Aalto University
School of Engineering

Mikko Parviainen

Implementation of Industrial Internet to Discrete Automation Devices

Master’s Thesis submitted for examination for the degree of Master of Science in Technology

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Supervisor: Professor Petri Kuosmanen
Advisor: Reijo Smolander, M.Sc. (Tech), M.Sc. (Econ)

Aalto-yliopisto
Insinööritieteiden korkeakoulu

Aalto-yliopisto, PL 11000, 00076 AALTO

www.aalto.fi

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Tekijä Mikko Parviainen

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Työn valvoja Prof. Petri Kuosmanen

Työn ohjaaja Reijo Smolander, DI, KTM

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Tiivistelmä

Teollinen Internet on termi, jolla kuvataan teollisuuden digitalisaatiota. Aihe on kasvavan kiinnostuksen kohde ja esim. Suomessa on useita tahoja, jotka panostavat aiheen tutkimukseen. Siltikin Teollinen Internet on käsitteenä epäselvä ja sitä vaivaa konkretian puute. Tämän työn tarkoituksena on tutustua Teollisen Internetin nykytilaan ja automaatiolaitteiden ominaisuuksiin Teollisen Internetin näkökulmasta.

Teollisen Internetin esimerkit jakautuvat pääasiassa kahteen luokkaan: alustalähtöisiin ja koneiden väliseen kommunikaatioon (M2M-kommunikaatio). Esimerkit tarjoavat listan ominaisuuksia ja vaatimuksia Teolliselle Internetille kummastakin näkökulmasta. Yleisiä ominaisuuksia ovat esimerkiksi skaalattavuus ja joustavuus, jotka saavutetaan erilaisilla tietoteknisillä vaatimuksilla, esim. palvelukeskeisellä arkkitehtuurilla.

Lisäksi työhön kuuluu käytännön osuus, jossa kirjoitin ohjainlogiikan ja datankeräyksen testilaitteeseen, joka simuloi aktiivimagneettilaakerien pudotuskokeita. Ohjainlogiikka koostui PLC-laitteesta ja siihen liittyvistä ohjelmistoista. Datan keräys koostui mittausdatan keräykseen ja purkamiseen vaadittavista ohjelmistoista sekä laitteistosta. Kirjallisuudesta kerättyjen vaatimusten ja käytännön kokemuksien perusteella esitän pilvipohjaisen, Teolliseen Internetiin suunnatun ohjelmistoalustan kehittämistä testilaitteen ympärille. Ohjelmistoalusta voi toimia yliopistollisen jatkotutkimuksen pohjana.

Ohjelmistoalustan toteuttaminen tapahtuu kahdessa vaiheessa: ensimmäisessä vaiheessa kehitetään pilvipohjainen alusta, joka saavuttaa testilaitteiston nykyisen toiminnallisuuden. Toisessa vaiheessa ohjelmistoalusta muutetaan vastaamaan Teollisen Internetin vaatimuksia, jolla saavutetaan sovellusriippumaton järjestelmäratkaisu.

Avainsanat Teollinen Internet, tavaroiden Internet, IoT, PLC, automaatio

Aalto University
School of Engineering

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi

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Abstract

Industrial Internet is a term that is used to describe digitalization of industry. It is a research direction in Finland, where there are already various groups studying it. Despite this, the term Industrial Internet is still relatively vague and there is a lack of concreteness around the topic. The objective of this thesis is to explore the current status of Industrial Internet and study the capabilities of automation devices from an Industrial Internet point of view. I explore Industrial Internet through a literary review where I study various use cases.

The use cases of Industrial Internet are divided into two main types: platform centric and machine to machine (M2M) communication centric. The use cases provide a list of characteristics and requirements for Industrial Internet from these two perspectives. General requirements are, for example scalability and flexibility, which are achieved through various IT technologies, such as Service-Oriented-Architecture.

This thesis also consists of a practical part where I configured the control logic and data collection for a test bed that simulates drop tests of active magnetic bearings. The control logic consists of a programmable logic controller and corresponding software. The data collection consists of software for collecting and analyzing measurement data and the measuring equipment. After the literary review and practical part, I propose the creation of a cloud based Industrial Internet platform around the active magnetic test bed. The purpose of the platform is to provide a direction for further research.

The creation of the platform consists of two phases: first phase includes the creation of the platform so that the test bed achieves current functionality but cloud based. The second phase consists of changing the platform to meet the requirements of the literature review. The end results will be an application independent system solution for Industrial Internet.

Keywords Industrial Internet, Internet of Things, IoT, PLC, automation

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Symbols and abbreviations

AIIC	Aalto University Industrial Internet Campus
AMB	Active magnetic bearing
API	Application programming interface
BAS	Building automation system
CPU	Central processing unit
EDA	Event-driven architecture
ERP	Enterprise resource planning (system)
FTP	File transfer protocol
IoT	Internet of Things
LAN	Local area network
M2M	Machine to machine
OPC	Open Platform Communication
OPC UA	Open Platform Communication Unified Architecture
PaaS	Product as a Service
PLC	Programmable logic controller
PWM	Pulse width modulation
RIFF	Resource Interchange File Format
SaaS	Software as a Service
SCADA	Supervisory Control And Data Acquisition
SOA	Service-Oriented-Architecture
WAN	Wide area network
WAVE or WAV	Waveform Audio File Format

1 Introduction

1.1 Background

Product range of a company can be described as a vertical value chain. Consider for example, a production line in a manufacturing process. The production line will have different types of devices such as sensors to measure different parameters in the process and various actuators. These actuators could include complex devices such as machine tools, welding machines, robots etc. or simpler ones such as motors, pumps and valves. The suppliers usually offer their own selection of devices completed with proprietary firmware and software that is used to control the devices. Communication between these devices is usually done in a vertical manner with fieldbus protocols and an industrial PC.

In reality, very rarely is every device in the production line purchased from a single supplier. Instead, usually production lines consist of equipment from various suppliers which brings configuration issues as devices from different suppliers can be difficult to integrate into a single system. In addition, the number of different types of devices we can connect to each other is fairly limited. All of these issues bring limitation to scalability, flexibility and ease of use of the system. If we could flatten the vertical control chain and ease the configuration of devices, we could improve the response time and flexibility of the system. Machine to machine (M2M) communication achieves this to some extent (Höller, J. et al. 2014).

Even more recent trends are the so called “Internet of Things” (IoT) and “Industrial Internet”. These terms are many times used interchangeably but usually they refer to the phenomena of adding connectivity to various devices to improve their functionality in some way. For example manufacturing equipment could be embedded with Internet based technology to improve their flexibility, ease of use and application. In the end, this could lead to devices being fully integrated to the Internet in which case we would not only have a network of connected computers but also individual devices, actuators and sensors (Höller, J. et al. 2014). Later we will make additional clarifications about the differences of IoT and Industrial Internet.

Industrial Internet seems to have much in common with M2M but there are fundamental differences. In the simplest form, Industrial Internet could be a solution for achieving M2M-communication through internet protocols. In reality, Industrial Internet could offer a lot more, as the connection of devices to the Internet can allow the creation and generation of totally new kinds of products, industrial systems and business models. Naturally this has generated a significant amount of hype around the topic. The vision is that Industrial Internet will bring significant advances for monitoring, controlling, optimization and automation applications, which will then introduce radical changes to many areas of business (Porter & Heppelmann. 2014, Höller, J. et al. 2014)

Problem of Industrial Internet is that currently it is used as an umbrella term for different activities. Depending on the source, Industrial Internet can mean networking technologies and communication protocols, software architecture, the actual physical connected objects, a pool of data or something else. There is no comprehensive definition about the actual practicalities. For example, what kind of devices, protocols, systems, architectures and business models are a part of Industrial Internet?

1.2 Research problem and objective

This thesis is a part of a larger Industrial Internet research effort between Aalto University School of Engineering, School of Science and School of Electrical Engineering. The objective of this thesis is to explore the current state of Industrial Internet and study what are the capabilities of current automation devices from an Industrial Internet point of view. We want to explore how the devices should be connected in an Industrial Internet environment. Eventually we will propose a network topology for an Industrial Internet solution. This solution provides basis for further research.

1.3 Scope of the study

The scope of this study includes research on the current state of Industrial Internet by studying use cases of Industrial Internet. The practical part of this thesis includes studying the Industrial Internet capabilities of current automation devices and software. I will deploy a programmable logic controller (PLC) to an active magnetic bearing test bed (AMB) in the Aalto Industrial Internet Campus paper machine lab. The AMB test bed was designed by a student team for a project course. The scope includes installation and configuration of the PLC modules and relevant components for local use. Further research includes studying the Industrial Internet capabilities of the said automation devices and additional supporting software. I conclude this thesis by proposing a plan which will convert the AMB test bed into an Industrial Internet connected test bed.

We are interested in Industrial Internet from a mechanical engineering perspective and will mainly search for examples in that field. The scope of the study does not include generation of new communication technologies or software.

1.4 Research methods

The research methods include a literature review in to the background and current state of Industrial Internet through relevant publications, literature, articles and conference papers. The experimental part of this thesis was conducted in the AIIC paper machine lab. The experimental part included the mechanical installation of a variable frequency drive, the PLC device, power supply unit for the PLC and relevant wiring. Main content of the experimental part was the configuration of the PLC device to control the AMB test bed and exploring the various software components that enable the PLC to function. I studied the PLC to find out if there are features that could be useful from an Industrial Internet point of view.

I will present the background of Industrial Internet in chapter 2.1 by comparing it to M2M communication and I will discuss the architecture and public research efforts in chapter 2.2. I present future prospects of Industrial Internet in chapter 2.3. and explore Industrial Internet through use cases in chapter 2.4. I will then proceed to gather common characteristics from these use cases in chapter 2.5.

Chapter 3.1 presents the AMB test bed and chapter 3.2 presents the ABB automation devices. Chapter 3.3 presents the programming and start-up of the devices. Chapter 3.4 presents the various software components and the results will be discussed in chapter 4.

2 Evolution of Industrial Internet

2.1 M2M vs. Industrial Internet

We are used to the idea of Internet which, in its basic form, is a network of connected computers. Due to advances in technology and progress of digitalization we have seen more and more other kinds of devices, such as phones, also gaining Internet connectivity. The next natural step is that even simpler devices acquire connectivity and it is believed that, in the end, virtually every device will be connected to the Internet. In addition to the connectivity, these devices will have sensors that stream their data to the Internet for various purposes, and actuators that can be used to control the device.

This phenomenon has many names: it has been described as “smart connected devices” and “smart connected things, -objects and -services”. Even more common terms include “Internet of Things”, “Industrial Internet”, “digitalization of industry” and “Industry 4.0”. Especially the term “Internet of Things” has a large amount of hype around it. However, there is no clear definition about the content of Industrial Internet or IoT and which kinds of technologies, solutions or systems they consist of. Most of the time all of these terms are used interchangeably but I think it is useful to make clear definitions. The underlying trends are digitalization and smart connected devices and services. Therefore I think that the best way is to separate these trends by user and purpose: digitalization from an industrial perspective is referred as Industrial Internet and digitalization from a consumer perspective as Internet of Things.

Before I define Industrial Internet or IoT any further, I will mention a similar concept: machine to machine (M2M) communication.

M2M communication

M2M communication refers to direct wired or wireless communication between industrial devices for a specific business purpose and application. These could be for example, measurements in an industrial process, inventory status or alerts. Industrial applications could be remote monitoring and control of devices. In other areas, M2M communication can be applied for example in connected vending machines or point of sale terminals for credit card transactions (Höller, J. et al. 2014). Notable is that M2M systems are almost always solutions for specific problems. Broadly speaking every M2M solution can be said to consist of certain similar components (Höller, J. et al. 2014). The implementation of these components can vary but they appear in every M2M solution in one form or the other. M2M systems are industrial systems so the owner and “user” is almost always a company which we will refer as “the stakeholder”.

- **Asset** refers to the device, phenomena or subject that is of interest. It is the object of the M2M system that the stakeholder tries to monitor, control and integrate to their business process through the M2M system. Asset can be, for example a vehicle or a building.
- **M2M device** refers to the device that provides the actual monitoring and controlling capabilities. They are usually attached to the asset or are at least in the

close proximity. “M2M device” is just a generalized term as there is a large amount of realizations of these devices.

- **Network** is the component that provides connection between the M2M devices and application-side servers. The network can have many forms such as Local Area Network (LAN) or Wide Area Network (WAN). WANs can include for example cellular networks.
- **M2M service enablement** is a system level component that is included to decrease implementation costs and ease application development. Service enablement component provides software functionalities that are common in multiple applications which promotes resource reusability.
- **M2M application** is the software component of the M2M solution that describes the desired monitoring or control process accurately. The purpose of the M2M application is to integrate the M2M system to the business process system of the company. The M2M application can be of any type for example, remote diagnostics of a car or remote electricity metering (Höller, J. et al. 2014, p. 12).

The purpose of M2M communication is to achieve increased productivity and/or better control of assets. The main drawback of M2M solutions is that the data these devices gather usually remains inside the boundaries of the M2M system (Höller, J. et al. 2014). M2M systems generally do not allow broad sharing of their data or connection of the devices to the Internet. Additionally, the devices are usually of the same type and the available device combinations (or “device space”) are fairly limited. (Höller, J. et al. 2014)

Internet of Things

Internet of Things or IoT, is a term that is used in different contexts. I use the term IoT to describe the general phenomena of digitalization of products and services from a consumer’s point of view (Ailisto. et al. 2015). I see the IoT currently as a technology platform but eventually it will refer to a network of individual devices that have their own identity in the network and can share and acquire data. It is expected that IoT will bring connectivity to devices and applications that have not had connectivity before. Connectivity and increase of data sharing will impact products and services in various ways, for example actual usage data from products will allow the manufacturer to optimize their products. These activities bring a better user-experience through for example, more customized products and services or additional knowledge offering (Ailisto. et al. 2015).

Industrial Internet

Industrial Internet refers to the same phenomena of digitalization and smart connected products but from an industrial point of view. The term “Industrial Internet” was generated by General Electric (Draht & Horch 2014). In contrast to the IoT, Industrial Internet has clearer goals: for example, control and optimization of industry equipment and processes. It is left open how this optimization will actually happen but most sources conclude that it requires getting more information out of the industrial systems and, for example, finding hidden relationships between operating parameters. The former will require extending the scale of said systems which could also be a goal of Industrial Internet. Since the scale of the systems is expected to be large, it is usually assumed that Industrial Internet will use Internet based technologies, interfaces, analytics and visualizations. Other technologies include similar technologies as in M2M systems, for example real-time measurements, M2M communication and systems and software that will optimize and automate manufacturing processes and increase productivity.

Big data is closely related to this. The term “big data” means the study of extremely large data sets that the Industrial Internet systems are expected to produce. Thorough analysis is expected to produce insights and information which can be used to refine processes. These can be for instance, hidden relationships between operating parameters. Industrial Internet can also be used to optimize other activities such as deliveries and customer relations (Ailisto et al 2015). In this thesis we use the term ”Industrial Internet” instead of “Internet of Things” or “Industry 4.0”.

There are also many other definitions of Industrial Internet, but usually they revolve around the same idea of combining data from sensors, smart devices, PLCs and RFID tags with the Internet to allow other systems and analysis software to study the data (Michel 2014). Industrial Internet is also known as Industry 4.0. This refers to the fourth industrial revolution that the Industrial Internet will eventually bring. Industrial Internet has a lot in common with the IoT but there are several key differences as presented in table 1.

Table 1: Main differences of Industrial Internet (adapted from Parviainen, V. 2014)

IoT	**Industrial Internet**
• Consumer oriented • Technology platform for developing new technology • No clear goal / various goals	• Industry oriented • Clear goals • Does not necessarily require new technology • Can consist of current technology that is used in a new way • Based on the key concepts of IoT

Table 2 presents more a more accurate comparison of differences between M2M communication and Industrial Internet.

Table 2: Comparison of differences between M2M communication and Industrial Internet (adapted from Höller, J. et al 2014)

Aspect	M2M communication	Industrial Internet
Applications and services	Single application	Multiple applications
	Communication and device centric	Information and service centric
	Asset management driven	Data and information driven
Business	Closed business operations	Open market place
	Business objective driven	Participatory community driven
	Business to business	Business to business
	Established value-chains	Emerging value-chains
	Consultancy and systems integration enabled	Open and as-a-Service enabled
	In-house deployment	Cloud deployment
Technology	Vertical system solution approach	Horizontal enabler approach
	Specialized device solutions	Generic commodity devices
	De facto and proprietary	Standards and possibly open source
	Specific closed data formats and service applications	Open APIs and data specifications
	Closed specialized software development	Open software development
	SOA enterprise integration	Open APIs and web development

Market perspective

Industrial Internet is expected to bring of horizontal integration between companies instead of vertical value chains. Increased integration can generate new opportunities: traditionally only goods and services have been treated as chargeable products but in the future, data and knowledge can also be treated as a product. This idea has spawned the concept of Industrial Internet information value chain.

The concept relies heavily on the information value chain of M2M which can be described through a simplified global value chain –model (Höller, J. et al. 2014). Actually, the global value chain can describe all cases similarly whether the product is a physical object or a refined piece of information.

- **Input** is the raw data from the M2M device that will be turned in to a piece of information

- **Production/manufacturing phase** in M2M or Industrial Internet is the part when the M2M data becomes a part of the value chain. M2M data is tagged and the origin of the data is verified.

- **Processing** is when the product is refined. M2M data is aggregated with multiple data sources to create information that can be used in decision making. The result after this phase is an information component (Höller, J. et al 2013).

- **Packaging** refers to the part where data is combined with other data sources from the producer's databases. The purpose is to produce an "information product" which is recognizable to customers and can be visualized through various methods.

- **Distribution/marketing** is where the information product is distributed to the customers. The purpose of the information product is enable creation of knowledge within a company such as an improved product design or manufacturing process.

The information product of a M2M system is usually internal to the system and to the company which owns the system. The purpose of Industrial Internet is to improve them even further and therefore the next logical step would be to open the systems also to third parties such as sub-contractors and customers. In this scenario the sub-contractors and customers have access to the information products, which will require new of compensation methods. This is the essence of the increased horizontal integration that is mentioned in many sources. The key points of Industrial Internet value chain are repeated below:

- Industrial Internet information value chain is based on the M2M information value chain

- Industrial Internet information value chain will increase horizontal integration. It will allow access for third parties to the systems of the main contractor. For example sub-contractors can have access to the measurement data and customers will be able to purchase the "information products".

- The Industrial Internet value chain will be enabled by open application programming interfaces (APIs) and other Internet based technologies.

The discussion about Industrial Internet and IoT is often combined with new business models. It is believed that Industrial Internet and IoT will enable new kinds of business models, for example the so called "product as a service" (PaaS). In this model the product or more precisely, the production of the product, is the service that is offered to the customer. An extreme example of this could be a manufacturing system. Typically, when company A wants to produce a product, they either buy a manufacturing system and build a factory around it or combine the products of multiple factories to produce the final product. Either way the manufacturing equipment is typically bought from another company called B. In the PaaS model, company A does not buy the manufacturing equipment from B and instead A buys the result which in this case could be "production at 98% capacity". The manufacturing equipment is still owned by company B. This kind of model seems similar to traditional outsourcing but in this case the point is basically outsourcing equipment instead of labor.

PaaS model is also well suited for IoT and can easily be applied to consumer markets for example selling light as a service instead of selling lamps (Ailisto. et al. 2015). An interesting example of this is Brad the Toaster which was an experimental "addicted product". The purpose of was to bring interaction to small kitchen appliances which usually are just passive devices. Instead of being just a passive toaster, Brad the Toaster is a device that starts to behave in various ways depending on how much they are used. They make noises or can even Tweet comments on how they are used. The designer also made it so that different toaster units would have their own personality in a way: some would become "sad" when they are not used. Additionally, the toaster could not be owned, only hosted which meant if the toaster was too sad, a courier would come to take it away. The project was only a concept and the drawback was that it did not have any business model. Still, it brought interesting insights about ownership of products and the concept of using product as a service. Additionally the project showed interesting insights about the value people give to devices such as kitchen appliances. For example some people became attached to their toaster in a way and organized toasting parties to prevent the toaster becoming too unused. The activity in the project has ceased but the information can still be found about the idea in the Internet address http://www.addictedproducts.com (Rebaudengo Simone 2016).

2.2 Public development efforts and architecture

Industrial Internet and IoT are a growing research interest across the world with many countries, corporations and instances having their own research projects and platforms. Some of these are actual research projects that try to define basic functionalities of Industrial Internet while others appear more as collaboration platforms. Industrial Internet is also a research effort in Finland. Innovation funding agency Tekes has an Industrial Internet program and Aalto University opened The Aalto University Industrial Internet Campus in August 2015. The purpose of the campus is to serve as the research and education center of Industrial Internet in Finland. It will serve as an interdisciplinary meeting hub where researchers and students from any discipline, for example: mechanical, automation, computer & networking, construction and IT, can prototype and experiment. Additionally, the campus is meant to attract partners from various industries. The largest international Industrial Internet research groups are in Europe and USA.

- The Internet Protocol for Smart Objects Alliance (IPSO)
- AllSeen Alliance
- Platform Industrie 4.0 in Germany which is Industry 4.0 related program
- Industrial Internet Consortium in USA
- Dialogplattform Industrie 4.0 which is another Industry 4.0 related program in Germany

Industrial Internet Consortium and Platform Industrie 4.0 seem to be the largest groups.

Currently, Industrial Internet or IoT do not have a common all-encompassing standard that would offer a comprehensive definition of the structure and architecture of devices and/or systems (Höller, J. et al. 2014). Instead, there are multiple research groups each trying to define the basic architectural background. It has to be noted that these research efforts target mainly the IoT but since Industrial Internet will be based on key concepts of IoT, it is worthwhile to note them here.

Architetural background:

- European 7th Framework research projet: SENSEI 2013
- IoT-A: Architectural reference model
- ETSI M2M TC 2013

The common objective among these is a horizontal system approach. They have a clear separation of communication technologies from the devices that provide sensing and actuation capabilities. Additionally, they want to create uniform interfaces towards the devices that provide the sensing and actuation. Finally, they want to separate application specific logic from logic that is common across large set of applications (Höller, J. et al. 2014). This is to allow reuse of technology as much as possible. In addition to the architectural background, there are also detailed requirements for IoT:

- ETSI TS 102 689 (2013)
- IoT-A UNI (2013)

Theory about the architecture:

- Rozanski & Woods 2011 (Höller, J. et al. 2014)

The SENSEI, IoT-A and ETSI programs provide a set of design principles (Höller, J. et al. 2014):

- **Reusability of resources**. Resources typically refer to the Industrial Internet devices. M2M solutions are usually point solutions that are made for a specific application for a specific customer. Industrial Internet systems in contrast, are generic solutions and their components should be able to be applied in many situations. Therefore the devices are application independent and their functionality and services they provide are produced in a uniform way to allow reuse. There should be uniform interfaces towards the devices and functionalities should be uncoupled and abstracted from the devices that provide the functionalities (Höller, J. et al 2014).
- **Support services**. In addition to the resources, there has to be a set of support services that provide access management, allow finding and publishing the resources, provide tools for information modeling and offer information related to the real world entities that are of interest. Additionally, they offer capabilities for complex services.
- **Abstraction levels**. Industrial Internet systems will have a large number of heterogeneous devices. Therefore there is a need for different abstraction levels that hide the complexities of the system. This will ease the integration and application

of the technologies when system integrators will not have to understand underlying devices technology.

- **Support for multiple business environments**. Industrial Internet applications will be deployed in different business environments. They can run across departments within a company, between a set of companies or be completely open. Therefore there has to be various security mechanisms such as identity management, authorization and access control. The purpose of Industrial Internet systems is to transfer information and there needs to be mechanisms to provide accountability. Furthermore, there needs to be capabilities for new business models such as PaaS.
- **Security**. Industrial Internet environments have to take measures to ensure reliability of the system and integrity of information. The data must be accurate, traceable and cannot be manipulated afterwards. Ensuring privacy is also important as individuals must not be able to be identified from the data.
- **Scalability**. Industrial Internet systems can potentially consist of millions of devices which all provide monitoring data. The data will have different characteristics: it can be infrequent or continuous. Systems must be able to support extremely high amount of inputs. Furthermore, systems must provide sufficient performance for example Supervisory Control and Data Acquisition systems (SCADA).
- **Compatibility**. Industrial equipment can have long expected operational times and this is true also for Industrial Internet devices. Therefore the devices have to be able to support a large number of current and future protocols. The use of old so called “legacy devices“ must be supported by some method, such as the use of specialized gateways.
- **Simplicity of management**. A large number of connected devices in Industrial Internet systems will bring challenges to system administration. Therefore Industrial Internet compatible devices should have features to simplify management. Auto-configuration and –provisioning will ease Industrial Internet deployments (Höller, J. et al 2014).
- **Support for new service delivery models**. Most industries have moving from a product offering to a combined product and software offering and software as a service (SaaS) (Höller, J. et al 2014). Industrial Internet solutions should be able to support new kinds of delivery models.

These design principles allow the creation of an architectural outline for Industrial Internet (Höller, J. et al. 2014). This outline shares common elements with the M2M architectural outline in chapter 2.1.

- **Asset** is the real-world object or entity that is to be monitored and/or controlled and it has a digital representation and identity in the network. Assets can be physical such as machines, infrastructure or utilities (water, electricity etc.) but also virtual such as driving routes of delivery vehicles or traffic intensity etc. Assets themselves do not provide any functionality in the Industrial Internet system.
- **Resource layer** is the layer that makes the assets part of the network. Embedded technology in the assets serves as the link between physical and digital worlds. Resource layer offers the monitoring and controlling capabilities and the digital identity of the device. This is also the layer where different types of gateways are placed. Gateways provide communication functions but can also provide data aggregation or other functions that are closely related to basic resources. Important part of resource layer is identification of assets which can be done in various ways such as RFID (Höller, J. et al 2014).
- **Communication layer** offers connection between resources and servers that host service support logic (Höller, J. et al 2014). The communication can be based on different network configurations which are usually divided to local area and wide area network (LAN and WAN). LANs are usually networks that consist of a single room or house and WANs are network that comprise regions, countries or the world. There is no clear definition about what is LAN but in the Industrial Internet/IoT scene, examples can include home or building area network in home/building automation systems, and neighborhood area networks in smart grids. Wireless LAN technologies include for example the IEEE 802.11 standard, the specifications based on the IEEE 802.15.4 standard (Zigbee and Z-Wave), Bluetooth and its addition: Bluetooth Low Energy that targets IoT applications.
- **Service support layer** are services that typically run on server farms or cloud environments. They are support services that perform routine tasks which are common to all applications, typically communication and resource related tasks. They provide uniform handling of devices and networks and are used to hide the complexities of resource and communication layer (Höller, J. et al. 2014). Examples could include, remote management functions such as remote updates, remote diagnostics and recovery and configuration. Communication functions could include for example communication channel selection. Additionally, location based services and geography information system services can be important for Industrial Internet applications. Finally service support layer could offer directory capabilities and offer information about the available resources and how to access them. These could be used, for example, to get information of devices using RFID tags.
- **Data and information layer** offers functions for knowledge management and advanced control logic support. It contains the data and information models of the system with the focus on organization of information. The purpose of this layer is to form knowledge from the input data that can range from raw sensor data to domain specific expert knowledge.

- **Application layer** is the core of the Industrial Internet system and the reason why the system exists. It is similar to the M2M application layer as it describes the process accurately. It offers the specific Industrial Internet applications for example smart monitoring in the smart grid, vehicle tracking, building automation or participatory sensing.
- **Business layer** is the final layer of Industrial Internet architecture whose function is to support the core business of the stakeholder that uses the Industrial Internet application. This is where the Industrial Internet application is integrated to the business process and system of the stakeholder. The business system can be for example, an enterprise resource planning (ERP) system. The business layer also provides interfaces and APIs for third party access to the data.

2.3 Future prospects

In this chapter I discuss the vision about Industrial Internet. I already gave a definition for Industrial Internet in chapter 2.1 which includes implementation of Internet technologies to industrial equipment and systems. This technological perspective is often mixed with future visions. Most of the technological ingredients are already in existence but they are used mainly in consumer industry (Drath & Horch 2014). Therefore one of the aims of Industrial Internet is to use existing technology in a new way, rather than inventing totally new technology.

Industrial Internet is expected to bring improvements on certain areas:

- Industrial Internet is expected to boost modularity, cloud services and embedded technology. The amount of software in products is expected to increase which will allow more flexible and customized products and configurations. Device manufacturers have combined product and software offerings which include online portals that allow better collaboration between different stakeholders. (Rüsmann et al 2015)
- Currently there are some challenges when connecting field devices to an enterprise resource planning system (ERP). In a perfect Industrial Internet environment, this connection will be cloud based. This will allow easier acquisition of real-time data from the field devices and better access for analysis and process historian software to manipulate the data. (Michel 2014)
- Industrial Internet will produce new or improved ways to use and share data. For example, car manufacturing industry uses RFID-tags to track the status of the products on the production line. The next step would be to use RFID-tags also in the manufacturing devices and tools to optimize the process itself. A simple example, a torque wrench could recognize the assembly that is currently at the spot and adjust itself accordingly. Additionally, they could trigger the correct work instructions to be visible in the proximity. (Michel 2014)
- Developers can also find new ways to use data by sharing it in a cloud environment. One of the methods will be finding and combining data from two different sources, devices or systems that do not have an obvious correlation (Michel 2014).

Hypotheses

Drath and Horch present hypotheses that are related to Industrial Internet (Drath & Horch 2014)

- The amount of communication infrastructure will increase in production systems and IT will become a self-evident part of production equipment. This trend is already happening and is similar to the spread of the mobile phone. This development will be useful in many purposes such as engineering, configuration, services, diagnostics, production and maintenance.
- Field devices, plants and whole factories will be connected to a network. They will have a digital representation as data objects that can store real-time data and take other actions. They become searchable, explorable and analyzable in the network (Drath & Horch 2014). This leads to a surge in the amount of data objects in the network.
- Field devices, plants and factories will be able to store information about themselves outside of their physical body in the network. For this, they will obtain individual digital identifiers. They can store for example documents, 3D models, simulation models etc. In addition to the data, the devices will have functionalities on the network which augment the physical device. (Drath & Horch 2014)

Industrial Advancement

Rüsmann et al present several milestones of industrial advancement (Rüsmann et al 2015). Some of the milestones do not belong to Industrial Internet but still they are closely related to it or other phenomena around Industrial Internet.

- **Big data and analytics**. Big data refers to the study of extremely large data sets. In an Industrial Internet environment these data sets include measurement data from devices and production equipment, enterprise software data and other data sources such as customer management systems. Additionally, external open data sets such as public weather data can be combined with internal data sets. Big data methods include for example descriptive and predictive analysis and clustering and anomaly detection. The purpose is to study and compare the data sets to acquire deeper understanding of assets industrial processes. For example semiconductor manufacturer Infineon Technologies correlated test data from the final testing phase of a production line to process data from an earlier phase. Using this method they were able to identify faulty chips and decrease the amount of product failures. As Industrial Internet systems come more common, this kind of optimization will spread to every phase of a process. (Rüsmann et al 2015)
- **Simulation**. Currently 3D simulation is used mainly in engineering phase, for example for designing products, materials and even production processes (Rüsmann et al 2015). In the future, 3D simulation will be used also to simulate plant operation in a more extensive way. This will lead to increased knowledge about products life cycle and plant processes. For example, operators can test and optimize machine settings for next product line in a virtual environment while the current product line is still in manufacturing (Rüsmann et al 2015)**.** For example,

Siemens and a German machine-tool vendor developed a virtual environment where they can simulate machining of parts based on data from real machine tools (Rüsmann et al 2015).

- **Horizontal and vertical integration**. Industrial Internet will bring further integration on several fields. First is enterprise level which refers to deeper collaboration on the IT-level. Currently companies are usually not connected on the IT-level and collaboration can also be difficult even between departments of the same company. For example, in many cases various enterprise functions and their systems such as engineering, production and maintenance are not fully integrated. Data sharing mainly goes through the ERP system which is rigid. Industrial Internet is expected to improve this for example through cloud based collaboration portals (Rüsmann et al 2015). The purpose is to ease communication and data sharing between various stakeholders so that all activities do not have to go through the ERP.

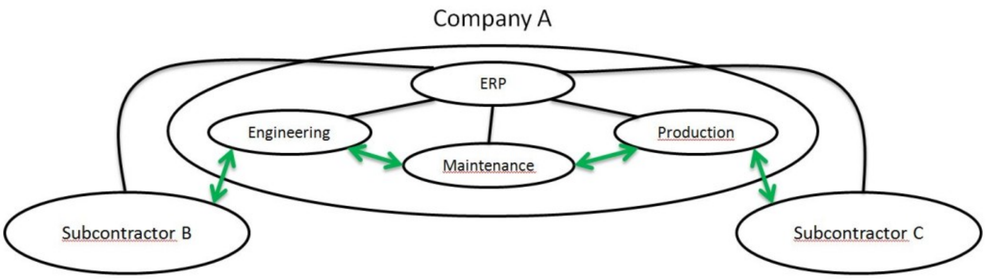

Figure 1: Example of current status of Enterprise level integration

For example, Dassault Systémes and BoostAeroSpace launched a collaboration platform called AirDesign. It is a cloud based service that serves as a common workspace for design and manufacturing functions. Purpose of the platform is to exchange product and production data between multiple stakeholders. (Rüsmann et al 2015) Second area where there is increase in horizontal integration is industrial IT systems such as automation and field devices. Currently the command structure of industrial IT-systems can be described with a vertical pyramid where field devices form the lowest level. The next level consists of controlling devices such as PLCs followed by data acquisition, information and data analysis levels. On top of the pyramid is the enterprise resource planning system (ERP). Figure 2 presents the idea in practice.

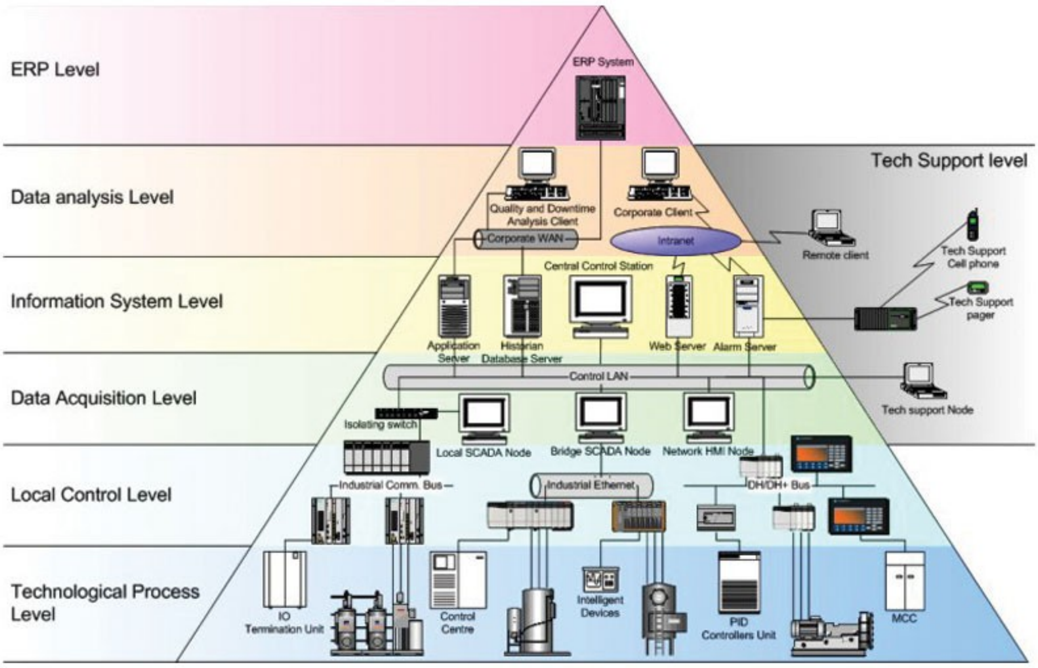

Figure 2: Automation pyramid shows the different levels of traditional automation system (Kraken Automation 2016)

Traditionally data flow is bottom-up from the lowest level to the ERP. Command flow is top down from the ERP to the field devices. Industrial Internet will change the nature of the systems as devices will be able to communicate horizontally within a single level. This improves flexibility and real-time behavior of the systems as inputs that trigger an action do not have to always move through the vertical chain. The idea is presented in figure 3.

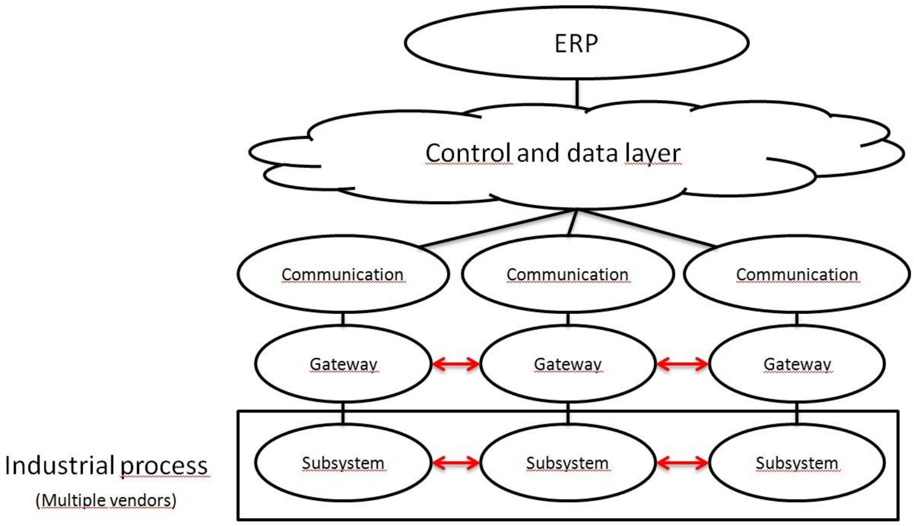

Figure 3: Topology of a typical industrial system

This is basically a form of edge computing which is a relevant concept. Edge computing is a concept where computing power, data and services are moved to the logical extremes of a network or system. In practice it means that computing and processing are distributed across multiple devices instead of a central unit.

- **Cyber security**. Currently most companies rely on closed production systems for security purposes. Process controlling equipment can be connected to a plant network and the company's intranet but not usually to the Internet. Industrial Internet systems will bring increased connectivity and use of standard communication protocols. In the future, many systems will require active connection to various stakeholders and therefore companies cannot rely on closed systems for security. This calls for increased security features, reliable communication and advanced authentication and access management for humans and machines.

- **The Cloud**. Cloud computing and cloud based solution are currently used for some enterprise and analytics applications (Rüsmann et al 2015). Industrial Internet systems will require data sharing between sites of a company and over the company borders. Cloud technology is the most potential technology in allowing this. Additionally, cloud technologies will evolve to achieve fast response times. At some point they will be fast enough to allow machine data and services to be stored in the cloud. This will enable more data-driven services for production systems (Rüsmann et al 2015). In the end, even process monitoring and controlling applications may become cloud based. Vendors of manufacturing-execution systems are among the companies that have started to offer cloud-based solutions (Rüsmann et al 2015).

2.4 Example cases

In this chapter I will present examples and use cases of Industrial Internet found in literature.

2.4.1 Asset management

Asset management is one of the most important applications of Industrial Internet. Asset management can refer to for instance the management, configuration and maintenance of machinery and devices of an industrial enterprise. Furthermore asset management can also refer to management of buildings, vehicles and utilities etc. or they can be more abstract like financial assets. The challenges of managing assets such as industrial devices, are increasing complexity as number of assets can be extremely large, interoperability between assets, security and QoS-ensured communication (Höller, J et al 2014).

Luckily there are actual cases of Industrial Internet asset management for example, Dematic produces automated material handling systems launched a remote service system called Alert Monitoring Service (AMS) which provides remote monitoring and diagnostics services. The system can be used to alert Dematic technicians of errors and also allows remote access and troubleshooting it with the customer. Dematic is working towards combining the AMS with its cloud based maintenance software. (Michel 2014)

Additionally, The Raymond Corporation offers an IWarehouse solution which is meant for lift truck fleet and warehouse optimization. The IWarehouse can be used to see how the lift trucks are used exactly, for example to inspect usage patterns, under used lift trucks and collisions. The purpose of the system is to generate fleet information about the lift trucks, to view this information and to suggest ways to optimize the lift truck fleet and the warehouse (Michel 2014). The information is generated based on data from onboard computers on the lift trucks. The system can be integrated to other systems such as labor management portals where information of the operators and their travel patterns can be used to provide additional knowledge.

Furthermore, the IWarehouse is used extensively in handling problems such as collisions and part failures. The system keeps track of collisions including the time, location and operator and this information can be compared to the operational data of the warehouse to pin point possible problem areas. For example, a customer using IWarehouse found that a group of collisions were because of an improper arrangement of unloaded goods (Michel 2014). The system also sends information to the Raymond Corporation for engineering purposes. The Raymond Corporation uses data from the IWarehouse system to investigate part failures and other technical issues which could be used for design improvements. For example, pinpoint problems that arise when the lift trucks are used in cold storage (Michel 2014). The IWarehouse demonstrates the data sharing capabilities of Industrial Internet systems. The system uses multiple data sources that are combined to create knowledge about the warehouse and lift trucks. The system also allows using data beyond the original purpose. Traditional systems use data only for a single narrow purpose but instead, data could and should be exposed to a variety of applications.

E-mainetance

An important part of asset management is maintenance of assets. The concept of E-maintenance was proposed as early as 2000 but with the rise of Industrial Internet the term is becoming relevant again. The E in E-maintenance stands for “excellent”, “effective”, “efficient” or “enterprise” maintenance (Muller, A et al 2008). E-maintenance can be thought as a maintenance strategy, maintenance plan or maintenance type. The key strategies for E-maintenance consist of remote, predictive, real-time and collaborative maintenance (Muller, A et al 2008, Höller, J. et al 2014). As a maintenance strategy E-maintenance is basically a maintenance management process. I use the word to describe “Industrial Internet maintenance”.

It is expected that E-maintenance will manifest as an electronic collaboration portal or platform where maintenance requests are generated based on real-time data acquired using digital technologies, such as remote monitoring, mobile devices and Internet technologies (Muller, A. et al 2008, Höller, J. et al 2014). Introducing E-maintenance as an IT-platform would require that the system is scalable and flexible which would suggest event-driven approach and Service-Oriented-Architecture (SOA) instead of traditional information pull (Höller, J et al 2014). Event driven approach will allow precise response to notifications in the systems and also minimize the network traffic which improves performance. The maintenance platform should also host open APIs which would allow further app-creation.

In the essence, E-maintenance is a network to manage, provide and synchronize asset information in the right place at the right time. E-maintenance can also be thought as a maintenance plan which combines condition monitoring and predictive, remote and collaborative maintenance activities. Third way to describe E-maintenance is as a maintenance type. This includes mainly transfer from traditional maintenance types to predictive/proactive maintenance (Muller, A. et al 2008). Additionally, instead of periodical predictive maintenance, E-maintenance should bring intelligent assessment of maintenance needs for example through a system that offers monitoring and predictions of equipments status.

E-maintenance improves maintenance activities in various ways:

- **Remote maintenance** can enable access to the devices from anywhere in the world, which means that system administrators and technicians do not need to be located physically at the site. Activities such as configuration, diagnosis and analysis can be done remotely. Remote maintenance services also allow communication with a remote maintenance centers which can offer the best possible knowledge. Additionally, web-based maintenance management systems could allow software maintenance even without the users' knowledge.

- **Collaborative maintenance** is an improvement of cooperative maintenance and the purpose is to bring additional coordination and synchronization to the maintenance management. Collaboration IT-platforms and information infrastructure bring communication between geographically distant locations and improves coordination between people, departments and subcontractors (Muller, A. et al 2008). Collaborative maintenance will reduce maintenance stops and improve the lead-time of maintenance projects as it brings two-directional information flow to decision making and planning. This was presented in figure 2.

- **Real-time maintenance** is the response to current failures on the shop floor. E-maintenance will improve monitoring functions to provide the best real-time status of the equipment. This information combined with programmable alerts allows faster responses to problems. Furthermore, improved communication methods allow rapid acquirement of external expertise. The purpose is to decrease the time it takes to detect, diagnose and repair an error. Real-time knowledge of the devices status is crucial as better information brings improved maintenance decisions. Decision making can use knowledge like use history, status, expected usage and equipment dependencies.

- **Predictive maintenance** is one of the most important aspects of any maintenance effort and it relies on predictions of products condition under certain conditions. I expect to see an improvement on this as E-maintenance/Industrial Internet increase the amount of measurements in products/processes and introduce databases that store extensive information about a devices history. Predictive maintenance could also benefit from a maintenance platform that would trigger notifications about the predicted maintenance requests and alerts before immediate breakdowns. Product information databases bring the possibility to compare the products performance in a global monitoring system. This allows the transition from fault detection and diagnosis to monitoring and prognostics (Muller, A. et al 2008)

The E-maintenance can bring improvements to maintenance efforts in many ways but there are challenges that need to be solved before it can be truly successful (Muller ,A. et al 2008).

- **Remote maintenance** is mostly constrained by the security and reliability of the remote connections. There has to be a balance between security and ease of use as increasing one decreases the other. Additional challenge is the amount of information that the systems will generate as the users have to be able to digest all the information. Therefore the information must be generated, transferred and used in a uniform way.

- **Collaborative maintenance** needs a platform for the collaboration. The aim is to bring many stakeholders together which brings integration challenges: for example data transformation mechanisms, design of communication, communication protocols and safety. The maintenance platform should also have integration to enterprise systems to allow the formation of key figures about maintenance. This allows better decision making and resource allocation towards maintenance on a daily basis and strategically.

- **Distributed maintenance**. To make E-maintenance successful it needs a distributed decision making and optimization system (Muller, A et al 2008). This is because of the system will have a large amount of data and therefore some of the processing should be distributed to a lower level.

- **Predictive maintenance** relies heavily on the development of the actual predictive methods, models and algorithms. These are not necessarily directly related to Industrial Internet but Industrial Internet will provide the foundation through real-time measurements and product history databases.

- **Maintenance documentation / recording function** needs to be accounted in the maintenance platform. Documentation needs a database to save information about degration models, frequencies, sections etc. This database has to be easy to use and allow multi-task and –user operation. It has to have methods of sharing the data for example with government officials.

E-maintenance consists of management and maintaining of assets. The number of assets is growing continuously and the systems need to have ways to handle the complexity. The systems should have knowledge of their “surrounding context” and be able to recognize the attached devices. Surrounding context could mean things like location and information on the process they monitor or control (Höller, J et al 2014). Decreasing the complexity of systems would also call for dynamic device discovery where assets could be connected to the system and they would be automatically recognized and configured according to certain instructions.

Hazardous goods

Decker, C. et al presented a case experiment of M2M of safe handling and storing hazardous materials (Decker, C. et al 2007. Höller, J. et al 2014). The purpose was to test the use of wireless sensor networks in handling of highly flammable or explosive materials. The purpose of the system was to execute storage regulations in two different locations with multiple storage positions (Decker et al 2007). The materials could form safety hazards if there was too much of certain material in one location or certain materials were stored too close to each other. The goal was to generate a system that could execute business logic with field devices and minimize vertical communication between devices and backend systems such as a business application which was basically a form of ERP system.

Each storage drum was equipped with a device that has information about the contents of the drum and can monitor the surroundings and discuss with other drums in the proximity. Furthermore each drum had a local list of incompatible chemicals and rules about the maximum amount of chemicals in a location. The devices on the storage drums can communicate with each other to compare the materials in each drum. There was also a gateway to provide connection from the devices to the ERP. The system notices if incompatible materials are stored in an incorrect manner. The system then makes a local alarm to notify the personnel about the situation and notifies the ERP. (Decker, C et al 2007)

The point of the system was in the M2M-communication of the storage drums. Part of the system intelligence was distributed into the field devices which resembles edge computing. They could the execute business logic which in this case were the system events and notifications. The notifications and alarms were generated locally by the storage drums and they did not have to go through the enterprise system to generate a response. This decreased the response times and network requirements significantly. The system also featured multi-direction communication as the drums were able to send and receive information to/from the ERP, such as status of the storage and updates to the incompatibility list (Höller, J et al 2014).

2.4.2 Industrial automation

Here I will discuss the connection of Industrial Internet and industrial automation.

Service oriented architecture

An emerging trend in industrial environments is to distribute system intelligence to different levels while traditional systems rely on one large application/system/device to provide the system intelligence. Currently systems there is a shift from a one large application to a more distributed one where system intelligence is provided by a large number of smaller intelligent devices. Devices on different architectural level will provide different capabilities. This term is also known as edge computing where the system intelligence is pushed to the logical extremes of the system or network. I gave an example of architecture for Industrial Internet in chapter 2.2 which fits to this concept.

Distributing intelligence to lower levels of a system requires that the capabilities of the devices are available and accessible in some way. One solution for this is the so called Service-Oriented-Architecture (SOA). It is a type of architecture in computer software design where the different functionalities and components of the software are published as services using communication protocols (Jammes & Smit 2005).

The purpose of SOA is to make the software independent of the vendor, application and technology. It is a way to hide the implementation of the software and present only the capabilities as services. This kind of architecture could also be implemented to industrial devices. For example an industrial valve could have services called “close valve” and “open valve”. The service could be published in a network and when the valve needs to be activated, a controlling application can call the close/open services to manipulate the valve. The benefit of this is that the system does not need knowledge, how the devices function internally.

Unfortunately, this development is yet to be fully realized as many industrial systems rely on traditional architectures (Höller, J et al. 2014). Additionally, the expected life times of industrial equipment are quite long. This means that while implementation of industrial equipment devices and systems is advancing, many systems still have and will have older devices that are incompatible with Industrial Internet. They will then require specialized equipment to handle the communication between these “legacy devices” and present their functionalities as services.

This can be achieved with two types of devices:

- **Industrial Internet gateway**. Gateway in general is a device that allows a device using protocol A to communicate with device using protocol B. Industrial Internet gateway would be more advanced: it would have the same protocol functions and could also present the legacy devices as services in a system or network. The services that the gateway publishes are linked to the capabilities of the legacy device. The need of gateways decreases as more devices will be able to host their own services.

- **Service mediator** provides similar functionalities as gateways but they also can manipulate the data that the devices produce before it is deployed as a service. They can aggregate, manage and present the service based on some semantics

(Höller, J et al 2014). For example service mediator could form a compound service that consists of multiple physical devices.

Both of these solutions will help when the amount of devices in a system is very large. They could also enable dynamic device discovery (Höller J, et al 2014).

Socrades Integration Architecture

Socrades Integration Architecture (SIA) is a SOA based example of multi-level M2M communication between devices of different hierarchy levels and an ERP. SIA model uses gateways and service mediators which are called Local Discovery Units. There are several proof of concept examples of SIA integration between different devices (Karnouskos et al 2010):

- Integration between a PLC, a robotic gripper and SunSPOT wireless sensor nodes. The devices were monitored by SAP Manufacturing Integration and Intelligence software (SAP MII)
- Example of event based interaction between heterogeneous devices. The system features a RFID reader, robotic arm, a wireless sensor which monitors the movement of the robotic arm, the use of an emergency button and an IP-switch controlled lamp. Additionally there is a monitoring system. The devices perform actions based on events.
- A test bed that simulates a manufacturing cell or a machine tool and the use of a Industrial Internet gateway. The system consists of a PLC and pneumatic hardware execute operations such as picking, placing, moving, drilling, proximity checking and stacking (Karnouskos et al 2010). The PLC was connected to a gateway (or mediator as it is described in Karnouskos et al 2010) that monitors the data in the PLC through OPC and exposes functions of the PLC as web services. The main point is that SAP MII was used in production planning, execution and monitoring of the test bed.

IMC-AESOP 2013

IMC-AESOP is a envisioned next step from SIA. It takes the idea of M2M communication further and introduces the cloud component. Instead of machines communicating with other machines, IMC-AESOP starts with the assumption that devices are connected to a cloud environment. This is to harness the benefits of cloud services, mainly flexibility and scalability (Höller, J. et al 2014). In this vision, all systems, components and devices expose their capabilities, functionalities and structural characteristics as services in the "service cloud". This kind of system would be highly scalable and link devices from all levels to monitoring systems and would perform SCADA, DCS etc. functions. This is a game changer in industrial automation systems which are traditionally vertical chains. In contrast, the IMC-AESOP vision is meant to be a dynamic flat, information-based architecture (Colombo & Karnouskos 2011).

2.4.3 Commercial building automation

Building automation system (BAS) is an intelligent system for controlling and monitoring heating, ventilation, lighting, security and electrical and mechanical systems in a building. The aim is usually to reduce energy and maintenance costs and improve the use experience of the whole building (Höller, J. et al 2014). I will discuss examples of a current and future commercial building automation system from a technological and value chain point of view.

Case 1: building automation today phase I.

Company A wants to improve energy efficiency in a building and they order a building automation system from Company B. They agree on a step-wise plan for the BAS which includes increasing monitoring of water use, electricity, heating and the performance of ventilation and room temperatures. The monitoring allows optimization of existing systems. Further improvements are made by installing new software such as building control software which is based on SCADA.

The new control system hosts a web portal where anyone can log in and inspect and compare the energy costs and other relevant parameters. These can be used to make short and strategical decisions about the operation of the building. All of these efforts succeed in reducing energy costs.

Company A also decided to outsource the maintenance and monitoring of the system to Company B. Therefore communication between companies A and B is important to the success of the system. Problems will generate a system event and send text and email messages to the supervisors and maintenance staff of company A. Notable in this system is that it was made and offered solely by company B. This is the current state in many cases in automation systems in various industry fields. Therefore the value chain of such systems is quite narrow as presented in figure 4 (Höller, J et al 2014).

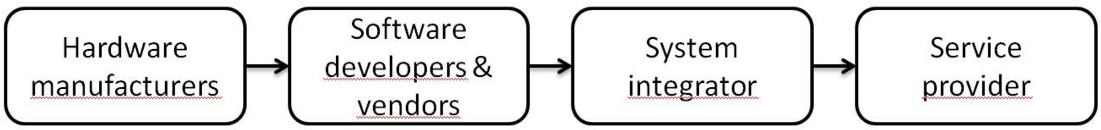

Figure 4: Value chain for building automation system (adapted from Höller, J. et al 2014)

The BAS consists of sensors and meters that monitor the various parameters mentioned earlier. There is also a PLC to control the various devices in the system which communicates with the devices using digital, analog and for example, M-BUS and Z-Wave protocols. The PLC has an interface that can be used to configure, calibrate and control the various devices. The PLC itself is calibrated through a PLC control system. The PLC communicates with an IP-modem through RS-485. The IP-modem uses Ethernet to connect to a 3G modem that connects remotely to an OPC server. This OPC server can be used to access all data, alarms and events in the PLC. Various OPC clients can be used to access the OPC server, which in this example are the PLC control system, a SCADA system for operational monitoring and control and a data analysis server that stores all the data from the PLC. Personal authentication can be used to access the SCADA system and data analysis servers where the user can inspect various parameters, generate graphs based on the data and form cost analyses etc. This is the part for value creation in the system as the stored data can be used to generate information such as improved regulations for water use or control scheme for heating and ventilation. Figure 5 illustrates the BAS.

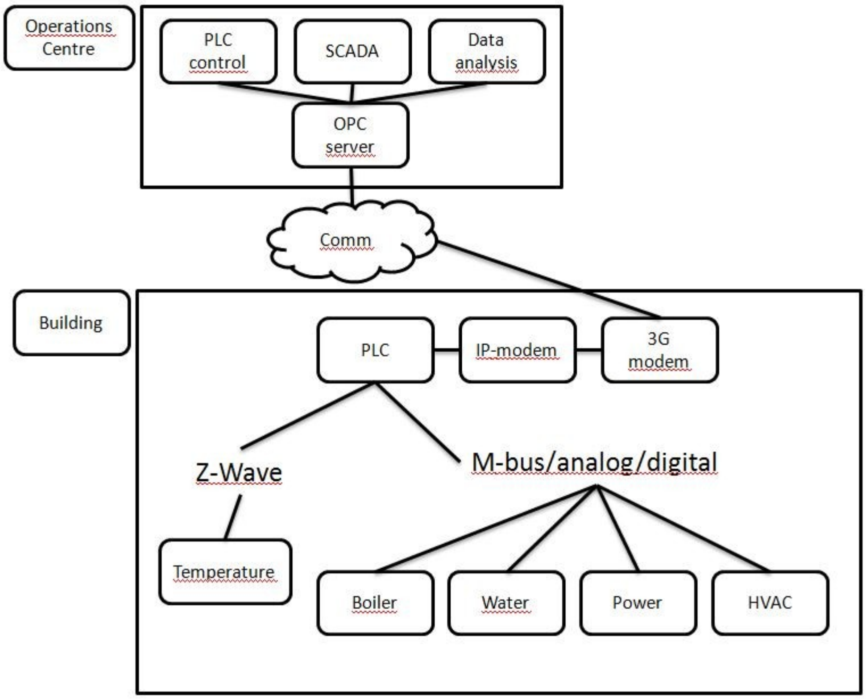

Figure 5: Building automation system phase I consists of local network inside the building and remote operation center (adapted from Höller, J. et al 2014)

Case2: building automation phase II

The second case of building automation presents the same system after a time period when there is a growing need for remodeling of certain parts. Notable about this case is that it is more about the changing value chain in an Industrial Internet environment than the actual system and devices (Höller, J et al 2014). It has been stated many times that Industrial Internet will bring further collaboration between various stakeholders. This is true also in BAS. In this case the increase and distribution of collaboration is the essence.

Phase I BAS was mainly offered by the Company B but phase II will change this significantly. BAS will see a radical change in the form of a new player: the cloud service broker (Höller, J et al 2014). This cloud service broker allows the customer to freely choose the providers of different system components. For example, the customer would be able to buy monitoring, security, optimization, data logging etc. functions from different vendors instead of just one. The purpose of the cloud broker in this case is to act as an interface/platform where any vendor can produce a service.

In our BAS example this could mean that parts of the old system remain while others are upgraded. For example, the cloud service broker would permit new versions of the PLC control and SCADA systems while the other parts remain intact. The cloud service broker also allows data brokering which means organized access to data and capabilities based on access management. This could be used for example allowing certain officials access to relevant building data and new business models such as selling data. The cloud broker platform could also support an API for third party app creation.

This kind of automation system will probably be largely based on IP technology (Höller, J et al 2014). The system calls for energy efficient communication protocols since some of the devices could be battery powered. For example, Höller J et al chose to use CoAP and SenML which are IP based protocols. Their advantages are energy efficiency, support for dynamic device discovery and ability to semantically describe the services that the devices provide. These help to decrease installation costs.

The phase II is an upgrade to the system but older devices are still used in the system. They have to be supported through legacy gateways or service mediators as the described in chapter 2.4.2. Furthermore, the system has a local resource directory to keep track of the devices in the company network. The network in the building is protected by a firewall and the connection to the cloud service broker is established with a virtual private network (VPN) (Höller, J et al 2014). This allows best possible security for the system. Finally, the data that the system generates is stored in a similar way than in the phase I system. Now the cloud service platform offers the data management functions such as control and access management. The main difference is that the data storage and analysis services providers can now be chosen freely as well as the management portals. Additionally, the cloud service platform hosts a global resource directory that possesses the resource, data model description and other information about the system and its resources. The phase II BAS is illustrated in figure 6.

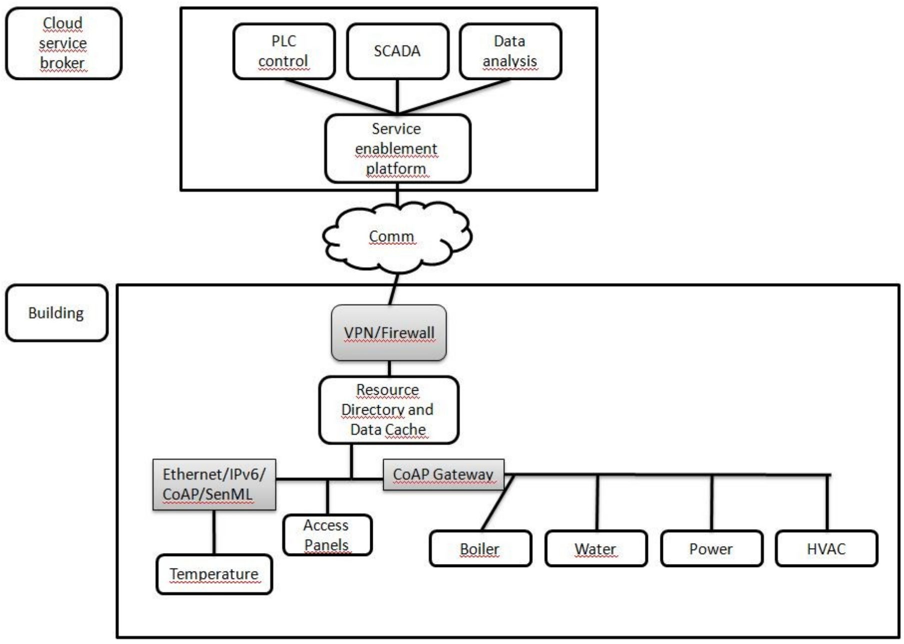

Figure 6: Building automation system phase II consists of local network inside the building and a cloud based platform that contains the monitoring and controlling applications (adapted from Höller, J. et al 2014)

2.5 Requirements and capabilities

The previous use cases introduced various features and characteristics that are relevant to Industrial Internet. In this section I will gather and discuss these under suitable topics. I will also introduce some requirements found in other sources.

From now on, I will call all the features, characteristics and requirements found in this chapter commonly as “requirements”.

2.5.1 The Platform

The E-maintenance and BAS use cases presented Industrial Internet as a cloud based service or system which I will call the platform. Platform is the component on top of which all other features are built. The platform should be cloud based to allow flexibility and scalability. Some features such as remote access could depend on the platform running in the cloud. I use the word “platform” for this feature but in practice it will manifest as a cloud based service or system.

- **Database**. There is a need for a component that can be used to store measurement data. The actual format of the database is left open but there are alternatives such as navigational, relational and object model etc. I think the database will manifest as a separate component of the system under the platform.

- **Resource directory** that stores information of resources such as the devices in the system. The building automation example made use of a resource directory which could also be a part of the database.

- **Data analysis and visualization possibilities**. The measurement data needs to be analyzed so the knowledge the data contains can be harnessed. There is also a need for visualization tools so that the harnessed knowledge can be used for decision making.

- **Event driven architecture (EDA)**. The system should react to changes in its state instead of traditional information pull. Event driven architecture is generally intended for integration of loosely coupled software components and services and it also keeps the strain on the network to the minimum.

- **Open API** for allows third-party app developers create additional content for the Industrial Internet system such as smart phone applications.

- **Controlling application** such as DCS/SCADA. This is an important component if there are devices that need to be controlled. Collaboration platforms, such as the E-maintenance platform, do not necessarily need one.

2.5.2 Devices

The use cases pointed out several features and requirements of the field devices in Industrial Internet. The device features should be aimed in fulfilling the design principles mentioned in chapter 2.2.

- **Dynamic device discovery**. Devices should be discoverable automatically and also should auto-configure themselves to a certain extent. This will ease integration and lower costs which allow scalability and compatibility.

- **Service-Oriented-Architecture (SOA)** is probably one of the most important features in allowing Industrial Internet from the device perspective. There are infinite amount of different devices and there must be a uniform way to interact with them. I think SOA is the key in enabling this as it makes software, and by extension, the devices independent from technology, platform and vendor. It abstracts and decouples the capabilities of the devices from their physical implementation. SOA will therefore allow easier integration and lower costs but more importantly, it will allow the devices to be connected and applied in almost any kind of network. SOA based devices are easily reusable and will be long-lived.

- **Legacy gateways and service mediators**. Industrial systems will inevitably have old devices that are incompatible with Industrial Internet. These devices should be supported through legacy gateways and service mediators that expose the devices as services according to SOA. These "Industrial Internet gateways" can be software based or physical devices. Nevertheless they are tied to the implementation of SOA. The need for legacy gateways declines as more and more devices are able to host their own services.

I am also interested in how big is the "device space" in automation systems. Device space means the number of different possible device types that can be connected to automation systems and to each others. This is related to the vertical control chains of automation systems that were presented in figure 3. Devices in traditional automation systems can mainly connect vertically which makes the device space is limited in our opinion. I think SOA based devices would allow communication also in the horizontal direction.

The main challenge of a larger device space is the managing the complexity which I think could be solved with digital identifiers (Höller, J. et al. 2014). There are already examples of digital identifiers, such as digital object identifier (DOI) for electronic documents, IP-addresses of computer networks and global unique identifiers (GUID). A similar practice could also be extended to Industrial Internet devices. It this concept each devices would have a unique identifier assigned by the manufacturer. This identifier could be used to locate the device in a network and to provide information about it (Höller, J. et al. 2014). This could include the type of device and how to interact with it, for example the standard library functions that can be used to interact with the device.

2.5.3 Monitoring

The use cases did not describe any requirements related to monitoring. Only that Industrial Internet systems and devices must be able to handle large amounts of measurements. This means mainly that the systems should be scalable. Crucial part of Industrial Internet is acquiring process data from a long period of time which will be enabled by the database component. There was also the notion of "surrounding context" of devices (Höller, J. et al. 2014). Devices should be aware of their surrounding context which could mean external conditions like location and information on the process they monitor or control.

Monitoring the surrounding context could yield important information for various purposes for example dynamic device discovery and automatic configuration. The devices could auto-configure themselves to the fit external conditions. External conditions could also be important for monitoring the assets.

Information of the surrounding context will be provided in various ways. For example, the devices can monitor the external conditions themselves such as weather, but information about the assets or the monitored process has to be provided by other sources in the system. Monitoring functions are important for controlling industrial processes and different kinds of events can be used in control applications and process historian software to monitor the process and trigger alarms (Porter & Heppelman 2014).

2.5.4 Security

Security is one of the main concerns of companies interested in investing in Industrial Internet systems (Drath & Horch 2014, Höller, J. et al. 2014, Michel 2014, Rüssmann et al 2015). Especially manufacturing industry has been slow to adapt Industrial Internet solutions because of concerns about security and lack of vision about the benefits. IT-departments in manufacturing companies may have strict rules about opening access from plant networks to cloud based services (Michel 2014). There are workarounds for cases when there is a need for remote monitoring but access through the firewall is not allowed. For example, B & B Electronics have used a wireless cellular router and mobile networks to get access to PLC devices (Michel 2014). While this kind of solution achieves the desired functions, it is not an Industrial Internet solution. A cellular router and mobile network is similar to the capabilities of the PLC in our test bed in chapter three.

- **Access management**. Industrial Internet systems must have components to guard the system from unauthorized use, allow user authentication and organized access to the system and the data. Furthermore, there was a need to give third parties access to data which can include government officials etc. There was also a note that systems should be accessible remotely. This would suggest support for virtual private networks (VPN).
- **Data security** (Drath & Horch 2014, Höller, J. et al. 2014, Michel 2014, Rüssmann et al 2015). There is a need for data authentication as systems and data they produce should be able to be verified and not be manipulated afterwards. Naturally data should only be accessible to authenticated users to protect the owning company’s know-how (Rüssmann et al 2015, Drath & Horch 2014). For example measurement data can contain private information and individuals should not be able to be identified from the data.

2.5.5 Compatibility

The shift to Industrial Internet will be gradual and there will be a considerable amount of time when both traditional and Industrial Internet systems must coexist. Actually, the implementation of Industrial Internet will probably start with upgrades to current systems. Therefore Industrial Internet technology and devices must be compatible and stepwise implementable to current industrial systems (Drath & Horch 2014). Furthermore the Industrial Internet devices should be made application independent and should be able to be used in many applications (Höller, J. et al. 2014).

Compatibility issues can be partly solved by standardization (Rüssmann et al 2015) Growing interconnectivity of machines, products, parts, and humans will require new international standards that define the interaction of these elements (Rüsmann et al 2015). Furthermore, Industrial Internet systems should be scalable to support different kinds business and industrial environments which can include Software-as-a-Service, Product-as-a-Service and using information as sellable products (Höller, J. et al. 2014).

2.5.6 Communication

The network infrastructure must be on a sufficient level before the implementation of any Industrial Internet solution. The main concerns about the infrastructure are speed, safety and reliability. Industrial Internet network has to be fast enough to allow real-time data transfer. For example, production processes cannot be interrupted disturbances and breakdowns. (Drath & Horch 2014, Rüssmann et al 2015)

- **Remote connections**. Industrial Internet systems must have accessible remotely. Remote connections are for variety of reasons such as remote operation, maintenance and diagnosis and data sharing for external parties such as government officials.

- **Edge computing**. The computing power of the system should be distributed so that the field devices are able to implement business logic themselves. This would keep the strain on the network minimum and allow faster response times.

Therefore the field devices have to have extensive communication and interaction possibilities. Devices should work in various environments with heterogeneous devices which will require larger amount of IT in the devices (Rüsmann et al 2015).

3 Case study: Implementation of Industrial Internet to an active magnetic backup bearing testbed

3.1 The AMB test bed

Active magnetic bearings (AMB) are bearings based on magnetic levitation and support loads without physical contact. There are two kinds of magnetic bearings: passive and active. The passive bearings are based on permanent magnets which do not require external power to generate the magnetic field. In contrast, active magnetic bearings are based on electromagnets where the magnetic field is controlled by electrical current. They require constant power and a system to adjust the field.

The main benefit of active magnetic bearings is frictionless support and thus no need for lubrication. Additional benefit is the possibility to include vibration damping with the magnets. These characteristics make them energy efficient and allow a broad range of operating speeds. Active magnetic bearings are also almost maintenance free. Disadvantage is larger size compared to similar rolling bearings, which results in a heavy weight and high cost. Usually magnetic bearings are used in high speed applications such as turbines and compressors.

Active magnetic bearings have backup bearings in case there is a power shortage or the bearing is overloaded. Overload means that the vibration amplitudes become too large for the magnetic field. There is a small clearance between the shaft and the backup bearing and if there is a power shortage during operation, the shaft will fall on the backup bearing. Various parameters such as load condition, the shaft, the clearance and the drop can result in, for example whirling which could produce a fatal breakdown of the backup bearings.

The Aalto University paper machine laboratory has a test bed for drop testing the backup bearings of a simulated AMB system. The test bed was built as a student project for the Mechatronics project –course and the purpose is to research the behavior of the shaft after the drop (Viitala, R. et al 2016). The test bed does not contain actual active magnetic bearings because they are expensive and research was aimed at the drop-phenomena which can be simulated with conventional ball-bearings. The test bed provides us with a physical framework for Industrial Internet. The test bed is the real world “asset” as described in chapter 2.2 that were are controlling and monitoring. Assets themselves do not provide functionality in the Industrial Internet system.

The test bed consists of the shaft, an electrical motor and belt drive system, pneumatic cylinders and controlling valves for dropping the shaft, backup bearings and their housing and sensors for measuring the shaft xy-position. A schematic of the test bed is illustrated in the figure 7.

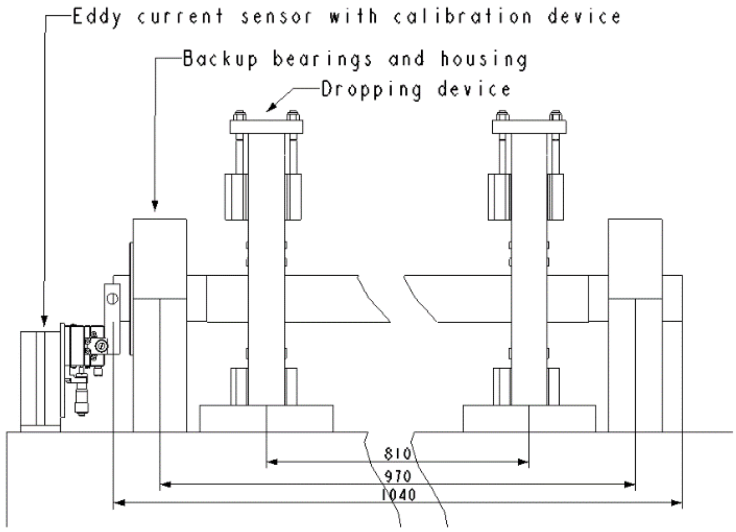

Figure 7: A schematic of the active magnetic bearing test bed (Viitala, R. et al 2016)

The active magnetic bearings are simulated by two drop devices that consist of ball bearings and pneumatic cylinders. The left side dropping device is illustrated in figure 8. The backup bearings have a 0.250 mm clearance around the housing so that the shaft is not touching the backup bearings in normal operation. The belt drive system accelerates the shaft to the desired speed. The gear ratio for the belt drive is around 9.8. The shaft is supported by the two ball bearings and their housing. The housing is supported between two pneumatic cylinders. The pneumatic cylinders are controlled by the programmable logic controller (PLC). The drop event is simulated by releasing the pneumatic cylinders simultaneously. The shaft then drops the 0.250 mm clearance on to the backup bearings.

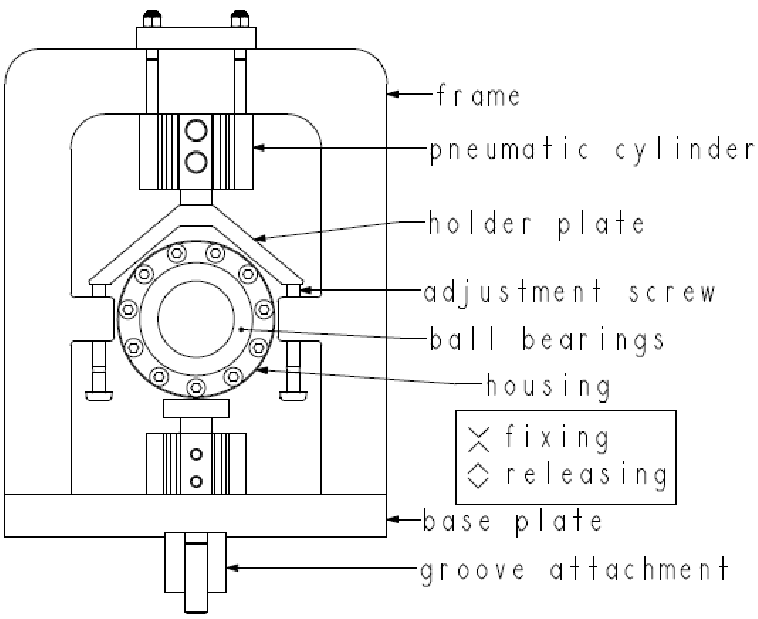

Figure 8: A detailed schematic of the dropping device and main bearing that are simulating an active magnetic bearing (Viitala, R. et al 2016)

The position of the shaft is measured with eddy current sensors (Microepsilon S1 sensors with DT3010-M signal conditioning electronics). The position is measured from the free end of the shaft in the x- and y-directions. The sensors give out a voltage that is comparable to the distance. The benefits of eddy current sensors are contactless measurement, relatively good precision and high measuring speed. Later the plan is to add sensors multiple sensors to allow measurement of mode shapes.

The speed of the shaft was measured with a photoelectric sensor and a piece of reflective tape attached to the shaft. A switch turns the analog speed signal to a digital 0/24V input signal. The test bed was designed to measure so called overcritical speeds of at least 12 000 rpm. Figure 9 present the shaft center points in 15100 rpm and 18900 rpm dropdowns.

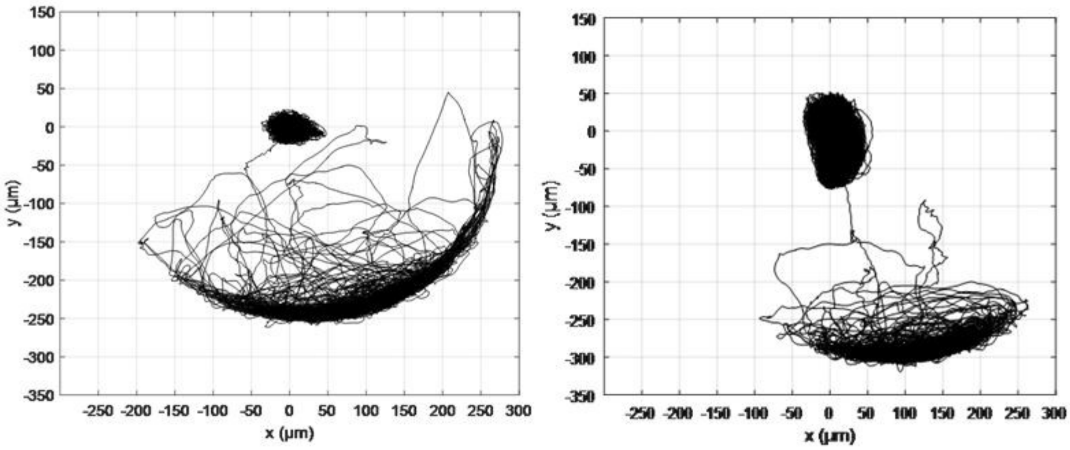

Figure 9: The position of shaft center point in 15100 rpm drop (left) and 18900 rpm drop (right) (Viitala, R. et al 2016)

The test bed is presented in the pictures 10 and 11. The belt drive mechanism, the dropping device and the bearings and backup bearings are visible in the picture. The position sensors are the white wires at the left end and the speed sensor is in front of the electric motor.

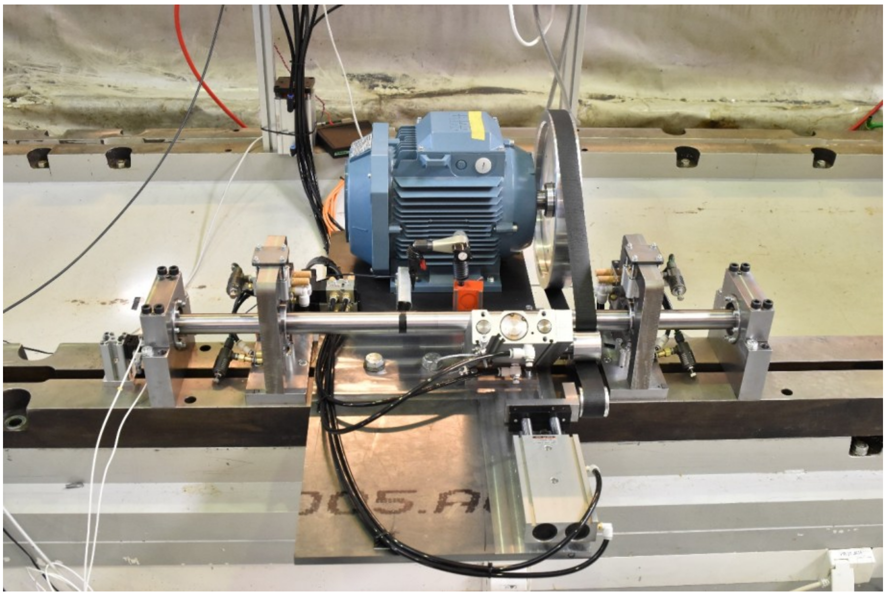

Figure 10: Overview of the test bed. The main components from the left: backup bearings, drop device 1, belt drive system, drop device 2 and backup bearing.

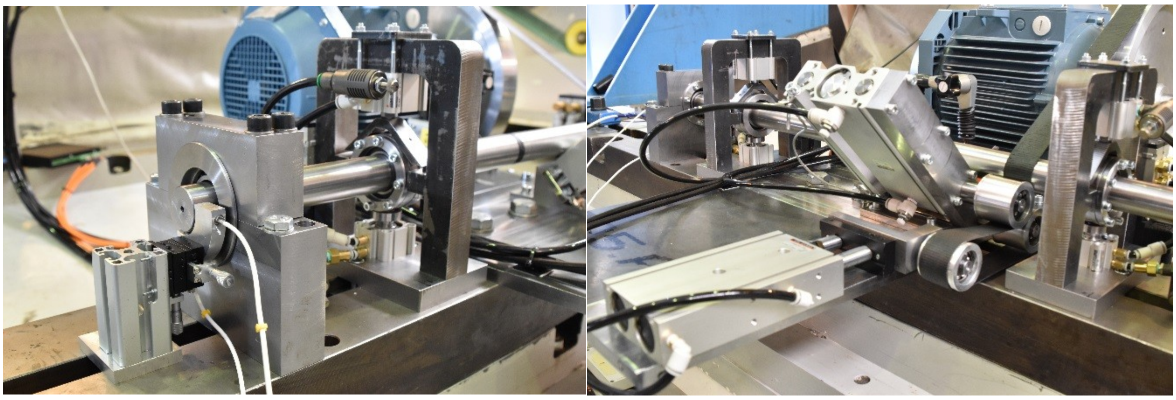

Figure 11: Left picture presents the eddy current sensors, backup bearing and dropping device. Right picture presents the belt drive and pneumatic cylinders that control the belt.

3.2 Automation

3.2.1 Programmable logic controllers

I installed a programmable logic controller (PLC) to control the test bed. PLCs are microprocessor-based, discrete process controllers that use stored instructions in programmable memory to implement logic, sequencing, and math control functions for procedural machine and/or coordinated system control of machines and processes (Kandray 2010, p.385). The purpose of PLC was to replace hardwired systems and provide small reprogrammable devices for industrial control applications.

Current generation PLCs are essentially standardized computer systems designed specifically to interface with industrial components and equipment. PLCs can withstand harsh industrial environments. PLCs are intended for procedural control applications which means that a process is divided into steps that PLC then performs procedurally: step A -> step B -> step C. PLCs can also be used for coordinated system control which is similar but on a higher level: machine A -> machine B -> machine C. Usually PLC control is either event-driven or time-driven. Event-driven means that the device reacts to changes in status and time-driven means that the device performs instructions after fixed amount of time. (Kandray 2010)

A PLC consists of several components:

- Processor
- Memory unit
- Power supply
- Input/output (I/O) module
- Programming device
- Additional modules such as fieldbus modules etc.

A single operation cycle of a PLC consists of three phases called scans:

- Input scan where the PLC reads status of the inputs and stores them in the memory
- Program scan where the PLC takes the input values and performs logic and calculations that were specified in the program
- Output scan where the PLC updates the status of the outputs

The time needed to perform these scans is called scan time.

From an Industrial Internet perspective, PLC devices belong to the resource layer as described in chapter 2.2. The PLC makes the assets part of a network and provides a link between physical and digital worlds. Current generation PLC might not provide all the functionality that is described in chapter 2.2 but in the future they will become more advanced.

3.2.2 ABB automation devices

The equipment provided by ABB includes a PLC device from the ABB high end AC500 -series. The CPU model is PM592-EHT. It has Ethernet connectivity and Ethernet functions include TCP/IP, UDP/IP, Modbus TCP, integrated Web server, IEC60870-5104 remote control protocol, SNTP (simple Network Time Protocol), DHCP, FTP server, HTTP, SMTP, PING. Serial communication includes RS-232/485, Modbus RTU, ASCII and CS31 master. Users can program the CPU locally through the Ethernet and serial communication ports. In addition, there is the FM502-CMS module which is meant for condition monitoring, precise measurement and fast data logging applications. It has analog inputs, digital inputs and outputs, encoder input for a total of 16 samples. The maximum sampling rate of the FM502-CMS module is 50 000 samples per second. (ABB 2015a)

The test belt drive system is actuated by a variable frequency drive (ABB ACS880) and a 7,5 kW induction motor. DC541-CM interrupt I/O and fast counter module was used to control the pneumatic cylinders of the test bed. The module offers PWM outputs with resolution of 1 kHz and time and frequency measurement and output. This module is used as an I/O module to control the valves which control the pneumatic cylinders of the dropping devices. The valves are on/off-type valves which require a 24V controlling signal, where 0V presents OFF and 24V presents ON. The test bed has strict requirements for the simultaneous control of the valves. Especially the lower cylinders have to retract faster than the shaft will drop due to gravity, so that the cylinders will not affect the drop event.

I did not actually tested how fast the I/O functions of the DC541-CM are. I assumed that because the device is industrial scale, they are fast enough. The actual dropping tests were conducted with an Atmel microcontroller which had to be configured to open the valves simultaneously. Because of this I also thought about controlling the valves with pulse-width-modulation (PWM). Further dropping tests will reveal if the DC541-CM is fast enough in the current setting. If it is not then PWM is probably necessary.

Furthermore, I wanted to control the variable frequency drive through the AC500. This can be achieved with fieldbus control. The AC500 family has extension modules for every relevant fieldbus protocol. Additionally, our CPU has an integrated Modbus RTU capability and the drive ACS880 also has embedded fieldbus module for Modbus RTU. Modbus RTU refers to a RS232/RS485 based Modbus protocol or so called serial Modbus. In our case the protocol for Modbus RTU is RS485. I did not get the Modbus RTU to work and had to look for other fieldbus options. ABB PLC service desk suggested using EtherCAT –protocol if the application needs a very fast fieldbus control or for high dynamic applications. In our application, the EtherCAT is excessive but it was remarkably easier to configure and program than the Modbus RTU. For this, ABB gave us the CM579-ETHCAT communication module. The fieldbus communication requires also an additional fieldbus adapter FECA-01 in the drive. The parameters of the ACS880 drive had to be adjusted to allow the fieldbus control.

The modules stand on a terminal base model TF521-CMS which has internal communication buses and the modules are connected to each other through the terminal base. The inputs and outputs are connected to the spring terminals of the base. In addition, the terminal base has Ethernet and serial ports which are automatically connected to the Ethernet and serial ports of the CPU. ABB also provided a 100 W Murr power source for powering the AC500 modules.

Figure 12 presents the automation system for controlling the test bed. The PLC is on the left. The leftmost module is CM579-ETHCAT, the next is DC541-CM, then CPU PM592-EHT and last is the FM502CMS. The speed measurement switch is the small black device next to the PLC. The MURR power source is in the middle and on the right is the ACS880 variable frequency drive.

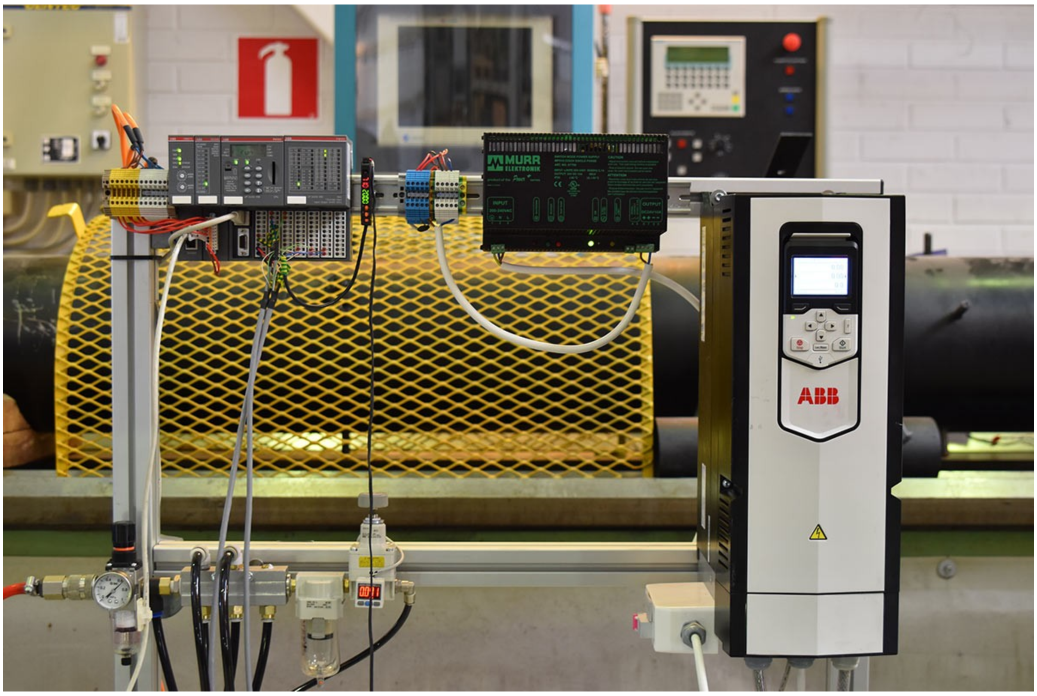

Figure 12: Picture of the complete automation system. From the left: AC500 PLC, speed measurement block, power source and ACS880 variable frequency drive with the assistant control panel

3.2.3 The project

The startup of the test bed automation had five phases:

1. Introduction to CODESYS
2. Configuration the CPU PM592-EHT and FM502CMS
3. Configuration of additional modules DC541-CM and CM579-ETHCAT
4. Configuration of fieldbus
5. Testing the system

I did not have any experience with PLC devices so the project started with studying the devices and software ABB gave us. The relevant software packages for ABB PLCs are Automation Builder and CODESYS. First I installed these and studied what is their purpose and capabilities. Surprisingly Youtube proved to be a useful source of information as there are Youtube-channels with instructional videos about ABB PLCs and how they are operated using simple example projects.

First I wanted to test the system with a simple setup with a signal generator connected as an analog input. I can adjust the signal to a suitable one in the signal generator and then measure the analog input in the PLC. In this setup the modules seemed to work partially because I could get connection, but could not see the analog input. Initially I thought that there has to either be a problem with my user program because the program refused to “run” or that the analog channels are faulty in some way. As I lacked the experience with PLC it was hard to determine the problem.

I found out that the firmware version of the CPU was outdated and had to be updated. It seems that the PLC modules I got were prototype versions that were published during

Q1/2016. The modules had developer firmware inside which led to unstable behavior. Updating the firmware required an ABB licensed SD card and acquiring the card took considerable amount of time. Other types of SD cards could have worked but because there was no guarantee, I chose to use the ABB one. Generally the CPUs can also be updated through the FTP-server, but in this case the FTP-server did not work because of the faulty firmware. After the update the user program started up normally.

After getting the device to run I could upload our user program. It took considerable time to understand how the PLC modules are supposed to be operated. It seems that each extension module has their own logic on how they are operated. For example the FM502CMS module is operated using a specific library that contains the relevant function blocks. First the user must initialize the module and then it can be operated using the library function blocks. In contrast the CM579-ETHCAT module does not need to be initialized nor does it have any specific function blocks. The user sets the communication parameters for the module and writes the suitable control words. In the end I got the all measurements to function including position and speed measurement. The drive can also be controlled using my user program. A larger problem in the project turned out to be the measurement files which we will talk about in section 3.4.1.

The main problem in configuring the PLC device was my lack of experience and the quality and availability of the support material. ABB provides material about their PLC modules but the main problem is that the material is distributed into various locations. Some material is installed with Automation Builder to various folders on the computer and some are located in the ABB Internet-page. The quality of the material varies and is sometimes erroneous. Furthermore the material rarely had examples for our specific CPU or extension modules. The examples are usually simple and their quality varies. It seems also that there is no comprehensive explanation about the library function blocks and they are used. All of the material is found either in the help files of Automation Builder and CODESYS or in PDF documents. None of these were up to date nor were the best possible format for information. For example, sometimes the PDFs had bad quality pictures that were difficult to interpret.

3.3 Programming

3.3.1 Automation builder

Programming the ABB devices requires Automation Builder software from ABB. It is a proprietary software package that is meant for generation and configuration of automation projects. Automation Builder is meant specifically for selecting the devices and configuring their settings. The actual user made program is programmed using CODESYS that is installed with Automation Builder.

The main function of Automation Builder is the configuration of “automation projects” which are projects files that contain all information about the PLC modules and their settings. The main window of Automation Builder consists of two parts: tree-like list that contains devices and the information window that contains detailed information and settings of the currently selected device. An automation project is created by choosing a CPU, which in our case is the PM592-EHT. The user then adds the necessary extension modules to the tree-like list under the CPU. The settings of each module are revealed by selecting the corresponding module from the list. The user can then configure each module through the Automation Builder. The settings for the CPU include for example the communication and network parameters such as IP address. Additionally the user can configure how error messages are handled etc. Similarly the settings for the FM502CMS module include for example the number of open analog channels and their sampling rate etc. After the modules are configured, the settings can be uploaded into the devices.

In reality it was quite hard to understand the purpose of Automation Builder. The settings of the PLC modules are configured with Automation Builder but it seemed to only bring an unnecessary level of complication. I understood that much of the same functionality for PLCs could have been fulfilled by CODESYS. It has to be noted that I only used CODESYS for programming the PLC. Naturally there can be other devices that are configured solely with Automation Builder.

3.3.2 Drive Composer

Drive composer is a Windows application that is meant for configuring and maintenance of ABB drives (ABB, 2015e). It offers a variety of features that are dependent on the connected drive and option modules. The main purpose of Drive Composer is to monitor the status of the drive and it can be used to view and adjust of drive parameters. Finally, if there is no alternative, it can be used to can be used to control the drive and to set the speed and direction.

At first I had Drive Composer as a standalone installation but Drive Composer also comes with Automation Builder. I mainly used Drive Composer in the beginning of the project when I did not have a fieldbus module to control the drive. I also configured drive parameters with Drive Composer but they could also be configured through the assistant control panel. Drive composer can connect to the drive in various ways: either with fieldbus adapter modules or embedded Ethernet port, usb-connection if there is an Assistant control panel available or OPC-based maintenance and commissioning tool. The options are dependent on the drive. I used the mini-usb port in our Assistant control panel to connect Drive Composer to the drive. Later I used EtherCAT.

3.3.3 CODESYS - Controller Development System

Controller Development System (CODESYS or CoDeSys), is a software package that combines several industrial automation software into a single development environment. It can be used to program and create PLC applications and produce visualizations of these applications. The purpose of CODESYS is to provide a single interface that is compatible with all devices. The programming is based on IEC 61131-3 standard which defines five programming languages for PLC application programming. The languages are:

- Structured text (ST, text based)
- Instruction list (IL, text based)
- Ladder diagram (LD, graphical)
- Function block diagram (FBD, graphical)
- Sequential function chart (SFC, graphical)

CODESYS also has an additional graphical editor which is called Continuous Function Chart (CFC) which is not defined in IEC61131-3.

CODESYS has a simple user interface that can be used to create the program. A automation program can consist of many sub-programs which can be programmed using any mix of the fore mentioned IEC languages. The interface of CODESYS is very simple to learn and has extensive help files about the different features. An important part of CODESYS is the generation of visualizations that can be used to interact with a specific user program. CODESYS also provides several examples on how to program and visualize these user programs. CODESYS natively contains extensive libraries of functions and function blocks for various purposes. Additionally, the libraries are extended automatically according to the configured modules in Automation Builder. The amount of functions and function blocks is large so it is very good to keep the CODESYS help file at hand.

CODESYS is installed with Automation Builder and it is started through the generated automation project. It is unclear, what is the connection between these software packages as they seem to have similar features, such as “PLC browser” that I used to debug the devices. My guess is that Automation Builder sends the device configuration, such as the available channel addresses etc. to CODESYS as a file. There is also a CODESYS gateway server which is installed along with CODESYS development environment. CODESYS IDE communicates with the PLC through the gateway server. Chapter 2.2 described that different gateways belong to the resource layer of Industrial Internet architecture. In our case this is debatable as the gateway server is software based and does not provide any additional functionality such as data aggregation etc. I think the CODESYS gateway server could also belong to the communication layer of chapter 2.2 as it provides connection between resources (PLC) and other software such as CODESYS.

I used CODESYS in creating our user program and the visualization that can be used to control the test bed. In our case the user program is quite simple and uses simple if-else logic to turn on the measurement, the drive and control the pneumatic valves. The source code for our user program is presented in Annex I.

From an Industrial Internet point of view CODESYS has many possibilities as it combines a PLC programming environment with a controlling application. Furthermore it can create visualizations for controlling the PLC. CODESYS seems simple but it is a powerful tool in capable hands and it can be used as a controlling application. CODESYS is the de facto standard programming environment for IEC61131-3 which means that basically PLCs of all major vendors are supported by CODESYS. This, in a way, is “application independence” as mentioned in chapter 2.5 and exactly the kind of functionality Industrial Internet will require. There is a need for a PLC programming environment in Industrial Internet applications as these functionalities were also mentioned for example in the BAS use case in chapter 2.4.3. I added it as a requirement in chapter 4. I would have to consider DCS/SCADA if the test system was more complex.

3.4 Networking

There are several possibilities for interacting with the AC500 in a network. The main options are file transfer protocol server (FTP) and a web server. File transfer protocol can be used to access the files on the PLC memory and web server can access visualizations. A more advanced interaction method is OPC server which can be used to connect the AC500 for example, to a database.

It is self-evident that the measurement data needs to be collected from the device for further analysis but the requirements of chapter 2.5 also mentioned SOA-functionality and edge computing. Edge computing is completely out of scope of current PLC devices and I do not expect to see any edge computing functionality. I am mainly discussing the networking capabilities of the PLC devices in this chapter.

3.4.1 File transfer protocol

File transfer protocol can be used to access the files in the various memory locations of the PLC. The measurement files are usually saved to the devices flash disc or on a SD card if there is one. The FTP server can be accessed with any FTP client such as, FileZilla. Initially I had problems using the FTP-server as the client refused to connect to the client. A workaround for this was to allow more connections to FTP-server. I used FTP because there was a need for quick access of the measurement files and I did not have the time to come up with more advanced transfer methods.

At this point it is worthwhile mention byte endianness. Endianness refers to the order of bytes in computer memory or in a digital link. There are two notations for endianness: “little endian” or “big endian”. Little endian means that the least significant bit is stored at the first memory location and the most significant bit at the last memory location. Big endian is vice versa, where the most significant bit is saved at the first memory location and the least significant bit in the last memory location. The big endian order is also referred as “Motorola byte order” and the little endian “Intel byte order”.

The condition monitoring module FM502CMS has a special library CMS_IO_AC500_V24.lib that has a function block CMS_IO_MEASMNT_CTRL to start an analog measurement. The measurements are saved in Waveform Audio File Format or WAVE -files (WAV) and the content of the WAV-files are in Resource Interchange File Format (RIFF). RIFF is a generic file container format for storing data in tagged chunks. There is also similar file format like RIFF which is named RIFX. The only difference between these two is that RIFF is “little endian” and RIFX is “big endian”. The byte order of the CPU is big endian. This means that the files are actually RIFX-files and the material ABB provided on the topic was erroneous. The CMS_IO_MEASMNT_CTRL –function block saves the measurements of each analog channel in a separate WAV-file with corresponding filenames for example: “CH00_nEN” and “CH01_nEN”. The WAV-file format is used because the AC500 can have a large sampling frequency.

Table 2 presents the content of the WAV-files. The measurement files of the FM502CMS module differ from the standard RIFF-format in several ways. As mentioned, they are actually in RIFX-format due to the big endianness of the CPU. Even more important is that the measurement data is saved as 32-bit integers (DINT in CODESYS) instead of 8-bit numbers as the table would suggest.

Table 3: Contents of RIFF-format WAV-files (ABB, 2015b)

Data type	Endian	Length	File offset	Identifier	Value
BYTE[4]	Big	4	0 (0x00)	bfChunkID	"RIFF"
DWORD	Little	4	4 (0x04)	dwChunkSize	Data length - 8
BYTE[4]	Big	4	8 (0x08)	bfRiffType	"WAVE"
BYTE[4]	Big	4	12 (0x0C)	bfChunkID	"fmt "
DWORD	Little	4	16 (0x10)	dwChunkSize	Data length -8
INT	Little	2	20 (0x14)	wFormatTag	0x0001 (PCM)
INT	Little	2	22 (0x16)	wChannels	0x0001 (1 ch.)
DWORD	Little	4	24 (0x18)	dwSamplesPerSec	100Hz – 50.000khz
DWORD	Little	4	28 (0x1C)	dwBytesPerSec	Sample rate * Block Align
WORD	Little	2	32 (0x20)	wBlockAlign	2, 3, 4 Byte
WORD	Little	2	34 (0x22)	wBitsPerSample	16, 24, 32 Bit
BYTE[4]	Big	4	36 (0x24)	bfChunkID	"data"
DWORD	Little	4	40 (0x28)	dwChunkSize	Data length -8
BYTE[]	Little	Undef.	44 (0x2C)	bfData	Measurement data
BYTE[4]	Big	4	44+sz(bfData)	bfChunkID	"labl"
DWORD	Little	4	48+sz(bfData)	dwChunkSize	Data length -8
DINT	Little	4	52+sz(bfData)	dwIdentifier	Channel / Encoder ID
BYTE[256]	Little	256	56+sz(bfData)	dwText	Zero terminated string storing Channel /Encoder file info

Usually the byte order of a standard computer is “little endian”. To make the files readable in a standard computer I would have to change the byte order, convert the WAV -files to another format or use software to read them in big endian format. Simplest way to get the measurement data visible was to use Matlab to read, analyze and the plot the data. Matlab has fopen- and fread-functions to read binary files. As mentioned, the measurement data is saved as 32-bit big endian integers and therefore I had to make sure Matlab reads the data correctly. After reading the files, Matlab saves all data points as 64-bit double precision floating point numbers.

A simple Matlab script that reads the contents of measurement files from channels zero and one is presented in Appendix II. The script also plots the position of the axle. Figure 13 presents a measurement of when the shaft is just rotating normally.

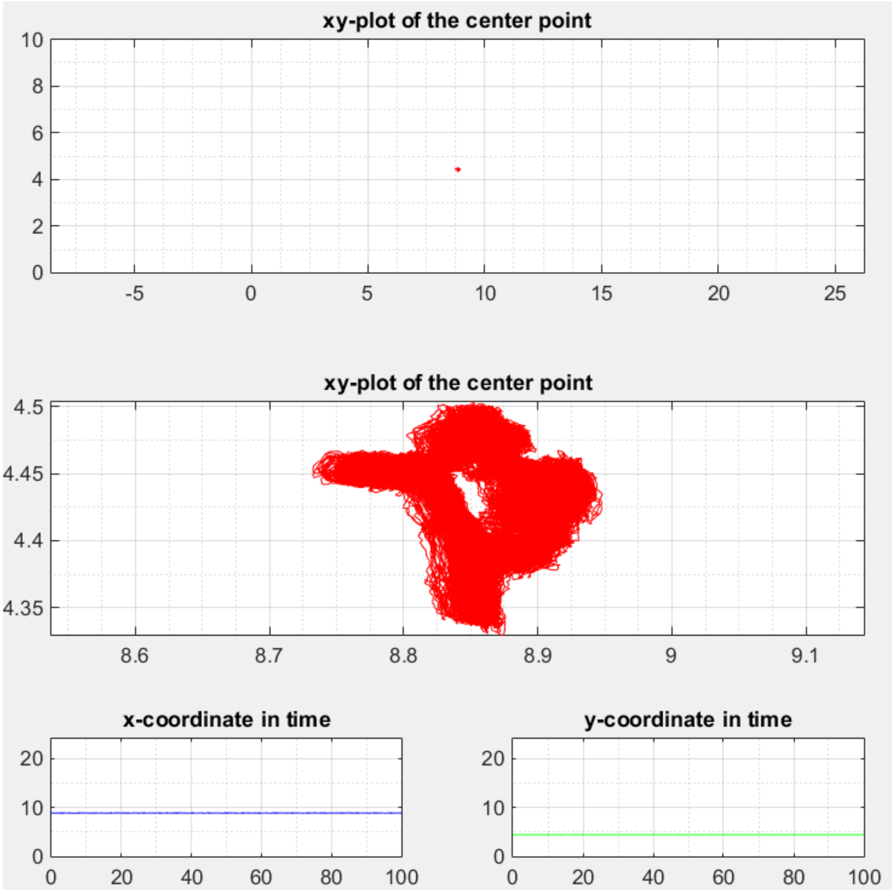

Figure 13: Matlab graph of the shaft when it is rotating in normal conditions

3.4.2 Webserver

The PLC also has an integrated webserver for external access of the PLC. The purpose of the web server is to give an alternative access to the CODESYS made visualization. The web server presents the visualization as a web page that can be accessed with any browser such as Internet Explorer.

Initially I was interested about the web server possibility as it could have meant that the device could be used in a SOA kind of fashion as discussed in chapter 2.4.2. Sadly it turned out to be not as advanced as initially thought. The web server functionality requires the website files in XML-format, a gateway server and the PLC handler which is an API for accessing CODESYS variables from an external system (Codesys help 2016). It turned out that all of these files and software need to be hosted by a windows PC and cannot be hosted by the PLC. This hinders the usefulness of the web server from an Industrial Internet point of view considerably.

The reason behind this arrangement is processing power. Even though PLCs are powerful devices they usually lack the capabilities to host a web page. It is also counterintuitive to the purpose of PLCs to add an integrated web server even if it would be possible. Therefore it is better that the web server is hosted elsewhere so that the web server and web-site do not occupy the memory of the PLC. Additionally, the opening time of the website is kept low and the refreshing time of the variables is minimal.

The reason I brought up the possible web server configurations of the device is to demonstrate the capabilities of current automation devices. This kind of web server arrangement was noted to be useful for example in situations where remote monitoring is needed but there are problems with opening up corporate firewalls (Michel 2014). The communication between the PLC and PC can be arranged with every relevant method as presented in table 4.

Table 4: The various communication methods that can be established between the PLC and the PC

- Ethernet
- Intranet
- Remote access service (RAS) such ISDN or DSL
- Serial connection such as RS232
- USB-to-FBP (fieldbus plug)
- Serial modem

The web server can be applied in many configurations. The question is mainly if there is a local PC or is everything hosted by the remote PC and is a single or multiple PLCs. Figure 14 presents a system where there is a single PLC and a diagnosis PC connected through a serial modem.

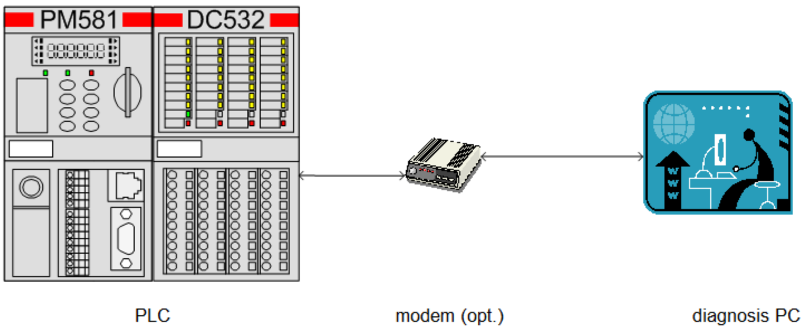

Figure 14: Configuration that has a single PLC connected to a remote PC (ABB, 2015b)

All the web server files and websites in XML-format are stored on the diagnosis PC. The diagnosis PC also hosts the gateway server and the PLC handler. There is a connection between the PLC and diagnosis PC where the PLC is accessed through a web browser. The web site is hosted on the diagnosis PC so only the values of all variables need to be transferred to the diagnosis PC (ABB, 2015b).

A second possibility is to use a local PC to host the gateway server, web server and the web page. The remote PC is used to access the web page and the PLC through the local PC. While this configuration seems complicated it is the most interesting one as it brings an element of Service-Oriented-Architecture to the device. Pictures X and Y present the idea with one and multiple PLCs.

3.4.3 OPC server

In addition to the FTP and web servers, the PLC can also be accessed through an OPC server. OPC stands for OLE for Process Control or Open Platform Communications which is a set of standards and specifications for industrial telecommunications and are maintained by the OPC Foundation. OPC is one of the most common industrial telecommunication standards and the purpose of OPC is to provide a standard communication method between Windows-based software applications and process control hardware.

The standard offers an open source method for different OPC client software to access the data in a device such as a PLC. After the OPC server is defined in a device, then all OPC client software can access it. The OPC is based the Microsoft Component Object Model (COM) and distributed component object model (DCOM) technology. COM technology allows real-time data exchange between Windows-based software applications and the process controlling devices such as PLCs'.

In our test case, the OPC server is not part of the PLC device itself and instead, it is installed as a separate software package on the PC. ABB recommended CODESYS OPC server for connecting to their devices. Figure 15 presents the communication between CODESYS software and a PLC. The version is CODESYS OPC server V3. The OPC server uses the same CODESYS gateway server that the CODESYS IDE uses to connect to the PLC. The connection between OPC and gateway servers can be local or TCP/IP. The connection between OPC client and server is based on COM/DCOM.

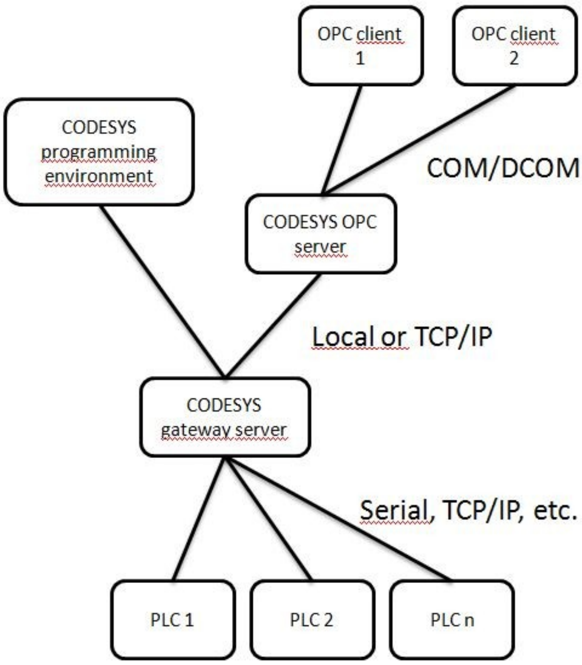

Figure 15: Communication topology between the CODESYS IDE, Gateway, OPC server and PLC (adapted from ABB 2013)

After the server is set up, it can be accessed with any OPC client such as the free Matrikon OPC explorer. This is again exactly the kind of functionality Industrial Internet will need. OPC is the most commonly used standard in connecting industrial devices to software components such as databases and DCS/SCADA systems. For example one of the industrial automation use cases in chapter 2.4.2 used OPC and the BAS and E-maintenance use cases in chapters 2.4.1 and 2.4.3 are almost guaranteed to require OPC. There is a successor for the original OPC standard named OPC UA (OPC Unified Architecture) which aims to bring SOA-functionality to process control. These developments will keep OPC a relevant standard for Industrial Internet. In our case ABB provided their proprietary client that will be discussed in the next section.

3.5 CpmPlus History

ABB also provided their cpmPlus History process historian software which is a complete software package for data logging in an industrial environment. CpmPlus History offers a software platform to build products and systems for process industries and utilities. The core of the software package is a relational database which is optimized for time series signal processing and storage (ABB, 2015d). CpmPlus History is highly scalable: it can be applied for asset and process management in manufacturing facilities or other industries and for control and monitoring of individual pieces of equipment or whole manufacturing lines (ABB, 2015d). The communication between the field devices and cpmPlus History in our case is based on OPC as it was illustrated in figure 15. There are also other communication methods.

The predefined information models of cpmPlus History include:

- Process data which is a time series variable that represents a measured or calculated signal. The information model contains the engineering attributes, current value and time series histories.
- Alarms and events according to OPC AE/AC definitions.
- Equipment model which is a hierarchical structure to manage assets that can be for example logical like control loops or virtual representations of industrial production equipment.

CpmPlus History also hosts tools for visualization and analysis of the process data. The whole software package consists of several parts that are usually installed on different levels of the enterprise network. Figure 16 presents the hierarchical system layout of cpmPlus History which consists of several parts called nodes:

- **Data collection node** is usually installed in the automation network to be near the devices. It contains the database and its purpose is to buffer data and to act as a backup in case there is a network failure or the main part fails.
- **Main node** utilizes the services of the data collection nodes to gather data from several nodes. Main node is usually installed in the plant network level. It serves as the main data storage level and application interface.
- **Vtrin** is the graphical user-interface that is used to access the main nodes.

The main difference between data collection and main nodes is the length of the collected data and use of resources. Data collection nodes can gather data up to eight days but their benefit is the lower use of computing resources.

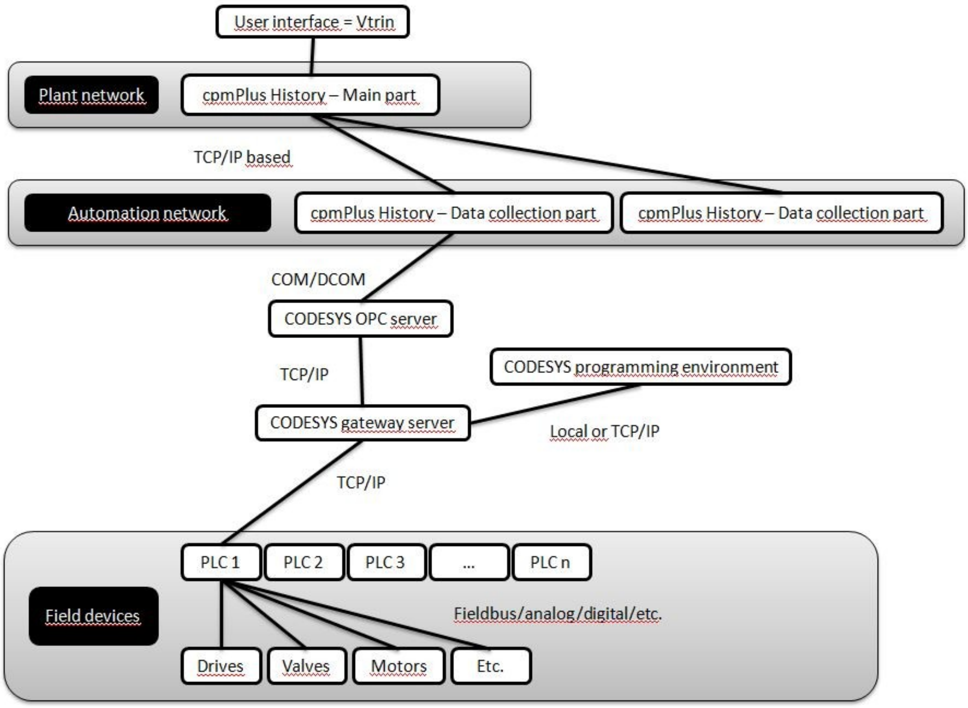

Figure 16: ABB cpmPlus History hieararchical system layout. Normally the system consists of separate "data collection" and "main" parts (adapted from ABB 2015c)

In a typical installation the nodes and Vtrin are installed on different layers of the enterprise network. In my case the whole system was installed on the single PC which is illustrated in figure 17.

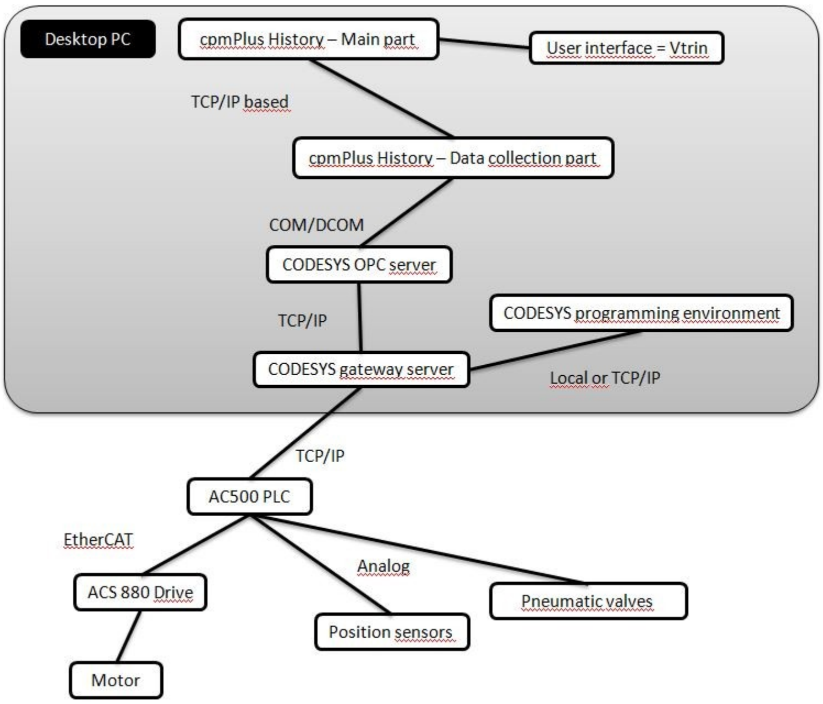

Figure 17: Components of the current system that was installed inside a single PC

I tested the cpmPlus and achieved connection to the PLC through the OPC server. Sadly in this case, I did not find any meaningful application for cpmPlus History because the system was relatively simple. CpmPlus History is meant for recording, analyzing and visualizing process history continuously from many sources, which was unnecessary. The test bed was simple and I only needed a way to start a measurement at a certain time and end it shortly afterwards. For this the function blocks of CODESYS seemed to be enough.

CpmPlus History contains a set of tools for data analysis and visualizations. There is for example the possibility to compare data from several sources and draw their results on a graph. There also seems to be some kind of API for writing software for access to external systems such as DCS. The ABB material about this is vague so I could not figure out its capabilities. There is also a software development kit for creating analysis applications for cpmPlus History. I did not find use for these because of the simplicity of the test system. Still, if Industrial Internet systems are to enable optimization and improved decision making, there needs to be tools for analysis and visualizations. The E-maintenance use case in chapter 2.4.1 pointed out that users must be able to digest all the information the systems generate. CpmPlus History has been developed this in mind as it can produce graphs from key figures. There clearly is a need for this kind of software.

Another interesting feature of cpmPlus History was the programmable events and alerts. In a more complex system these events could be used to trigger alerts and notify personnel of problems in the system. Of course it is good to keep in mind that cpmPlus History is not a control application. This kind of event based control is better suited for actual control software such as distributed control system (DCS).

4 Results

In this chapter I will summarize core points from the literature review and also revisit the requirements from chapter 2.5.

4.1 Design goals of Industrial Internet

I defined the main purpose of Industrial Internet in chapter 2.1 which is optimization and control of industrial processes using measurement data and internet based technologies and visualizations. During this thesis it became evident that this is not the only goal. The public research efforts and use cases also provided other goals and perspectives to Industrial Internet:

- Extending the scale of industrial processes
- Increase flexibility
- Increase scalability
- Enlarge the device space of industrial systems
- Provide a generic industrial solution instead of point solutions
- Increase horizontal integration of devices, systems and enterprises
- Support new business models

These goals should be achieved using current technology as much as possible. I also gathered a set of design principles that were presented in chapter 2.2:

- **Reusability of resources**. Simply putting system components should be produced in a uniform way to allow them to be reused as much as possible. Components should have standardized interfaces.
- **Support services** mean a group of service that are independent from the resources and provide support functions such as access management.
- **Abstraction levels** are needed to hide complexities of the system.
- **Support for multiple business environments**. Industrial Internet solutions should be designed so that they can be applied to various environments such as internal to an enterprise, enterprise and subcontractors or completely open.
- **Security** is needed to enable system and data integrity. Individuals should not be able to be identified from the data nor can the data be manipulated afterwards.
- **Scalability**. Industrial Internet systems should be able scalable from a handful of devices and measurements to millions.
- **Compatibility**. Industrial devices have long expected operational times and therefore Industrial Internet systems should be able to be support new and old devices alike.
- **Simplicity of management**. As the scale of the systems is large there must be features that ease installation and management
- **Support for new service delivery models**. Industrial Internet must support various service delivery models such as combined product and service.

These design principles allowed the creation of an architectural outline for Industrial Internet in chapter 2.2.

- **Asset** is the real world object or entity that is of interest. Asset does not provide any functionality in the Industrial Internet system and it is presented digitally by the resource layer.
- **Resource layer** makes the assets part of the network and serves as the link between physical and digital world.
- **Communication layer** provides communication between resource layer and backend servers.
- **Service support layer** consists of services that perform routine tasks which are common to all applications.
- **Data and information layer** contains data and information models of the system and offers knowledge management and advanced control logic support.
- **Application layer** is the core of the Industrial Internet system as it describes the desired industrial process accurately.
- **Business layer** integrates the Industrial Internet application to the business system of the stakeholder.

4.2 Main requirements

I will now revisit the requirements of chapter 2.5. Our use case was about the active magnetic bearing test bed and I will go through the requirements from the perspective of the test bed. I discuss the relevant requirements and choose the requirements that could be implemented into the AMB test bed. After this I will propose a plan which aims to convert the AMB test bed into an Industrial Internet test bed.

I presented the platform component of the Industrial Internet system in chapter 2.5.

- **The platform** is the most important requirement since other components are built upon it. Obviously I do not have any ready Industrial Internet platform available. I think the platform should be cloud based to provide scalability and flexibility even though in our case scalability is not a priority. One problem is that all of the software I used is Windows based which would require Windows compatible cloud. There are commercial cloud platforms such as Microsoft Azure but experts tend to prefer Linux-based servers because of performance.
- **Database**. During our experiments with the test bed, I did not particularly need a database because the features of CODESYS proved to be sufficient at the time. In contrast, many of the use cases possessed a database component and it is not hard to imagine a situation where a database is required. The database becomes more important if there is a need for longer measurements and especially if the system is extended to include additional devices. ABB provided their cpmPlus History process historian software which is a relational database.
- **Resource directory** was used in the use cases to store information about the resources of the system, such as devices and assets. This requirement is especially useful in cases where there are a large number of devices. For example, cpmPlus History could simulate this requirement since there is a possibility to create

"equipment models". Equipment model can be used to present all devices in an industrial process. Still, this is not a prime requirement since there are other requirements that need to be fulfilled before.

- **Analysis software**. The use cases point out a need for analysis tools which can be used to analyze and manipulate the measurement data. I think these will be important in any Industrial Internet solution. I used Matlab in analyzing the measurement files and cpmPlus History also provides a set of analysis tools.
- **Visualization**. The platform will be used in decision making and therefore there must be the possibility to visualize the data about the system and measurements. These will be even more important in more complex systems where there is a need to combine information from multiple sources. In our case I created a Matlab script which analyzes and plots the contents of the measurement files but this could have also been achieved with NumPy or SciPy. These could have been replaced with cpmPlus History as it contains the database, analysis tools and visualizations. I think cpmPlus History or comparable software is paramount to any Industrial Internet solution.
- **PLC programming environment**. I assume that our PLC program must be tweaked at some point and therefore the platform must provide a PLC programming environment. I programmed our PLC using CODESYS which can continue to serve in this function.
- **Event-Driven-Architecture**. This requirement is a guide line for software developers in the field of Industrial Internet. It especially affects the controlling application and measurement functions which should react to changes in state i.e. events. For example, to stop the test bed if the speed grows too large. The cpmPlus History can manage two kinds of events: internal events created by programmed triggers and OPC events that are defined in the OPC standards. Event-driven-architecture is even more obvious if the test system consists of more than one device. Different devices should react to events generated by other devices or the controlling applications. I believe this is a important requirement for the platform and test system even though I am not able to personally influence it
- **Controlling application**. The platform must obviously provide an application for controlling the test bed and possibly other devices. I used CODESYS to control the test bed through a self-made graphical interface but for example, cpmPlus History can also be used to generate an equipment model which represents the different devices graphically. CpmPlus History could then use OPC to push commands to the PLC but with this method I am concerned about real-time behavior. It has to be kept in mind that cpmPlus History is not a contolling application. I would consider DCS/SCADA if the test bed is extended with additional devices.
- **Open API**. I think that an API is an important for the implementation of the platform. API will provide access for third party applications and possible integration with, for example, government systems. API will also help support new business models such as PaaS and SaaS. At the moment, cpmPlus History provides an API only for analysis software. The platform should provide an open API but I recommend focusing on more important requirements..
- **Monitoring and amount of measurements** is not a specific requirement for out platform but for Industrial Internet in general. The platform and other components

should be able to support extremely large amount of measurements and data although it was not a problem in this case.

- **Support for new business models** was mentioned in literature. It is not a relevant requirement in this case, as there are more important requirements that need to be solved first. New business models will be partly supported by the API and access management functions.
- **Access management** is mandatory in all systems that are connected to the Internet. The platform must have access management and security solutions to enable user access, remote operation and enabling third party access to data. I think that remote operation is especially important for the test bed. In our case cpmPlus History has security features but I did not have the capacity to fully investigate these. Security must be kept in mind later if the system is extended.
- **Data integrity** means that the data the system generates cannot be compromised and manipulated afterwards. CpmPlus History probably provides data integrity but it is not an important requirement for us.

The previous requirements covered more the platform and common concepts of Industrial Internet. The following requirements cover the actual Industrial Internet devices.

- **Dynamic Device Discovery** is important especially when the amount of devices is large. In this case I could have also benefitted from a smoother installation. Currently installing and programming the PLC is a manual process. The PLC was programmed through Automation Builder and CODESYS. Neither of these recognizes the PLC automatically and instead, I had to manually select the CPU and all extension modules. In my case I even had to manually download configuration files for the extensions modules since they were not included in the original Automation Builder package. Each extension module has to be manually configured, for example the FM502CMS did not recognize the analog inputs automatically and I had to manually choose the analog channels and their sampling frequencies. I also had to choose the settings manually for DC541- and EtherCAT – modules. Creating the PLC program proved also to be a challenge. Each module has their respective function blocks and logic how they are operated. For example, the FM502CMS is controlled using specific function blocks but then EtherCAT is operated by generating the "control words" which are binary numbers. The programming itself was simple but understanding each module was not. Understanding the control words of EtherCAT was especially difficult. Some of the problems arose because of our lack of experience but I also note that the quality of ABB material around the topics varies considerably. Keeping this in mind, I think that dynamic device discovery and auto-configuration features could have helped us significantly. I think dynamic device discovery is crucial in future Industrial Internet systems but at the moment, I cannot influence it currently.
- **Service-Oriented-Architecture** is similar requirement as event-driven-architecture: it is a guide line, how device manufacturers should create their products. It is an important requirement for Industrial Internet as it will enable scalability, flexibility and application independency on the device side. SOA will be crucial also in situation such as the hazardous materials use case where field devices communicate with each other without an ERP. Many other requirements

are directly or indirectly related to SOA. The only drawback is that SOA in devices seems to be relatively rare.

- **Legacy gateway** is directly related to SOA and equally important as they are the only way to present pre-Industrial Internet devices as services. In this case legacy gateway is one of the most important requirements as the system would require a method for exposing the functionalities of the PLC in the platform. This means that a legacy gateway needs to be created or the PLC has to be presented some other way, for example using OPC. The PLC web server achieves some of this functionality but it is unclear how. The web server could possibly also be used for faking SOA-kind of functionality.
- **Digital identifiers** that provide information about the corresponding resource are important when the system has a large amount of devices. In our case this is not an important requirement since our test bed is relatively simple.
- **Large device space** will be realized as the side product of previous requirements such as dynamic device discovery and SOA. Our test case does not need a specifically large device space but further research will benefit from it.
- **Application independency** was noted several times in literature but I think it as a synonym for SOA. The purpose of SOA is to make software application independent.
- **Edge computing** is a concept that distributes computing power to the logic extremes of a system or network. Edge computing is too wide topic to be discussed in this thesis and I only conclude that there is no need which could be fulfilled with edge computing.

Table 3 presents a summary of the requirements, if they are relevant to the test bed and also if I already have components that fulfill the requirement.

Table 5: My requirements for Industrial Internet, the corresponding software component if there is any and relevancy of the requirement from the test bed perspective.

Requirement	Availability	Corresponding component	Relevant to the test bed
The platform	×	-	✓
Database	✓	cpmPlus History	✓
Resource directory	×		×
Analysis software	✓	cpmPlus History/Matlab	✓
Visualization software	✓	cpmPlus History/Matlab	✓
PLC programming environment	✓	CODESYS	✓
EDA	?	cpmPlus History	✓
Control application	✓	CODESYS	✓
API	×	cpmPlus History	×
Monitoring / large number of measurements	✓	AC500 PLC	×
Support for new business models	×		×
Access management	X		×
Data integrity	?	cpmPlus History	×
Dynamic Device Discovery	×		×
Service-Oriented-Architecture	×		✓
Legacy gateway	×		✓
Digital identifier	×		×
Large device space	×		×
Application independent	×		×
Edge computing	×		×

Some of the necessary components are already available. Notable is also that basically all of the requirements are directly related software. I conclude that physically Industrial Internet has no development needs.

4.3 Solution proposal

I propose the creation of an Industrial Internet platform according to the requirements presented above. I use the word “platform” for this feature which in practice will manifest as a cloud based service or system. The idea of a platform was presented in the use cases and I also think that it is the most sensible research direction for the test bed. The test bed by itself is relatively simple device and requires something more to be an example of

Industrial Internet. The platform can also act as a basis for further study in the area of Industrial Internet, for example M2M-communication, big data etc. I propose the creation of the platform in the following two phases: The first phase is aimed at the creation of the actual platform and achieving the same functionality through the platform that the test bed has currently. The second phase becomes more an independent software platform experiment. The AMB test bed provides the real-world link and the platform is used as a test setting to connect independent software components to a cloud service enabler.

1. Step one: Industrial Internet platform phase I

The purpose of the first phase is the creation of the platform. I assert that the platform must be cloud based to allow scalability, flexibility and remote access to the test bed. At this point the "business case" of the platform is to achieve same functionality as the AMB test bed has now, but using the cloud based platform. I recommend taking advantage of the already available software components, for example cpmPlus History and CODESYS. Their use serves several purposes: they are already available and their use can reveal insights about the performance of cloud services. Additionally, the PLC, cpmPlus History and CODESYS were all provided by ABB Finland and therefore their use should be preferred everywhere.

The main challenge of this phase is figuring the actual form of the platform. I recommend using already available options as the basis such as Microsoft Azure. Creating the platform completely from scratch is not a viable option. The second challenge is getting the other components to run on the cloud platform. The main concerns are about the real-time behavior and performance of the cloud service. Additionally, our software components are Windows based which can prove to be a problem since many experts prefer Linux based solutions on the server side.

Figure 18 illustrates the structure of the AMB test bed with the phase I platform. I used cpmPlus History for the data base, visualization, and analysis tools. CODESYS is the PLC programming environment and controlling application. I also added a FTP client and NumPy/SciPy script that will be used to analyze the WAV-files. I used Matlab in analyzing and visualizing the WAV-files but I think NumPy or SciPy can achieve similar results.

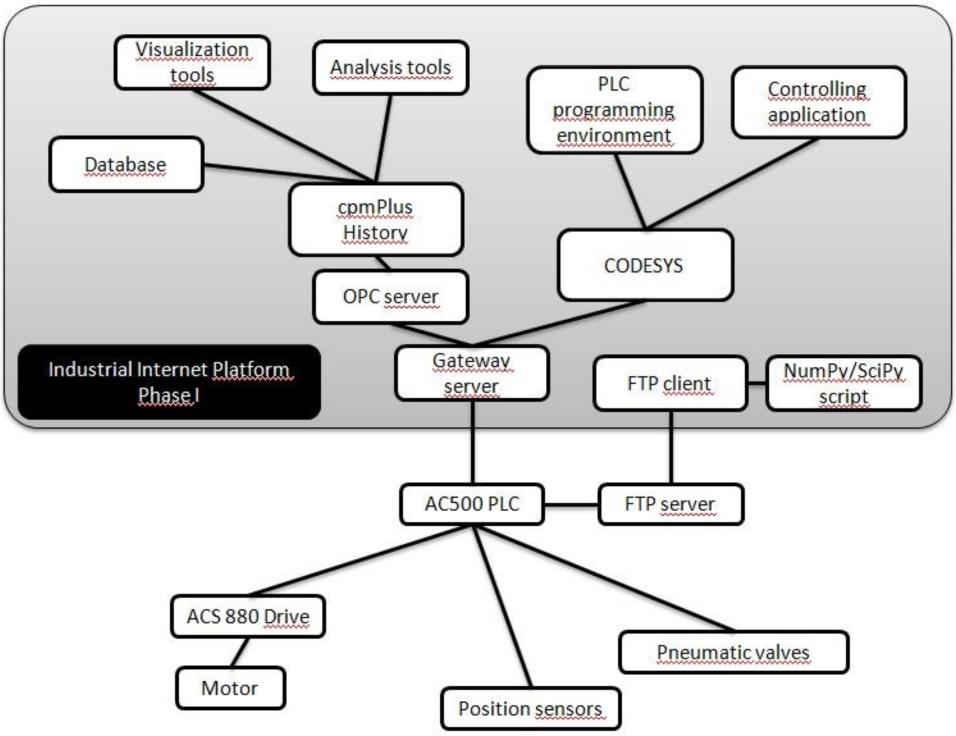

Figure 18: Solution proposal for Industrial Internet test bed and platform phase I

2. Step two: Industrial Internet platform phase II

The purpose of the phase II platform is to fulfill the requirements of chapter 4.1. At this point I assume that the platform itself is already in existence and thus the focus is on the content. Step one for this phase is the creation of the "legacy gateway" that can be used to expose the PLC as a service-oriented device. Currently the test bed is controlled using the visualization in CODESYS. It has a graphical interface for controlling the variable frequency drive (speed reference, start, stop and error reset) and opening and closing the pneumatic valves. The purpose of the legacy gateway will therefore be exposing these functionalities as services. The gateway can be software based. Initially the other software components, such as data base, can remain the same.

Phase II platform is the basis for further study. Step two of phase II platform is the creation of the "cloud service enabler". At this point I would change the platform to match the IMC-AESOP and BAS use cases. Cloud service enabler becomes an integral part of the platform as it is the interface through which the other software components function. The underlying idea is to keep the software components independent and allow changing them without compromising the system. Naturally there can also be direct communication between the components.

Figure 19 illustrates phase II Industrial Internet platform. I have drawn each component as a separate box to illustrate the independency, but it is acceptable if a software package fulfills the role of several components. It is also completely possible that the other software components remain the same as far as possible. For example cpmPlus History can be a viable component through the whole project. Any performance issues can probably be mitigated, for example an employee of ABB said that they have achieved to run cpmPlus History on a Raspberry Pi computer. I added also a graphical user-interface as a requirement.

Our proposal fits in to the architectural outline that was presented in chapter 2.2.

- The **asset** is the AMB test bed and. The PLC is monitoring the speed and position of the test bed and controlling the pneumatic valves that perform the drop tests. I define that the PLC is part of the asset.
- The legacy gateway belongs to the **resource layer** as it makes the device part of the network. The PLC could also belong to the resource layer.
- **Communication layer** is presented with a separate box. At this point I leave the actual implementation open.
- One purpose of the platform is to serve as an interface to various software components. Some of these functionalities could belong to the **service support layer**.
- **Data and information layer** provide data and information models. For example the cpmPlus History could present these functionalities.
- **Application layer** describes the desired industrial process. Currently our process is only the controls for the test bed. In our case CODESYS could provide these functionalities.
- Currently our solution is lacking the **business layer** since I do not have any system to integrate to.

The current system configuration was presented in figure 17. The phase II platform changes this layout to a more layered one.

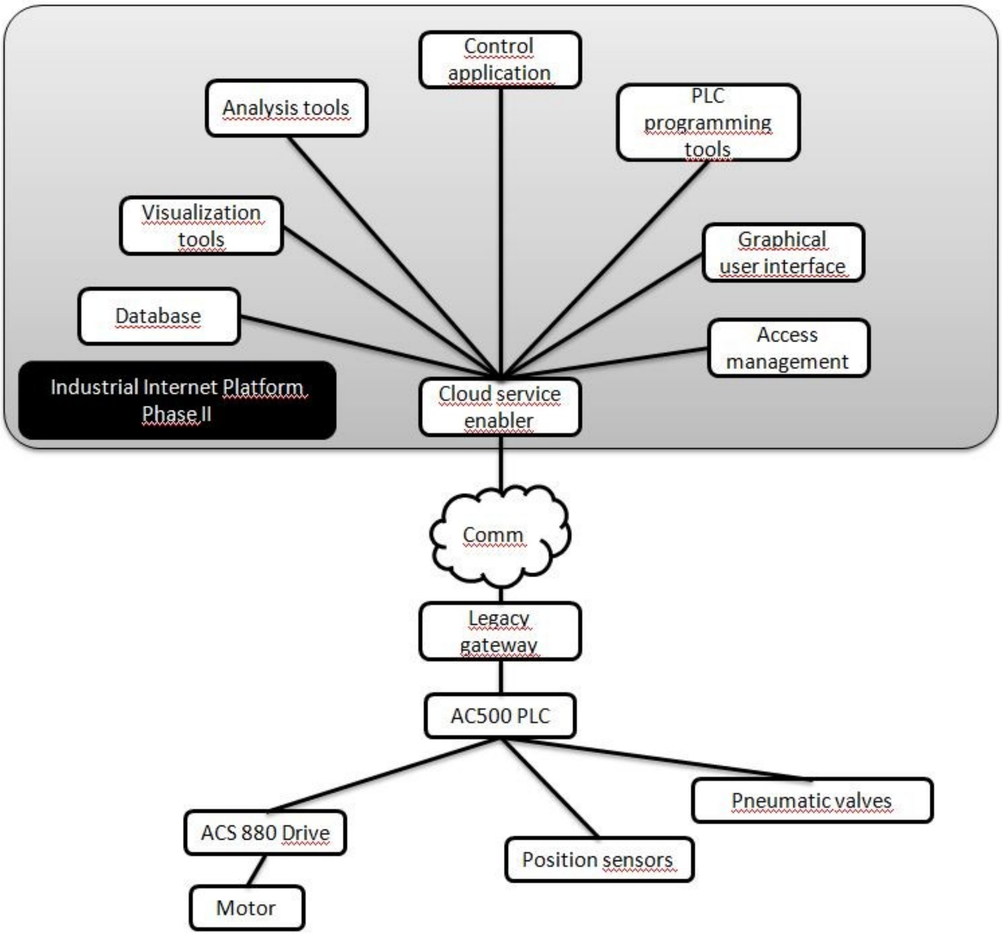

Figure 19: Solution proposal for Industrial Internet test bed and platform phase II

5 Discussions

5.1 Results vs. literature

Most of the literature about Industrial Internet and IoT seems to be based on future prospects. Many sources state that Industrial Internet will improve industrial processes but concrete examples on how this will be achieved, are hard to find. I think it is wrong to simply state that Industrial Internet will optimize processes without stating how this will actually happen. This lack of concreteness should be removed as simply connecting a device to the internet does nothing. For example instead of just stating "Industrial Internet will optimize products", I would like to see statements that contain actual steps how the optimization is made: "Industrial Internet systems will gather more measurement data compared to current systems. This data can then be analyzed with methods A, B and C. The analysis can be used to improve the product." Even with this statement I realize that it is actually the analysis which will yield the piece of information that allows the optimization. Stating that Industrial Internet will do it is erroneous but I see that Industrial Internet is the enabler. In a way I would like to see literature answering more to the question "how?" when discussing Industrial Internet.

Even more important question than "how?" is "why?", when discussing Industrial Internet/IoT. Without answering these, the discussion has no meaning. IoT especially is sometimes notoriously used to describe various gadgets that may or may not have any feasible application, such as flowerpots that post their watering needs in the social media site Twitter. Most successful examples of IoT are probably home automation examples such as the Nest thermostat which can be used to control heating of a house remotely. Current IoT devices seem to mainly offer remote control possibilities. I think there is yet to be a product that could really be said to be an IoT device and have large impact economically or socially.

Industrial Internet examples provided much deeper explanations about the purposes and technologies behind Industrial Internet solutions. I found use cases about various topics such as E-maintenance, waste management, building automation etc. Broadly speaking, these use cases discussed Industrial Internet from two dimensions: platform centric or device centric.

Platform centric: Some cases presented Industrial Internet as cloud based platform or system. The purpose is to combine for example data storage, asset management and control application into a one solution or system. These components are the ones that can be used create value in an Industrial Internet system, namely the optimization etc. The assumption is that this system will be cloud based to allow scalability and flexibility. The platform needs also other components to make it functional, such as access management/remote access functions, open API and other security features. I use the word platform to describe this functionality but it will probably manifest as a cloud based service or system.

Device centric: some cases discussed the devices in an Industrial Internet environment. The interest points are M2M communication or characteristics that allow better integration with Industrial Internet systems. The platform and device centric views are not mutually exclusive and instead they support each other. The main goal of the devices is to be application independent. I think this will be enabled by Service-Oriented-Architecture where the capabilities of the devices can be exposed as services in a network. For example, an industrial valve could have “open valve” and “close valve” services that could be called by other devices and systems. Older devices that are not SOA can be presented by “legacy gateways”. Additionally, systems and devices should have certain features to improve the managing the devices in the systems, such as dynamic device discovery and digital identifiers.

Literature seems to be enthusiastic about bringing internet technologies to the devices but fail to concretize the actual benefit of this. The interest in internet technologies is probably because of the nature of the Internet: extreme scale, scalability and flexibility. As it happens the Internet is the largest network in the world, so many sources simply assume the benefit of internet technologies also in smart devices (hence the whole term “Industrial Internet”).

New technology is always new technology but with Industrial Internet I suggest a healthy dose of pragmatism. If a solution does not need internet connectivity or Industrial Internet, then it should not be forced. I think that before a device is connected anywhere there must clear business reason to do so. For example, the use cases in chapter 2.4. presented different approaches to Industrial Internet. Some sources point out that data sharing will be an important aspect of Industrial Internet but many of the actual use cases I found, presented Industrial Internet as a cloud based platform. Data sharing was only one of the purposes of the platform. Nevertheless, I came to the conclusion that the most interesting solution for the test bed would be to promote building a cloud service platform around the test bed. Of course it has to be noted that even our platform is nothing but a piece of technology without a purpose. In our case, the initial “business case” is to move the functionality of the test bed into a cloud environment. This would allow for instance: remote operation and access of the test bed. The phase II “business case” is changing the test bed into an actual Industrial Internet test bed. After phase II the platform is high suitable to be applied to situation such as the BAS use case. This is why I mentioned answering the question “why?” when discussing Industrial Internet because it states the purpose of a solution. I think the problem with IoT solutions is the inability to answer the question “why?” The situation is better with Industrial Internet as the why is simpler to answer for example, “optimize industrial process”.

5.2 How the goals were achieved

The objective of this thesis was to study the status of Industrial Internet and propose an Industrial Internet solution for the AMB test bed using the available equipment and software. Through this I wanted to provide a direction of research for the Aalto Industrial Internet Campus. Industrial Internet is a broad subject and it is easy to become fixated too much on the details and miss the whole image. For example, initially I were too concentrated on the PLC device itself and how should function in an Industrial Internet environment. I did not have any previous experience with PLC and PLCs seemed to be interesting devices. Only later it became evident that a PLC by itself was not interesting example of Industrial Internet. Through the literary review I came to the conclusion that there should be an Industrial Internet platform based on the AMB test bed as presented in chapter 4. The creation of the platform is the research direction I suggest. The scope of the study did not include the creation and implementation of the platform.

The devices ABB provided us seemed to be from a high quality line of PLCs. The specifications were superb but they obviously cannot be described as Industrial Internet devices. ABB has seemingly created PLC modules and software that have some features that are important for Industrial Internet but still they are not enough. The answer to the question, how devices should be in an Industrial Internet environment? I think the answer is service-oriented-architecture. I think it will solve many problems and fulfill the requirements that were discussed in chapter 4. Industrial Internet itself is a more complicated topic. I see two possible directions for companies aiming to invest in Industrial Internet research: first direction is to promote Industrial Internet as a platform which I proposed in chapter 4. The second direction is M2M-communication.

5.3 Future research

After the platform is completed I would suggest combining the test bed with M2M communication. The Aalto University manufacturing technology lab has a machining center and there were discussions that the AIIC would acquire a new Konecranes overhead crane. I propose connecting the overhead crane and the machining center to the cloud platform which would allow studying these devices as a system. They could be used to study for instance remote control, remote maintenance etc. These are the further "business cases" why the platform exists.

I suggest studying M2M communication with these devices like in the hazardous material container use case in chapter 2.4. The point of interest would be to implement business logic without a central controlling system. For example there are protocols such as Zigbee and Digimesh that enable devices to act as routers. These could be used to demonstrate a smart manufacturing cell: the machining center would perform action A which would trigger the overhead crane to perform action B. The communication would strictly be between the two devices.

During this thesis it became evident that research in Industrial Internet mainly consists of software development and computer networking as the systems are not interested about the physical implementation of the devices. Nevertheless, Industrial Internet is an industry field that requires knowledge of many fields such as mechanical engineering and IT. I believe that automation engineers, software developers and networking specialists are the ones who design and implement the systems and they essentially answer the question "how?". Therefore the responsibility to answer the question "why?" is left to the mechanical engineers. I think in the future mechanical engineers will be the ones who figure out the business reasons to add Industrial Internet capabilities to devices and processes. This is because mechanical engineers have the knowledge and are responsible for maintaining and developing the industrial processes and equipment. Industrial Internet is a tool and it requires an expert of a specific field to realize if that tool is needed in the specific situation. In believe concepts like my platform can actually be fruitful platforms for cooperation between mechanical engineering, automation, software development and computer networking.

Industrial Internet shares common characteristic with the Internet: it is not defined by the Industrial Internet devices much like the Internet is not defined by personal computers and server machines. Industrial Internet is defined by the content the devices produce.

6 Summary

The purpose of this thesis was to research the current status of Industrial Internet by presenting use cases of Industrial Internet found in literature and comparing a PLC device to the literature review. Through this comparison I proposed a creation of an Industrial Internet platform around the AMB test bed. I also discussed relevant concepts related to Industrial Internet, such as M2M communication and presented current research efforts that aim to provide standards for different areas of Industrial Internet. I wanted to know, how the devices should be connected in an Industrial Internet environment.

M2M communication refers to direct wired or wireless communication between industrial devices for a specific business purpose and application. Generally the purpose of M2M communication is to achieve increased productivity and/or better control of assets. The main drawback of M2M solutions is that the data these devices gather usually remains inside the boundaries of the M2M system. M2M systems generally do not allow broad sharing of their data or connection of the devices to the Internet in general. Additionally, the devices in M2M systems are usually of the same type and the available device combinations (or "device space") are fairly limited.

M2M communication offers point solutions to various problems. M2M systems are relatively closed systems and device and communication centric. In contrast, Industrial Internet is marked by a level of openness. The purpose of Industrial Internet is simple: to improve and optimize industrial processes. This optimization will be achieved using analysis techniques on measurement data, M2M communication, cloud services and computing and other internet based technologies and visualizations. Industrial Internet aims to be generic and application independent solution that has a horizontal integration and system approach. It is meant to be information, service and content centric and to support current and future applications and business models. The drawback is that Industrial Internet has not been clearly standardized or defined. Instead there are multiple competing research efforts and technologies that aim to provide the standard for Industrial Internet. There is a lot more hype around IoT than Industrial Internet which can be seen in the amount of research papers about IoT and Industrial Internet.

I wanted to understand the actual practicalities of Industrial Internet and because of lack of standards, I studied and searched for use cases. I found use cases of topics such as E-maintenance, waste management, building automation etc. These use cases discuss Industrial Internet from two view points: platform or devices. Platform use cases presented Industrial Internet as cloud based platform or system. The platform consists of certain software components that create value in the system. Other cases discussed the devices in an Industrial Internet environment. They state that devices should be application independent which will be enabled by Service-Oriented-Architecture. There were also other suggested features that would improve the integration with Industrial Internet systems.

I took these common characteristics and used them as requirements to propose a solution for an active magnetic bearing test bed. Our vision is that the test bed would benefit from an Industrial Internet platform that could be used to control and monitor the test bed. The platform would enable remote access to the test bed and the data. I proposed a two phase plan for creating an Industrial Internet platform for the test bed. First phase includes creation of the platform as a cloud service. I suggest using the already available software to fulfill the different requirements. CODESYS will present the controlling application and cpmPlus is the database. In the second phase the platform is modified towards component independency. There should be a “cloud service enabler” that provides interfaces for various system components such as the data base, controlling application etc. These components should be independent and interchangeable. The PLC device is not an Industrial Internet device and it cannot expose its capabilities as services. Therefore I also promote the creation of the “legacy gateway” that would allow the PLC to be exposed to the cloud platform.

The end purpose of this thesis is to provide a research direction for the AIIC. The scope included a literature review and configuration of the test bed for local use. The scope did not include the creation and implementation of the platform. The next step will naturally be the actual creation of the platform. Beyond that I suggest extending the platform to include additional devices. AIIC will supposedly obtain an overhead crane and the Aalto manufacturing technology lab has a machining center. First I propose connecting these devices to the cloud platform. The next step would be to add M2M communication to the system. Direct M2M communication between the devices could be the next step where the devices implement business logic without a supervising system. The devices could be used to study mesh networking in Industrial Internet devices: the AMB test bed would create a system event which is communicated through the machining center to the overhead crane. The machining center would act as a router in this case. In this kind of future system the devices would mainly function autonomically but they could be monitored and controlled through the platform at will.

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