Servicing industrial machinery

Challenges using wireless identification and networked sensing systems

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***Abstract*—Servicing industrial machinery and automation systems over their life targets at fast response and fast resolution. It requires skills, engineering knowledge and various data about the machine, its industrial environment, data from automation systems in the plant and historical information, which needs to be collected, correlated and analyzed. The advent of tiny smart devices such as RFID and networked wireless sensing nodes are promising and challenging for use in servicing industrial equipment. In this paper we identify fundamental challenges and requirements for establishing wireless networked sensing systems for industrial service applications. We further report on first design considerations for developing practical solutions and experiences from using prototypes in a test bed.**

Keywords-Internet of Things; Wireless Sensor Networks; RFID; remote sensin; maintenance; service

I. Introduction

Servicing of industrial machinery, optimal maintenance strategies and optimal asset management and costs reduction for asset management are intensively discussed and pursued in all industries. Visible effect of cost reductions and optimized asset management efforts is reflected in the increasing average age of installed industrial machines and increasing requirements for support to keep them operational. At the same time for machine manufacturers, service and after sales support is becoming increasingly important.

Any effective maintenance strategy where condition or risk are considered relies upon the availability of data and knowledge. In a modern industrial environments a lot of data is available in plant automation and maintenance systems, which are using fixed installed sensors and asset supervision systems. However, flexible on-site, ad-hoc data collection by the individual service worker proves helpful for diagnostics, increases the information amount and supports better diagnostic or decisions. From the Internet of things the two main areas supporting machine servicing are radio frequency identification (RFID) and wireless sensor networks (WSN).

RFID - Identification technology is essential for servicing actions, by proper identification of the machine or part and by allowing reliable data mapping. RFID is used a lot in logistic applications. Its application is also starting in industrial environments, with a pioneering role of the aeronautical industry. A challenging issue is the operation in industrial environment in case of very long machine lifetime e.g. tenth of years. In industrial environments the RFID is further facing the presence of metal, high temperature and fluids as well as sometimes hard EMC conditions. RFID tags incorporating sensors e.g. temperature offer new possibilities for service use.

WSN - Wireless sensor networks are under consideration in a very wide range of applications, from environment to military and health [1], each with quite specific requirements. Although commercial implementations are sparse, a broad range of sensor node hardware, communication protocols, operating systems and data access approaches exist. Standardization organizations, foundations and alliances are active e.g. regarding communication. From our perspective the most notable efforts are:

IEEE Standard 802.15.4(a) that specifies MAC and PHY layers for Low Rate Wireless Personal Area Networks which is supported by the ZigBee alliance and has already numerous implementation, which still have to prove interoperability [2]

6loWPAN is concurrently emerging and specifies IPv6 support on top of the MAC layer of 802.15.4 networks, which could connect every device to the Internet. This ease of access possibly could raise concerns in industrial environment.

ISA 100.11a which is also building on 802.15.4, has more emphasis on control and is thus relevant to industry automation.

Wireless HART uses the same physical layer; is rather designed to complement existing wired industry solution and specifies an application layer.

While those endeavors promise some clarity in terms of communication technologies it is hard to estimate to what extend wireless solutions will be applied to the industrial domain. While technology is promising more research is needed towards practical application. This fact is also reflected by publicly funded efforts in current international or national projects, which e.g. strives to enable the deployment of WSN technology to the aeronautic and automotive industry [3]. Specifically in the area of supporting industrial machine servicing limited practical work has been done apart from rather static installations for predictive maintenance [4] or pilots. We believe that ad-hoc networked sensing systems (NSS) can strongly enhance machine servicing by rapid and in situ collection of data from machine, equipment and plant environment. RFID and Wireless sensor networks can help to build a decentralized, ad-hoc data and diagnosis infrastructure to support industrial machine servicing.

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II. APPLICATION SCENARIO

In this section we describe an application scenario of a mobile service worker, in order to illustrate our vision of empowering industrial service using Internet of things technology. This vision comprises seamless access to:

- machine identification
- existing data obtainable in the industrial environment from exiting installed sensing or automation systems
- wireless ad-hoc data collection capabilities
- data from enterprise systems via on site data links, if needed or allowed.

The scenario itself pictures the use of mobile diagnostic units that compromise WSN hardware together with RFID technology. These diagnostic units can be used by a field service engineer to analyze customer owned machinery in situ. For this purpose he carries a mobile device that connects him to his wireless diagnosis kit and optionally to other information sources available through the local infrastructure. The following workflow depicts a typical use case:

1. the service engineer identifies machinery,
2. retrieves information from knowledge base,
3. retrieves a diagnosis program,
4. follows instructions for sensor placement,
5. uses automatic discovery and interlink with available machine data,
6. uses handheld visualization and diagnosis support for an manual and automatic failure classification
7. fixes the problem,
8. uploads service and sensor logs to central site

As a result of all above tasks and activities a collection of valuable real-time data becomes available to the service worker. The remotely collected data can be analyzed, compared to data from similar service tasks, or machines, and for example used for case based reasoning [5].

III. FUNCTIONAL REQUIREMENTS AND CHALLENGES

While it is easy to picture possible applications, in our experience designing a system for industrial servicing introduces many practical challenges for an integrated solution. For the past few years we have started to test prototypes and product using wireless identification and sensing technologies in an industrial context. Fig. 1 shows an application demonstrator installed at an industrial test-rig. Mobile handheld diagnosis device, RFID and sensor node technology allow to collect data from the machinery or to indentify machine or parts. First results from this and other tests are encouraging and work is ongoing to improve existing scenarios, approaches, devices and software. From our experiences, however, various focal points have emerged that are independent of the concrete technologies. In the following we identify what we believe are the cornerstones for a successful broad application of wireless sensing and identification technologies in a scenario like the one outline in the last section.

A. *Data Collection*

Beyond identification data typically two types of data are interesting for diagnosing machine conditions. Firstly that is information originating from the *system* itself, secondly it also important to collect data from the immediate *surroundings* being it ambient environment or data collected from other nearby industrial systems possibly related to the machinery itself. Practically this means that we can query data from a machine using passive RFID and data about plant environment using WSNs or active RFIDs. RFID technology can also provide static machine data and service histories. Networked sensors in contrast can be placed on the machine to retrieve dynamic signals.

Fig. 1 Measurements: mobile device and WSN at industrial test-rig

We can easily see that we can make use of different node capabilities depending on the specific application need and the role of a node in an application. Fig. 2 depicts an abstract classification of operation modes independent of the used technologies. As an example mode I describe the functionality of a simple RFID tag, while mode IV can only be implemented on a sensor node with more resources. We believe that applicability of different technologies to industrial servicing cannot be decided on general level. Rather based on the presented functional separation of the components we identify different key requirements and challenges.

1) Identification

Unique identifiers for machinery or parts basically ensure the correct association of data with a machine, measured values etc. They can provide a link to associated information and history for a specific machine. This is of key concern for knowledge management. Furthermore they are the basis for addressing and discovery within a local network.

Another important aspect of practical identification is the position of the nodes in an industrial environment. Far more then any technical IDs it is relevant to associate the collected data from attached sensors with the machine or part. Also the service engineer has to identify devices for setup and taking back after the measurement was performed. In both cases localization is needed. No fully satisfactory solutions are known especially for indoor ad-hoc applications, in an industrial environment. A shift towards application specific, relative or semantic positioning could yield better results.

2) Sensor Data Acquisition

When monitoring environmental conditions like humidity and temperature the requirements of the industrial domain do not differ from other WSN applications. In contrast to that

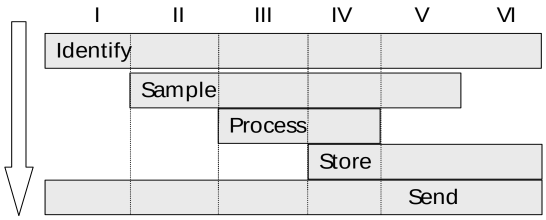

Fig. 2. Device Operating Modes

machine monitoring and especially sound vibration analysis need high sampling rates for digital feature extraction. This is challenging for long-term mobile operation, because there is only limited possibilities for low duty-cycle operation. One mostly unused opportunity by currently available WSN nodes is well-designed and well-defined analog and digital processing frontends, such as adaptive filters or signal transformations to reduce the data amount and to support digital processing that retain specific characteristics of the signal while reducing the bandwidth.

Another important issue is the synchronization of the sampled signals with a common time base. This is especially important for analyzing the collected data results in a diagnosis context. While this is relatively easy to achieve locally with hardware resources available, this imposes a big challenge for distributed wireless sensors. While online correlation of sampling data is desirable, accurate “post mortem” offline synchronization is a minimum requirement for data analysis. While most sensor systems have clock synchronization protocols, flexible synchronization strategies up to bit-clock precision (i.e. microsecond precision) need better exposure to the application.

3) Local Processing

There are two major motivations for having sufficient local processing resources on a node. First, it enables a simpler overall system where the wireless sensors already provide interpretable signal features for direct visualization and diagnosis. Consequently a decentralized system also enables better scaling of the number of connected devices in terms of processing power as each wireless sensor node does its part. Second, to attenuates some of the requirements on lower layers on accurate time synchronization and supporting high data rates and volume as already stated above. Local processing therefore should e.g. support algorithms e.g. transform signals to frequency domain (like FFT) or reduce dimensionality of data (like PCA)[6]. A closer integration of the processing with hardware optimizes the signal processing chain and can lead to higher accuracy and lower communication costs. This underlines the need for hardware and software platforms that not only support networking but also support mixed signal data processing at an acceptable low power consumption.

4) Data Storage

On node storage can be used for either holding static data like identification and service history logs or as a buffer for sensing logs. For identification and meta data the size of the storage area can be comparably small however might be of concern if a node is attached to machinery for as long as its lifetime as in the case of RFID tags. For this type of data the main concerns are persistency and authenticity. As outlined before in many analysis tasks a vast amount of data must be gathered. To be able to compensate for limited network bandwidth that might be slower than the overall data rate from all sensors and devices it is mandatory to have sufficient local storage on a sensing node, which has to match the application in size and speed.

5) Communication

Communication in a servicing application needs lossless transfer of identification data, events and time series from nodes towards the backend system. Metal dominated industrial environments are a main challenge, although the typical network will be rather dense. As for medium access it has to be compatible with other existing and future wireless applications. Further the envisioned scenario also requires the capabilities for ad-hoc networking and device discovery. Security is generally a critical issue. However, for service applications running in a closed location this may be less critical. An important cross-layer functionality of the communication component is the ability for accurate time synchronization.

B. Precision, Accuracy and Drift

The utility of a NSS for a supervision and diagnosis task will strongly depend on its overall accuracy, on the contribution to correctly detect the machine status. Challenges here are due to various types of mechanical and thermal influences, due to sensor drift and due to electrical noise (EMC). The ability to calibrate the system is critical for industrial application and practical experience with wireless ad-hoc systems is rather limited. Rather than trying to catch up with or outperform classical diagnosis systems in those aspects, it seams to be more important to model the effects of partially lower precision, noise and sensor or time drifts on the application. Accurate specifications on an industry level, seem to be missing for many wireless sensing systems. Besides modeling of accuracy and checking it against the specific application requirements the biggest challenge is the complexity which, must be hidden from the user while helping him to construct and execute diagnosis tasks.

C. Configuration and Deployment

Mobile wireless sensing and identification need tools for configuration of the nodes to adapt various situations on site. An important precondition for this is in situ re-configurability of the system. Many sensing wireless sensing systems lack the inductivity of their wired counterparts. Especially if used as an early diagnosis tool the service engineer needs to be able to quickly adapt the diagnosis task to the situation. Therefore the availability of downloadable diagnosis configurations and workflows needs to be supported. Such configurations need to be integrated together with diagnosis instructions into an electronic servicing knowledge infrastructure, which also gives interactive instructions for placing sensors.

By saving retrofitted wiring NSS promise important cost reductions as wireless communication provides the ability to monitor otherwise difficult to reach movable machines or parts. The deployment of smart nodes to build up a NSS needs

TABLE I

SENSORS AND ELECTRONCS – APPLICATION, POWER CONSUMPTION, DATA RATES, POST-PROCESSING COMPLEXITY

	Applications	pow	data	ppc
Acceleration	machinery with moving parts, shocks, vibrations: 1D, 2D and 3D	M	M-H	M-H
Machine Sound	Production machines, processing systems	M	H	H
Airborne Sound	Environmental	M	H	H
Ultrasound	Machines in manufacturing or batch processes	M	H	H
Temperature	Industrial processes, systems, parts, environmental	L	L	L
Humidity	Environmental	L	L	L
Gas(CO,HC, VOC)	Emission, leakage	H	M	L
Light(visible, IR, UV)	General supervision of areas, special processes or machines	L	L	L
DSP/other	For on board processing	M-H	n/a	n/a

easy installation of sensing devices on the machines and parts. This practically exposes the needs for localization and configuration of the nodes and of the whole network for a desired task.

D. *Software Integration*

An extremely important aspect of the aforementioned data collection modes, as well as the deployment and configuration support is software integration with mobile device and the backend application. This ranges from integration with storage infrastructures like databases to online visualization and analysis tools. A prerequisite for a future proof solution are well-defined stable interfaces that also provide clear semantics for data representation and are at the same time easily usable. The second important aspect is integration intuitive addressing and ad-hoc discovery of all (heterogeneous) devices in the system, that is suitable for humans and software alike. The targeted application in mobile service using handheld devices and the necessity to integrate into existing backend systems call for middleware, communication standards or a framework has to be light weight and generic.

IV. DESIGN CONSIDERATION

After we have extensively underlined the challenges based on principal and experienced practical issues of the application domain, we now extract some design consideration that we believe can help to approach a suitable solution. For this purpose we let us guide by common design principles: *reuse, separation of concerns, abstraction and simplicity*. All of those principles are also economically motivated to reduce the bottom line cost of the envisioned system.

We see a break-through for sensing technologies in other markets. The wide availability of low power and low cost Micro-Electro-Mechanical Systems (MEMS) for automotive and consumer electronic application provides a huge potential for wireless applications also in the industrial domain. Wireless sensing systems have not yet exploited the availability of special purpose processing components. Components like DSP and probably soon also FPGAs can readily be used in low power mobile NSS applications.

In table I we present an open list of sensors that we think have big potential for our application domain. Reusing this technology will enable a product for industrial service at low initial investments. A similar movement towards we see in the market for radio SOCs for IEEE *802.15*.4. While we think it is important to follow those trends, it may prove risky to bet on a certain technology in spite of official standards. This is why we strive for a modular platform design that separates concerns of networking and sensing in a way that it easily adaptable. From an engineering perspective it is important to put increased focus on local processing capabilities and analog circuit designs as well as mechanically sound packaging and mounting solution that fit industry application needs.

The biggest research challenge we see is abstracting from concrete technology while being aware of its specific effects on the system. Effectively this means enabling an Internet of Things for the industrial domain that supports the seamless interaction RFID, Wireless sensing and Wired sensing technology with machine monitoring applications and knowledge bases in a consistent way. Standards like DPWS are promising but they still prove difficult to map to WSN hardware at an acceptable overhead.

We see a big chance in the advances of model driven software development rather than technology specific solutions or API driven middleware. While models haven been an accepted way to describe electrical and mechanical systems for design, implementation, documentation, static analysis and testing for a long time, they also pick up in (practical) software engineering. For our service use case this means that it would allow capturing expert knowledge in domain specific descriptions and being able to generate diagnosis workflows and map them to specific software and hardware components as available and needed at the time.

V. CONCLUSION

The use of wireless identification and networked sensing systems in industrial environment is promising and gaining interest. This is enabled by progress in technology, yet some challenges and to-dos remain for the research community. Especially the enormous design space that we outlined in this paper includes many tradeoffs between desired functionality and in a sense contrast the demand for a universal solution for the industrial service domain. The obvious potential lies in obtaining fast and real-time data on the machine and about actual site condition, with reduced human effort, allowing advanced analysis and diagnosis in a way and in situations which where not possible previously.

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