A NETDEV 4.

IV. WSN LOCATION SYSTEM

WSNs applied on industry are used to monitor different production cells on the shop-floor, consisting of spatially distributed sensor nodes, which are equipped with several sensors to monitor the environmental conditions surrounding the cells where they are located. If a machine, located in one of the production cells needs information about, e.g., the luminosity conditions surrounding the cell to execute a given task, the machine may require from available sensor nodes placed in that location, valuable information for process parameterization.

In the I-RAMP[3] context, the Device NETDEV that is requesting the task should search on the network for available S&A NETDEVs with the required capabilities (described in the NSD), e.g., measuring luminosity conditions and, consequently can form a sensor group that measures luminosity. Facing a request for a group formation task from a Device NETDEV, the S&A NETDEV will only accept the task if it can fulfil the required parametrization and it is located on the same area as the machine that requested the task in the first place.

Every NETDEV is characterized by its task execution capabilities (NSD) and the area on the shop-floor where the correspondent equipment is located. The location on S&A NETDEVs can be calculated dynamically on sensor nodes that are using XBee communication protocol, using the incoming signal strength of the sensor node on several beacons for position estimation. Beacons are physical entities located in known strategic positions of the shop-floor, mainly in the limits of shop-floor sections like cells or production lines and are responsible by receiving messages from sensor nodes, assess their signal strength and position in order to assign the current relative location to S&A NETDEVs.

A. Methodology

Location systems on WSN is a very active research area and there is no universal solution for this topic. The main goal is to identify the physical location of a sensor node on the WSN. Each approach of node location is fitted to a specific operating environment, such as indoors or outdoors spaces like urban areas, forests or even underwater. In the industrial context, estimating the node positions in meters is not important, as the main goal is to find in which section on the shop floor the sensor nodes are located.

The algorithms for node location are made of two main components: 1) Estimation of distance or angle between two nodes and 2) Calculation of the node position. First, the distance or angle between two nodes must be estimated to be used on the calculation of the node position related to one or more beacons. Then, the information about the distance and the position is used by an algorithm to determine the node's location.

For distance estimation between the sensor node and the beacons, the Received Signal Strength Indicator (RSSI) method is used [2]-[4], which is a method that estimates the distance between two nodes based on the strength of the signal received on the gateway and a propagation model of the signal, in this case Free Space model [8][9], to convert the signal strength into distance. Since the accuracy provided by RSSI is enough for what it's intended in this scenario, this is the cheapest method to be implemented when compared to time delay and time difference based methods or signal angle/direction estimation methods, because measuring the signal strength doesn't required any extra hardware, such as transmitters and receivers of ultra-sounds, like in the Time Difference of Arrival (TDOA) [3] or specific antennas, like in

Angle of Arrival (AOA) / Direction of Arrival (DOA) [6][7], and no need for clock synchronization on the nodes, like required on Time of Arrival (TOA) / Time of Flight (TOF) [5].

The radio signal is highly susceptible to noise [10] caused by reflection, refraction, diffraction, scattering, fading, inter-symbol interference and shadowing, resulting in distance deviations in the end. This can be minimized by filtering the signal using a moving average to better approximate the path loss logarithmic curve. The path loss coefficient is determined dynamically using path loss log-distance model using measurements of RSSI between beacons, using (1), where $P(d)$ is the RSSI in dBm, $P(d_0)$ is the RSSI at a fixed reference distance from the transmitter d_0, n is the path loss coefficient, X_σ is a normal random variable used to modulate, d is the distance in meters between transmitter and receiver, P_{TX} is the transmission power and A is the signal attenuation. Manipulating the formula, first the path loss coefficient is calculated using (2), where the RSSI and distance are between beacons. Then, (3) is used to calculate the distance between a sensor node and a beacon.

$$P(d) = P_{TX} + A - 10n \times log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (1)$$

$$n = \frac{|P(d_0) - P(d)|}{10 \log d \times 2} \qquad (2)$$

$$d = d_0 \times 10^{\frac{|P(d_0) - P(d)|}{10n}} \qquad (3)$$

The node position is calculated using the distance estimation of the three anchor nodes closest to the sensor node with the Bounding Box method [2]. Bounding Box is a variation of the trilateration, which uses the position of three anchor nodes, with known positions and distances between them, to calculate the position of the sensor node. The position of the node is calculated by the interception of three circles, each one is centered on the anchor node and with radius equal to the distance to the unknown position node. With Bounding Box, the calculation complexity is reduced by replacing the circles by squares. The intersection of the different squares results on a rectangle, where the center is the estimated position of the node.

V. DISCUSSION

As discussed several times throughout the present paper, the use of WSNs is referred as a key element for the todays Manufacturing Systems, pushing forward the plug'n'produce concept, which is achieved by virtualizing shop-floor equipment into NETDEVs that can readily describe and detail their own capabilities and announce themselves into the network to other NETDEVs. NETDEVs are able to collaborate and execute shop floor tasks on demand, and therefore deliver an easy and flexible solution for the industrial domain.

As described, the collaboration between sensors by means of *Group Formation* task available at the S&A NETDEV

entity is, not only a way of reducing the communication entropy when several measurements from neighbor sensors need to be collected, but it also provides higher information about a set of sensors. Additionally, the Process Analyzer NETDEV provides feedback about the condition of the WSN making use of Sensor Validation techniques already explored in the literature and tested in manufacturing environments. Since all these functionalities refer to the software level of abstraction as a way of closing the loop for a ready solution to be used, also the hardware level was considered by means of location device functionality. This allows to know, with a certain degree of precision, the location of sensors in a restricted area, influencing and guiding how sensors should organize and collaborate among themselves, ensuring the system reliability and effectiveness.

Considering now a user perspective like Manufacturing System Designers or Technical Personnel of a Manufacturing company, there are benefits that should be highlighted. Based on the fact that most manufacturing environments are currently using wired sensors instead of WSN, the cabling complexity and savings in terms of time and cost can be reached. This means that no sensors need to be connected to a PLC or Machine Controller, which can be challenging due to the amount of sensors used and harsh locations. On the other hand, the easiness to integrate a new sensor into the system is achieved by only switching on a sensor node, which is automatically recognized as an S&A NETDEV becoming ready for use. This is referred as the plug'n'produce concept, that allows to rapidly react to any foreseen and unforeseen event, like sensor replacement, sensor addition for redundancy purposes in critical environment or in the case of sensor removal when disassembling a production line.

Another advantage of this approach is related with all the functionalities already available from a dedicated framework, releasing the user from being concerned about sensor collaboration and data processing. He only needs to take care of sensor integration using the S&A NETDEV template solution. From that point, information can be easily accessed, monitored and diagnosed. Thus, it is not required for the final user to know in detail, and mainly, to implement from scratch a WSN diagnostics system, but instead, he can focus on what to do when a certain malfunction has occurred and how to relate sensor group information with the product life-cycle in terms of process parameterization. This point is enhanced with the automatic process of forming, deforming and reacting to sudden changes in a sensor group, based on a certain task parameters and sensor location. Since the communication between NETDEV entities is based on a standardized task-driven XML language – DIL - it's very easy to implement a new system that encapsulates a machine, capable of communicating with these entities and easily interpret sensor information for process monitoring.

The main advantage of this is the formation of a self-reconfiguration capability when facing sudden sensor breakdown. A remedy for the breakdown diagnosed by the Process Analyzer NETDEV is embedded in the S&A NETDEVs collaboration, capable of handling a WSN

restructure, as described in the *Group Formation Fail* sub-section. In a real manufacturing environment situation, the shop-floor operator only needs to look for the broke sensor (information already provided by the Process Analyzer NETDEV) and replace it by a new one at the same location as the broke one, and automatically the sensor group will reconfigure itself to take on board the new sensor, not being necessary to write or rewrite any lines of code or to disconnect and connect wires.

These functionalities, together with the automated process for diagnosing and logically organizing a sensor group, plus the fact that a standardized communication language is used, are the cornerstones for intelligent WSN in the factories of the future.

VI. CONCLUSIONS AND FUTURE WORK

Innovative intelligent systems have driven technology for years, and industry has followed this track as a way to improve reliability, responsiveness when facing requirements changes from customer side or due to production downtime, efficiency to minimize costs and effectiveness to increase production quality.

All these goals made the guidelines for the S&A NETDEV development, with functionalities to share information, self-organize, collaborate as a sensor group by using a location system for identifying the positioning of motes at the shop-floor level. Therefore, taking advantage of these functionalities can greatly influence the decrease of ramp-up, scheduled maintenance and unscheduled maintenance times, resulting on a competitive advantage in current harsh and fluctuating markets.

The main developments presented throughout the paper depict that, in terms of WSNs applicability in industry, there are open opportunities to explore, and much can be done to improve the currently used systems. Despite all functionalities presented in this paper, the clear benefits it can bring to the shop-floor and all the experience acquired from I-RAMP[3], the acceptance of WSNs into industrial context needs to be worked out, by performing more pragmatic and real test-case demonstrators. The present work is a clear step forward into a reliable and flexible approach for industrial WSNs, aiming for paving the way into more intelligent manufacturing systems.

REFERENCES

[1] G. Gonçalves, J. Reis, R. Pinto, M. Alves, and J. Correia "A step forward on Intelligent Factories: A Smart Sensor-oriented approach." Emerging Technology and Factory Automation (ETFA), 2014 IEEE. IEEE, 2014. pp. 1-8.

[2] K. Vandenbussche "Fine-grained Indoor Localisation Using Wireless Sensor Networks." Signal, 75, 2005, p. 70.

[3] A. Savvides, C. C. Han, & M. B. Strivastava "Dynamic fine-grained localization in ad-hoc networks of sensors." Proceedings of the 7th annual international conference on Mobile computing and networking. ACM, 2001, pp. 166-179.

[4] P. Bahl, V. N. Padmanabhan, & A. Balachandran "Enhancements to the RADAR user location and tracking system." technical report, Microsoft Research, 2000.

[5] Y. Shang & W. Ruml "Improved MDS-based localization." INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies. Vol. 4. IEEE, 2004, pp. 2640-2651.

[6] D. Niculescu & B.Nath "Ad hoc positioning system (APS)." Global Telecommunications Conference, 2001. GLOBECOM'01. IEEE. Vol. 5. IEEE, 2001, pp. 2926-2931.

[7] N. B. Priyantha, A. K. Miu, H. Balakrishnan, & S. Teller "The cricket compass for context-aware mobile applications." Proceedings of the 7th annual international conference on Mobile computing and networking. ACM, 2001, pp. 1-14.

[8] T. L. Singal Wireless communications. Tata Mcraw Hill Education Private Limited, 2010.

[9] C. Levis, J. T. Johnson, & F. L. Teixeira Radiowave propagation: physics and applications. John Wiley & Sons, 2010.

[10] A. F. Molisch Wireless communications. John Wiley & Sons, 2007.

[11] A. B. Sharma, L. Golubchik, and R. Govindan "Sensor faults: Detection methods and prevalence in real-world datasets." ACM Transactions on Sensor Networks (TOSN), 6(3), 2010, p. 23.

[12] J. Ravichandran and A. I. Arulappan "Data Validation Algorithm for Wireless Sensor Networks." International Journal of Distributed Sensor Networks 2013 (2013).

[13] H. Ramamurthy, B. S. Prabhu, and R. Gadh, "Wireless industrial monitoring and control using a smart sensor platform," Sensors Journal, IEEE, 7(5), 2007, pp. 611-618.

[14] J. Chen, X. Cao, P. Cheng, Y. Xiao, and Y. Sun "Distributed Collaborative Control for Industrial Automation With Wireless Sensor and Actuator Networks", Industrial Electronics, IEEE Transactions on, 57(12), 2010, pp. 4219-4230.

[15] L. Ruiz-Garcia, L. Lunadei, P. Barreiro, and I. Robla "A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends", Sensors, 9(6), 2009, pp. 4728-4750.

[16] J. J. Evans "Wireless sensor networks in electrical manufacturing", Electrical Insulation Conference and Electrical Manufacturing Expo, 2005. Proceedings. IEEE, 2005, pp. 460-465.

[17] X. Cao, J. Chen, Y. Xiao, and Y. Sun "Distributed collaborative control using wireless sensor and actuator networks," Future Generation Communication and Networking, 2008. FGCN'08. Second International Conference on. IEEE, 2008, pp. 3-6.

[18] P. Neumann "Communication in industrial automation—What is going on?." Control Engineering Practice, 15(11), 2007, pp. 1332-1347.

[19] K. Xin, X. Cao, J. Chen, P. Cheng and L. Xie "Optimal controller location in wireless networked control systems", International Journal of Robust and Nonlinear Control, 25(2), 2015, pp. 301-319.

[20] Intelligent Network Devices for fast Ramp-up: I-RAMP3. [Online]. Available from: http://www.i-ramp3.eu/ 2015.10.02

[21] A. Presser, et al. "Upnp device architecture 1.1.", *UPnP Forum*, 22, 2008.

[22] P. Baronti, et al. "Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards.", Computer Communications, 30(7), 2007, pp. 1655-1695.