Internet of Things Technologies to Rationalize the Data Acquisition in Industrial Asset Management

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Abstract - *Based upon the needs of industry, academia is producing a growing number of decision-making models and tools for maintenance and asset management. At the same time the amount of data available for companies is overwhelming and unorganized, as our previous research and experience have shown. The acquisition of relevant input data for these models can be time consuming, prone to error and often difficult with the current technologies and systems. The emerging Internet of Things (IoT) technologies could rationalize data processes from acquisition to decision making if future research is focused on the exact needs of industry. This paper contributes to this field by examining and categorizing the applications available through IoT technologies in the management of industrial asset groups. Previous literature and a number of industrial experts are used to identify the feasibility of IoT technologies in asset management. This paper describes a preliminary study, which highlights the research potential of specific IoT technologies, for further research related to smart factories of the future.*

Keywords: Internet of Things, IoT, Data acquisition, Asset management, Smart factory

1 Introduction

As a result of the rapid and world-wide globalization in the industry today, companies and other organizations are networking, whether intentionally or unintentionally, in increasing pace. Complex interdependencies in the organizational interface set entirely new requirements for data acquisition and data transmission as well as for generating usable decision-making information from the data. Based upon the above-mentioned need to manage and control inter-organizational environments, academia is producing a growing number of decision-making models and tools designed for industrial asset management in particular. Our contributions in this area are the "Life-Cycle Model for Maintenance Service Management", created for inter-organizational operation and maintenance planning and decision making of a production asset [1]–[2], and the "Flexible Asset Management Model" or "FAM-model", targeted for optimizing a network's asset quantities and balance sheet -positioning in a strategic level [3]. However, the amount of data in companies and numerous information systems are constantly growing, which has caused problems in separating relevant data from irrelevant data. Therefore, it has proven very difficult to generate accurate, adequate and timely data for industrial asset management models and tools, such as the "Life-Cycle Model" or the "FAM-model". One potentially viable solution to improved data acquisition and transmission are Internet of Things (IoT) technologies that will automate asset-related data processes in smart factories of the future through embedded communication within the existing internet infrastructure [4]. IoT does not however intrinsically solve any difficulties in data utilization, i.e. turning data to business information, where suitable data penetration and analytics software or techniques, so-called middleware is highlighted instead [5]. As IoT technologies are altogether a novel approach, the field remains somewhat unclear, which creates a need to carry out research especially from an industrial asset management perspective. Therefore research is needed to clarify feasible industrial applications in order to improve data exploitation and data-based decision making in industrial environment. The objective of this paper is finding and studying asset management-wise relevant Internet of Things technologies by connecting an industrial asset group to an IoT technology both in theoretical and in practical level. Consequently, the objective of this paper is shaped into following research questions:

1. What are the essential IoT technologies to be employed in the data acquisition and data transmission of various physical industrial assets in smart factories of the future?

2. How does an industrial expert panel foresee the industrial asset management potential of IoT technologies in relation to their companies' businesses?

Our research employs two methods. Firstly, current knowledge on existing IoT technologies and their potential applications are studied by conducting a comprehensive literature review in order to achieve a theoretical overall view and determine if there is a research gap. Secondly, the outlook of industry, and therefore our empirical evidence, is mapped via an industrial expert panel that is comprised of industrial asset management and industrial maintenance specialists representing internationally distinguished companies in Finland and Sweden.

2 Theoretical framework

2.1 IoT technologies

IoT comprises of a network of smart objects that are connected to the Internet. In the context of industry, the term of Industrial Internet and Industry 4.0 are often used alongside IoT. Applications utilizing IoT technologies are increasing as enabling technologies are developing and becoming less expensive. IoT is transforming businesses and it has been stated to be an industry revolution taking place right now [6]. Companies are developing new applications and innovative uses for IoT technologies. IoT technologies have been applied to numerous environments, such as logistics, manufacturing, security, and healthcare. Hence, the applications vary from inventory control to e-Health applications. The possibilities of IoT enabling technologies and applications have received attention in the literature [7]–[10]. The categorization of IoT technologies is not uniform and different technologies are often applied together. Commonly discussed technologies are: RFID (Radio Frequency Identification), WSN (Wireless Sensor Networks), WSAN (Wireless Sensor and Actuator Networks), WPAN (Wireless Personal Area Networks), NFC (Near Field Communication), as well as naming and localization technologies. These technologies are mainly used for identification, sensing and communication purposes.

RFID technology uses radio waves to identify items. RFID technology is primary used for identification purposes but it enables also to store limited data in RFID tags [11]. RFID technology consists of electronic tags (RFID tags) and RFID readers. RFID tag stores the unique code of the attached object and RFID reader can act as a gateway to the Internet by transmitting the object identity, read-time and the object location which therefore enables real-time tracking [12]. RFID technology enables to automate the process of object identification and eliminate human link. Reference [13] has reviewed applications based on RFID technology in different industries. RFID technology enables to reduce shrinkage, prevent stock outs and excess stocks, improve data accuracy, and increase information visibility in the supply chain. RFID technology is applied, for example, to inventory control, product tracking, building access control and real-time location system in complex manufacturing processes [13].

WSN technology refers to a group of sensors that can monitor and record the physical conditions of the environment. WSN technology utilizes sensors to collect data about the targeted phenomenon and transmits the data to base stations that can be connected to the Internet. [12] There are many different types of sensors and they are able to monitor a wide variety of physical conditions, including temperature, humidity, vehicular movement, pressure, noise levels and mechanical stress levels on attached objects [14]. WSN technology can be applied to great variety of different applications, for instance, to machinery condition monitoring, traffic estimation, and power consumption monitoring [11], [15]–[16].

WSAN technology combines sensing technologies with actuating possibilities. Sensors gather information about the physical world, while actuators take decisions and then perform appropriate actions upon the environment. This allows remote and automated interaction with environment. [17] WSAN technology provides innovative application possibilities and it is applied to variety of building automation applications, for example, to temperature control, to air conditioning system which reacts to the presence of people, and to other applications that can provide energy savings in buildings [18]–[20].

WPAN enables the energy efficient wireless access and data transfer to smart objects over a short distance (1 m–100 m). Examples of WPANs are Bluetooth and ZigBee. Bluetooth defines a complete WPAN architecture, including a security layer. However, the main disadvantage of the Bluetooth is its relatively high energy consumption. Therefore, Bluetooth is not usually used by sensors that are powered by a battery. ZigBee is developed to be corresponding technology but simpler and less expensive than Bluetooth. Additionally, ZigBee has low power consumption and is more energy efficient. [12], [21]

NFC refers to short-range high frequency wireless communication technology which enables the exchange of data between devices over a distance of less than 20 cm. NFC technology is compatible with existing smartcards and readers but also with other NFC devices and it is suitable for use in mobile phones [12]. NFC technology can be utilized in public transportation, proximity payment and access keys for offices and houses, for example. NFC utilized in mobile phones enables peer-to-peer communication between two NFC devices and, for instance, business cards and other information can be exchanged [12], [22].

In order to be able to communicate via the Internet, smart objects need appropriate naming technologies. Smart objects need to be identified and the access path to the object needs to be established. Examples of naming schemes are barcodes, 2D (two-dimensional) barcodes, EPC (Electronic Product Code) and IP (Internet Protocol) address. Naming technologies make possible to identify items with appropriate accuracy. Then, sometimes it is adequate to identify items at item group level and sometimes an item specific identification is needed. Item specific identification is needed especially when particular object or device needs to be accessed, for example when tracking vehicle [23] or controlling particular appliance in building automation [18]. Then EPC or IP address would be more appropriate choice.

Localization technologies can be categorized into three groups based on the infrastructure of technology: satellite based, mobile networks based and local area networks based technologies. Satellite positioning technology utilizes distance measurement to satellites to determine three-dimensional location. An example of satellite positioning systems is GPS

(Global Positioning System). A satellite positioning system is intended to be used outdoors and it is not suitable for indoors. Network based positioning technology is based on mobile networks that maintain the location data. Whereas, local area networks can utilize technologies, such as RF (Radio Frequency) signals or local positioning properties of Bluetooth [24].

By applying and combining these IoT technologies, there is a huge potential to develop enormous amount of new IoT based applications in different environments. When considering supporting technologies, such as mobiles and memory capabilities of cloud computing, the IoT based application possibilities increase. These IoT applications produce increasing amount of data which is known as big data. Big data is often semi-structured or unstructured by nature and collected data is useful only if it is analyzed [25]. The challenge is how to effectively exploit the collected data in applications and therefore turn data into business information. In order that companies actually start gathering, analyzing and using the data, the decision making value and potential end use of data must be transparent for them.

2.2 Definition of assets

An asset is generally defined by ISO 55000 standard [26] as “an item, thing or entity that has potential or actual value to an organization”. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial. Tangible or physical assets usually refer to equipment, inventory and properties owned by the organization. Physical assets are the opposite of intangible assets, which are non-physical assets such as leases, brands, digital assets, use rights, licenses, intellectual property rights, reputation or agreements. [26]

In the context of this research the assets are considered as physical items in factory environment. Physical industrial assets include various assets with different management decisions and data needs. To include the special features of these various assets we have divided physical assets into the following five categories: machinery and equipment, buildings, vehicles, inventories, and spare parts. As the research is limited to explore physical industrial assets in factory environment, the category of vehicles includes all mobile vehicles at the factory area, such as motor vehicles and trucks. Vehicles can be considered as assets as long they are transporting the property of the company to other destination, although the vehicle leaves the factory area. Therefore, the company’s own railway wagons and trucks can be counted among assets in this research.

The asset group of inventories comprises four types of inventories: 1) finished goods, 2) work-in-process, 3) raw materials, and 4) maintenance and operating items, such as spare parts. Spare parts have been separated from inventories to be an own category. Spare parts are replacement items that are required to keep assets operating in a plant and they prevent excessive down-time in case of a breakdown [27]. The category of buildings at factory area includes factory buildings and other buildings, such as warehouses and office buildings. Machinery and equipment are the physical assets that are required in factory-specific processes. In addition to process-related machinery, this category includes also other equipment such as tools and computers.

Asset management is defined to be broader perception than the term of maintenance gives to understand. Asset management is considered as a set of activities associated with 1) identifying what assets are needed, 2) identifying funding requirements, 3) acquiring assets, 4) providing logistic and maintenance support systems for assets, and 5) disposing or renewing assets. Therefore, assets management aims to manage assets optimally and sustainably over the whole life cycle of assets. [28]

2.3 Matrix framework

In the context of this research, a matrix framework (Table 1) that combines the aspects of IoT technologies and asset management has been generated. A detailed literature review has been conducted to identify IoT based technologies and if they have been applied to the different asset groups and asset management. These findings have been included into the matrix framework (Table 1). Academic articles, in which IoT technology has been researched or applied to a specific asset group, are referred to in the matrix. The category of spare parts has been left outside the literature matrix, and is thus included in inventory category, due to the limited amount of research focusing on applying IoT technologies to spare parts.

According to the literature matrix, it can be stated that IoT technologies have been applied to a range of asset groups. RFID and WSN technologies have been researched widely and several applications have been identified. WSAN applications have not been studied widely but recently this technology has got more attention in literature. WSAN technology has not been applied to inventories or this just does not appear in literature. WPAN communication technologies have been applied in different contexts and especially the potential of ZigBee has been acknowledged in literature. Also NFC technology has been studied in literature and there are several applications. Barcodes have been in use for many years but 2D barcodes and their ability to store data and the potential of IP address to identify a certain object have become useful in the management of different asset groups. Localization technologies have also been applied to different asset groups and particularly in smart factory context the indoor localization applications stand out in literature. When examining asset groups, it can be noticed that machinery and equipment, buildings and inventories have most applications while vehicles and earlier mentioned spare parts do not have as many applications or they just not appear in academic publications.

Table 1. Literature matrix: IoT technologies applied to the management of asset groups.

IOT TECHNOLOGIES	ASSETS: Machinery and equipment	Buildings	Vehicles	Inventories
RFID	Remote condition monitoring, failure follow-up notifications, embedded health history with the asset [29, device management, equipment monitoring [21], maintenance information sharing platform [30], collecting real-time production information [31]	Access control system [32], [33]	Electric vehicle batteries [34]	Storage levels of parts, real-time information about products on assembly line [35], inventory control [36], [37], resource management system [38]
WSN	Condition-based maintenance [39],[11], fault diagnostics [40], collecting running parameters [41]	Energy monitoring, behavioral monitoring, space monitoring [20], energy management, power consumption monitoring [16]	Traffic estimation, traffic control [15]	Online inventory management system [42], inventory management [43]
WSAN	Gas detection and immediate isolation of gas leak source [44], process control applications [45]	Energy saving, maximization of the comfort in the building [20], temperature control in a work environment [19], power management [46], building automation [18]	Unmanned ground vehicle [47]	
WPAN (Bluetooth, Zigbee)	Collecting running parameters [41]	Bluetooth, Zigbee, Wifi: communication of smart living space [48]	Bluetooth-enabled headset and voice-activated features [49]	Inventory tracking with Zigbee [50]
NFC	Context-aware mobile support system [50], recurring maintenance processes: central process control and documentation [52]	Classroom access control [53] access keys for offices and houses [22]		Availability and stock information of products [54], inventory control [55]
Naming technologies, (barcodes, EPC, IP address)	Maintenance information sharing platform [30]	IP address: building automation [18]	IP address: tracking of individual vehicles [23]	2D barcodes: product information, mobile product verification [56]
Location based technologies (satellite, mobile networks, local area networks)	Tool tracking and localization with RF signals [57]	NFC smartphone indoor interactive navigation system [58]	Asset localization [24], GPS: location of vehicles [23]	Indoor locating with RF signals [36]

Based on the matrix framework, it can be concluded that 1) RFID technology has been widely researched and applied 2) WSN technology appears to be easily varied in different contexts, 3) WSAN has interesting applications and there might be untapped potential as automation can be employed more widely in the management of different asset groups e.g. in machinery and equipment, where automation can be used to prevent failures, or in vehicles, 4) NFC technology might have potential to be applied more widely in different contexts, such as in simplifying documentation during maintenance tasks and access control in various contexts, and 5) there are various applications for communication, naming, and localization technologies.

3 Empirical results framework

Empirical data have been gathered via an industrial expert panel that is comprised of industrial asset management and industrial maintenance specialists from five companies, representing original equipment manufacturers and customer companies from mining and energy industries. Mining and energy industries are traditionally asset and capital intensive industries where IoT technologies and automation create significant potential. In total, six experts from these companies participated in the panel. Experts were asked to evaluate the potential of IoT technologies in the management of different asset groups. The scale was 0–5, where 0 is "cannot say", 1 "no potential", 2 "some potential", 3 "potential", 4 "quite high potential", and 5 "high potential". The matrix (Table 2) sums up the views of experts, as an average number given by six experts. In addition to numbers, the potential is also illustrated by the shades of grey, darker grey representing higher potential and lighter grey representing less potential. White areas mean that potential is unclear or a large proportion of respondents, i.e. over half of the respondents could not say if there is potential, and therefore the average value could be distorted. The category of spare parts has been included here as a separate category because of the special attention given by experts.

Results indicate that 1) RFID technology is seen as a potential technology to be applied to different asset groups, 2) there is potential to utilize WSN in the management of machinery and equipment, buildings, and vehicles, 3) WSAN technology has potential to be applied especially to management of buildings, but to machinery and equipment and vehicles as well, 4) potential of WPAN has also been recognized, 5) NFC technology could be potential in the management of machinery and equipment, 5) naming technologies might be useful to important spare parts, inventories, and machinery and equipment, 7) localization technologies have been identified as potential technologies especially when tracking vehicles.

In addition to the summary matrix, experts have provided comments and usage examples of IoT technologies. For example, RFID technology could be applied to the control of raw material and spare part inventories. In addition, "RFID technology could benefit CBM calculation when operating hours can be targeted at each component". Regarding NFC technology, it has been said that "NFC can be utilized to access control and signing for working orders". NFC applications have been said to be "handy in mobiles and tablets, and therefore other separate devices are not needed". "NFC could work better in some contexts where RFID applications are inflexible to use." Regarding naming technologies, it has been said as follows: "while doing maintenance work, the equipment could be identified and then enter the information and conducted operations into the follow-up system". It was also said that "the most important spare parts should be named and this allows monitoring the spare part consumption of whole installed base" and "2D barcode could enable the access to the documentation". Even though the potential of localization technologies in the management of machinery and equipment is not high, it has been said that "sometimes it would be practical if maintenance worker could localize accurately the equipment that needs to be overhauled". However, apart from what mentioned above, the threats of IoT technologies have also been recognized: "If it is possible to control important assets, such as machinery, via IP address, information security challenges must be acknowledged".

Table 2. Potential of IoT technologies in the management of asset groups.

	ASSETS				
IOT TECHNOLOGIES	Machinery and equipment	Buildings	Vehicles	Inventories	Spare parts
RFID	3,0	3,7	4,0	3,7	3,0
WSN	4,4	4,0	4,7	2,7	2,0
WSAN	3,8	4,8	3,3	2,7	1,5
WPAN	4,8	4,0	4,0	2,7	2,8
NFC	3,5	2,3	3,5	2,5	3,0
Naming technologies	3,2	2,5	3,0	3,7	4,5
Localization technologies	2,8	2,7	4,2	4,5	2,0

4 Discussion and conclusions

IoT technologies and applications have been studied in detail. But this kind of summing-up literature review of IoT technologies and applications in asset management does not appear in the literature. Results establish understanding of how these technologies can be applied to the asset management of future smart factories and what technologies can be utilized to rationalize data acquisition and transmission in industrial applications. The research acts as a kick for interest to apply IoT technologies more in industry. The research also helps to identify the potential of IoT technologies for data processes and recognizes the themes of further research. Literature matrix and empirical matrix represent the responds to the both research questions. According to literature review, IoT technologies can be applied widely in the management of different asset groups. Also industrial experts see potential to exploit technologies in their business environments.

If the literature matrix and expert views are compared, the main difference is related to spare parts. While research is lacking, industrial experts see potential for a number of technologies, such as naming technologies. A reason for this might be the fact that researches have not been focusing on spare part inventories while asset management practitioners are more interested in spare parts in particular. Another difference is that, based upon the literature, there are fewer IoT applications for vehicles than the views of experts indicate. This could be because the research is only just increasing or IoT innovations related to vehicles might be carefully protected by companies from publicity. Thus, there could be a lack of academic publications compared to e.g. machine or inventory-related applications.

IoT technologies have a huge potential but more needs to be done before applications can be exploited more widely in real industrial environments. An important issue is how collected data can be effectively turned into business information. This sets high level requirements for middleware layer which filters and processes collected data. Data is required to be accurate, adequate, and timely. Additionally, data need to be integrated as much as possible into same system or database in order to enable automation and ease of use.

The limitation of this research is the small size of industrial expert panel, and therefore more comprehensive empiric research need to be conducted. Further research could concern more comprehensive empiric research about the potential to apply IoT technologies in different business environments. The future research could also focus on examining the lack of research in the field of spare parts. It should be investigated more carefully if IoT applications for spare parts are not researched at all or if there is any potential to apply IoT technologies. The next step is also to study how all the collected data could be used effectively in applications and decision making.

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