LUT University
School of Energy Systems
Degree Programme in Electrical Engineering

Janne Kauppi

The Benefits and Feasibility of IoT in Mining Equipment - Tracking of Consumable Components in Industrial Filters

Examiners: Assist. Prof. Pedro Juliano Nardelli
PhD Annika Wolff

Master's Thesis
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ABSTRACT

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The benefits and feasibility of Internet of Things (IoT) in industrial filters was investigated from the point of views of a manufacturer and a mining company. The role of IoT in automation and enterprise management systems was also considered. The proposed analysis showed that IoT may help improving and integrating enterprise and automation systems by offering wide possibilities for acquiring new data, which enables potential new services and data-driven processes. The findings can be used for assessing the advantages and drawbacks of new IoT systems as well as supporting material for developing IoT in mining environment.

More specifically, IoT system architectures were researched and considered in the case of industrial filters. The system architecture research can be used as a guideline and starting point for developing new IoT systems in filters or other equipment. Lastly, consumable components tracking system architecture for filter presses was designed, which can function as an example for future IoT projects. The designed system employed RFID technology for automatic identification and locating of the components. The architecture was a hybrid solution of cloud and local-only systems for flexible deployment options.

TIIVISTELMÄ

LUT-Yliopisto
School of Energy Systems
Sähkötekniikan koulutusohjelma

Janne Kauppi

IoT:n hyödyt ja soveltuvuus kaivoslaitteissa - Kulutusosien seuranta teollisuussuodattimissa

Diplomityö

2019

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Työssä tutkittiin esineiden internetin (IoT) hyötyjä ja soveltuvuutta kaivosteollisuudessa, sekä laitevalmistajien että kaivosyritysten kannalta. Myös IoT:n sopivuutta automaatio- ja toiminnanohjausjärjestelmiin pohdittiin. Analyysin perusteella todettiin, että IoT voi parantaa ja yhdistää järjestelmiä tarjoamalla uusia mahdollisuuksia kerätä dataa, joka mahdollistaa uusien palveluiden ja dataan perustuvien prosessien toteuttamisen. Tutkimuksen tuloksia voi hyödyntää uusien IoT-projektien hyödyllisyyden arvioinnissa sekä tukimateriaalina IoT:n kehittämisessä kaivosteollisuudessa.

Lisäksi tutkittiin IoT-systeemien arkkitehtuureja, erityisesti teollisuussuodattimien tapauksessa. Arkkitehtuuritutkimusta voidaan käyttää oppaana ja aloituspisteenä tulevissa IoT-projekteissa suodattimiin tai vastaaviin laitteisiin liittyen. Lopuksi suunniteltiin teollisuussuodattimien kulutusosien seurantasysteemin arkkitehtuuri, joka voi toimia esimerkkinä tuleville IoT-projekteille. Systeemi käytti RFID-teknologiaa kulutusosien automaattiseen identifiointiin ja paikannukseen. Arkkitehtuuri perustui hybridiratkaisuun, joka voi toimia joustavasti joko vain paikallisesti tai myös pilvipalvelussa.

PREFACE

This master's thesis was written at Outotec (Finland) Oy in Lappeenranta during 2019.

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14.6.2019

Janne Kauppi

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NOMENCLATURE

ARM	Architecture Reference Model
DCS	Distributed Control System
EPC	Electronic Product Code
ERP	Enterprise Resource Planning
HMI	Human-Machine Interface
IoT	Internet of Things
IPC	Industrial PC
LPWAN	Low Power Wide-Area Network
NFC	Near Field Communication
PLC	Programmable Logic Controller
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
UI	User Interface
UML	Unified Modeling Language
WSN	Wireless Sensor Network

1. INTRODUCTION

The Industry 4.0 revolution has been changing the way that many industries operate during the last decade. The key element is Internet of Things (IoT), which has enabled previously unseen massive data flow by using networked and ever smaller sensors [1]. This has improved monitoring capabilities, controlling devices and finding previously “hidden” information by big data analytics [1], [2].

Some examples of IoT use cases and systems in industrial environments can be found in food industry, wood products, automotive manufacturing as well as many others [3], [4], [5], [6]. Likewise, mining industry is looking to implement IoT to improve the devices, processes and services [7].

Mining industry, like other big process industries, is commonly thought as conservative and slow to adapt new technologies, and IoT is not an exception. While other industries have widely adopted IoT even a decade ago, it is only during the recent years that IoT is booming in the mining industry. Starting with the first automatic truck experiments in 2008, Industry 4.0 vision has matured enough to be accepted and implemented in the industry in a large scale [8]. Mining companies are implementing plant wide IoT solutions to improve their operation, and the mining equipment manufacturers, who are looking for new ways to raise the performance and improve product differentiation, are doing the same across their product portfolios. The equipment can be very similar for different manufacturers and the pricing competition is harsh – therefore, innovations, quality and service are the selling competences. Industry 4.0 and Internet of Things fit this need well by improving processes and operation performance as well as enabling numerous service options. On the other hand, the significant growth of Internet of Things signals that those without IoT systems may soon find themselves clearly behind the competition [9].

While IoT is now being adopted in the industry, there is still some resistance to overcome. Large companies have the resources and benefit of scale driving their research and development of IoT and industry 4.0, but the smaller companies have a lot to catch up. If a company has problems with their existing technology, their interest in trying the new technology in the naturally slowly developing, large-scale bulk production industry is greatly reduced. Therefore, it is good to investigate the benefits and feasibility of IoT in the mining and mineral processing industries. It is important to note that different parties – mainly the manufacturers and their customers, the mining companies - may have different views on the benefits of the new technology.

One example of a manufacturer looking to implement IoT system is to track consumable components in an industrial filter. Industrial filters are used to remove liquids from concentrated mineral ore slurry, and they can contain hundreds of consumable components in direct contact with the slurry. These components are subject to wear and tear and need to be monitored and replaced regularly. Previously monitoring their condition has been manual labor and easily neglected by the mining companies, leading to unplanned production stops when a component has been damaged and needs to be replaced. An IoT tracking system could automate the monitoring and speed up maintenance, allowing predictive maintenance and avoiding costly unplanned production stops.

1.1. Research Goal, Questions and Methods

In this thesis the research is focused on industrial filters and the aim is to find out how IoT could be implemented to improve the filter operation or performance. The feasibility of IoT is evaluated in the existing automation and enterprise management solutions offered by manufacturing companies. The benefits and possible drawbacks of the new technology are also considered, from the point of views of a mining equipment manufacturer and a customer mining company. The thesis aims to produce an example architecture for an IoT system for industrial filters, firstly on a general level, then for a specific case.

The thesis aims to answer the following research questions:

1. What are the benefits and drawbacks of automation systems with IoT compared to traditional automation without IoT in industrial filters for manufacturer and customer?

2. What value does IoT provide in the case of industrial filters for manufacturer and customer?
3. How does technological and informational architecture of an IoT solution look like in the case of industrial filters?

The main research methods are literature review and case study. The literature review has two distinct topics: firstly, IoT in mining and other comparable industries and secondly IoT system architecture. Based on the literature review, the architecture design process is outlined and a general IoT architecture for industrial filters is modeled. Case study is carried out to establish an architecture model for a consumable component tracking system in an industrial filter by modeling the technological and informational architectures.

2. IOT AND MINING INDUSTRY

In this chapter the thesis topic is studied in the existing literature. Firstly, background information is established for mining industry, mining equipment manufacturing and industrial filters. Similarly, the background information is established for IoT and the most relevant technologies. These are achieved mainly by scientific articles on IoT and Industry 4.0, information from mining equipment manufacturers and by using other case studies as examples. The background studies provide grounds for evaluating the feasibility of IoT in mining equipment.

After the background studies, IoT architectures are researched, with the intent to explore different options for the system design and the best practices.

2.1. Mining and Mineral Processing

In mining and mineral processing the intent is to liberate and concentrate valuable minerals from ore deposits in the bedrock [10]. After the concentration process the minerals can be used for example in smelting process to extract metals.

The process of concentrating the valuable minerals is called mineral processing. Ore deposits (profitable mineral accumulations) are mixed with other minerals and rock which creates the need for concentration process [10]. The process stages are presented in Fig. 2.1.

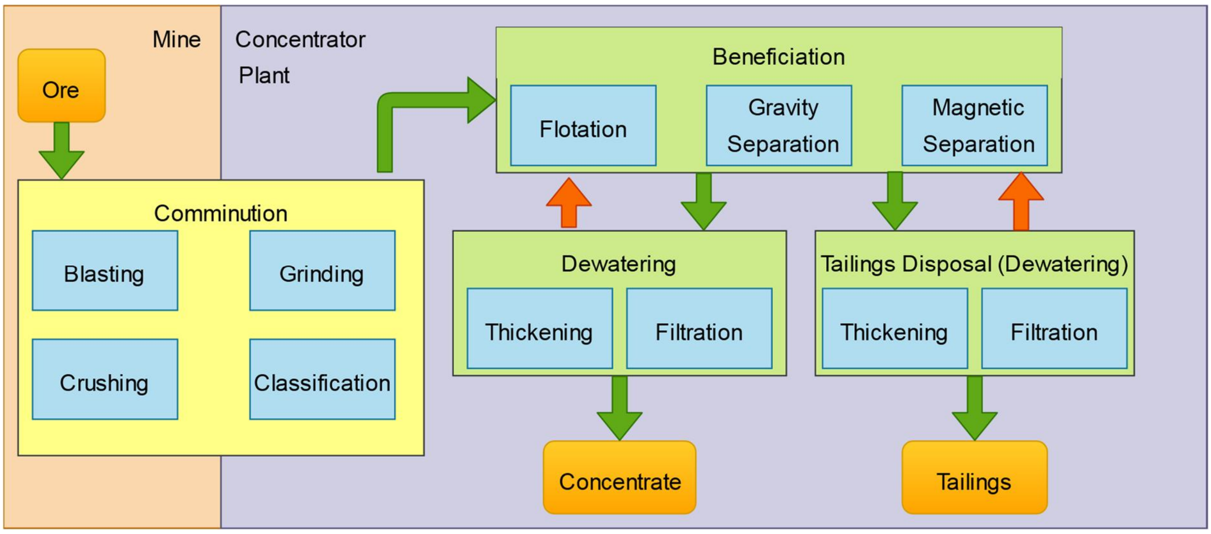

Fig. 2.1. General mining and concentration process block diagram, starting from the mine and ending at the concentrator plant with the concentrated product and tailings. Figure adapted from [10].

First step in mining is liberating the ore from the bedrock. This is mostly done by drilling and blasting with explosives [10]. The blasted rocks go through comminution process, where they are crushed to smaller rocks, usually starting already on the mining site for easier transportation [10]. Multiple crushers are used to get particle size distribution down to a few centimeters that is suitable for the next stage [10]. Crushed ore is then transported to concentrator plants, where crushing may be finished and then the process continues with grinding.

The grinding product particle size distribution must be smaller and more accurate than in crushing, because the goal of grinding is to get the particle size small enough that a single particle would contain mostly only single mineral type [10]. At the same time, overgrinding must be avoided. The optimal grind size depends on the process and the materials and can range from millimeters down to micrometers [11]. Normally during grinding water and chemicals are introduced to create slurry [10]. Screening and classification are methods to control the particle size in crushing and grinding stages [10], [11]. As grinding is the most expensive part of the process, sorting of valuable and non-valuable particles is normally performed already before it to reduce unnecessary grinding [10].

After grinding, the resulting slurry contains a mixture of small particles of different minerals. They are separated in beneficiation process. Common beneficiation methods are flotation, gravitational separation and magnetic separation [10]. In flotation, air bubbles (froth) are introduced to the slurry. Hydrophobic particles attach to the bubbles, start to float and are then collected while hydrophilic particles remain in the slurry [10]. Chemicals can be used to make particles hydrophobic or hydrophilic [10]. Gravitational separation takes advantage of the different density of different minerals and magnetic separation uses the magnetic properties of the particles [10].

The product of beneficiation is concentrated, almost pure ore. However, it is still mixed with liquids in the slurry form. Dewatering process removes excess water to prepare the ore for further processing as well as for transportation.

Dewatering is often done in two steps, firstly by thickening and then by filtration. Thickeners are used for high volume dewatering, while industrial filters can achieve much higher dry particle concentration at the cost of lower volume and higher operating expenses [10]. When combined, most of the water is efficiently removed in the thickener and the final product is achieved with the filter.

Usually thickening is done by feeding slurry into a funnel-shaped thickener, where solids settle in the bottom due to gravitational separation and mechanical raking [10]. The solids are discharged from the bottom of the thickener as dense slurry underflow and the clarified liquids from the top as overflow [10]. Coagulants or flocculants can be used to speed up the sedimentation.

Filtration can be performed with numerous different methods and the most suitable method depends on the slurry properties, such as particle size distribution [12], [11]. Most common filter types in mineral processing are pressure filters and vacuum filters, other filtration methods include gravitational and centrifugal filtration [12]. The methods can be divided into cake filtration, where the resulting solids form a cake, or depth filtration, where the solids are trapped inside the filtration medium [12]. Cake filtration is more common in mineral processing while depth filtration is common for example in water purification [12]. However, the basic principle is the same for all methods: slurry is fed into the filter, filtration medium separates the solids from the liquids and the resulting cake and filtrate are collected.

In addition to dewatering the ore slurry for the valuable minerals, the filtrate may also be important for water recovery and recycling, especially in very dry and remote locations [10], [11]. Another purpose is filtering wet tailings, that are the side-product of the beneficiation process. The amount of tailings is huge and there are several reasons to recover the water: water recirculation, reduce the spread of possible toxic chemicals as well as reduce the needed area for disposing the tailings [13], [14]. Recent tailings dam failures have also increased the interest in dry stacking tailings: new industry standards are being developed and more tailings dams might be replaced with filters [14], [15].

One of the oldest and still most common filter types is pressure filter, which has a stack of plates, membranes and cloths [12]. When pressed together, they form chambers between the membranes and cloths, where slurry can be fed. Air or water can then be pumped between the plate and the membrane to pressurize the chamber and push liquids through the cloth. The liquid is removed, and a cake forms between the membranes and the cloths. One type of pressure filters is shown in Fig. 2.2.

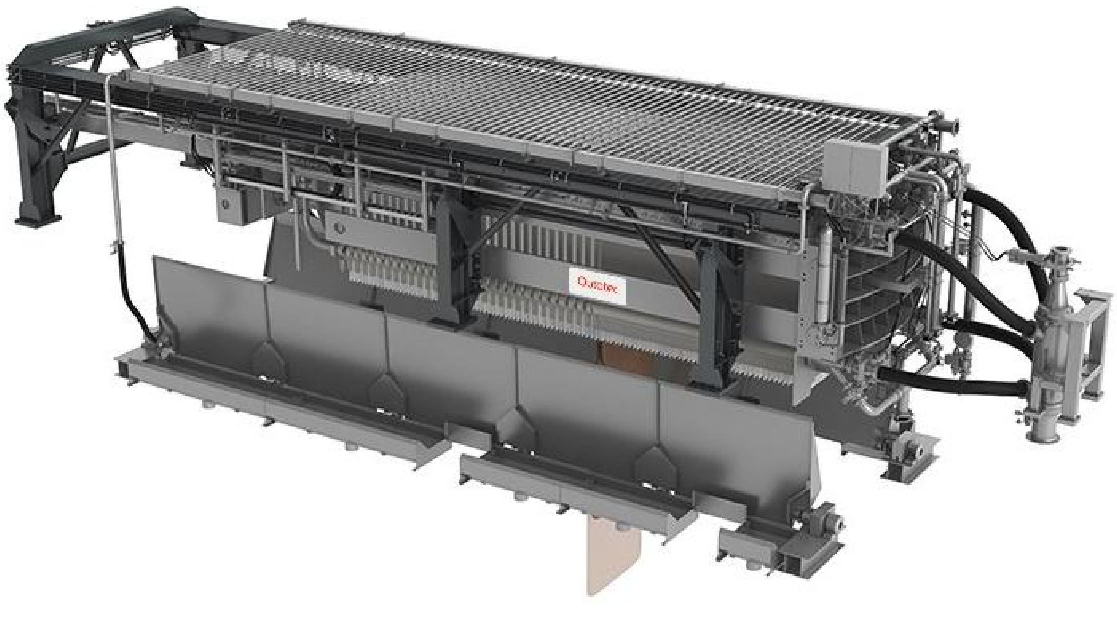

Fig. 2.2. Outotec Larox FFP pressure filter with vertically aligned plates [16].

Pressure filters are nowadays completely automated and are often preferred for their good filtration results, fast cycle times and small footprint in relation to their filtration area. On the other hand, they can be only batch operated and they can have high operating and maintenance costs.

Pressure filter plates can be arranged horizontally on top of each other as a tower or vertically side by side as in Fig. 2.2. The arrangement affects the mechanical structure, operation and slight differences in the filtration. Generally, the tower presses are used for higher quality filtration while the filter presses with vertical plates are used for higher throughput. One important difference is that the tower press needs only one long cloth that circulates between the plates, while the vertically arranged plates need separate cloths between each of them.

2.2. The Need for Innovations in Mining Industry

Industry 4.0 has been largely implemented in many industries, such as automotive and retail, during the last 10 years [1]. Identifying components on the production line and tracking the products in the shops and storages has improved the businesses greatly [17]. Mining industry is only now introducing IoT due to several reasons. First and foremost, the scale of the projects and investments in mining industry is huge and they normally take years to complete - there are not too many opportunities to involve innovations and testing new technology during a project. In contrast to, for example, automotive industry where changes to the product can be tested between every production batch or even single products, the wanted mining products are already defined before the plant construction begins and the production is in bulk. The equipment is intended for high production volume and long lifetime, and after the purchase and investment on equipment the incentive for new equipment and minor upgrade investments are low. Therefore, agile development has been traditionally rare in the industry.

Secondly, the industry is highly cyclical due to fluctuating market prices of metals and minerals [8]. During the high seasons, resources are used to answer the high demand, but during the low seasons there are few incentives or budget to carry out research and development [8]. Last but not least, development in the mining industry is expensive and slow, because safety and reliability requirements are high and extremely important. The development is cheaper and faster when new technologies have matured enough and are tested by other industries first – this way there are less concerns to adapt them. The same factors affect both the mining companies and the manufacturers.

Another point of view is that the slow introduction of new technology in the mining industry is caused by the hierarchical organizations [8]. Strong hierarchy allows easier management of the large-scale projects, but it also hinders the communication and knowledge sharing between different departments and requires management to be willing to innovate.

As IoT and industry 4.0 have been a hot topic for the last decade, they have shown and proven their benefits in other industries. At the same time, the mining industry now faces several factors that push for innovations [8], [18]. One major factor is the climate change and the continuously stricter public opinion and environmental requirements that require cleaner production throughout the life of a mining site and concentrator plants [19]. Another factor is Chinese manufacturing, which has driven equipment prices down and is hard to match by the manufactures in other countries. Also, many equipment product designs are very similar which drives the need for innovations and better service for competitive differentiation. The mining companies on the other hand need to focus on improving efficiency and management that were lost during the growth of the recent “super-cycle” and chase of economy of scale [18]. One solution to the challenges is data-analytics, where IoT can be very helpful [18].

Based on a mining industry supplier and customer survey, the most innovative mining companies share the vision of a so-called lights-out plant, which is fully automated and remotely monitored with no human employees [20]. The vision would increase performance, lower personnel costs and improve safety by requiring less human interaction with the equipment in a plant. However, the same survey indicated that the mining companies are not yet fully ready to pursue that vision, as it is considered too complex and risky investment. Additionally, many mining companies are still very cautious on sharing any process data and information, which limits IoT use case possibilities and slows their adoption. On the other hand, the survey revealed a clear difference in opinions and interests depending on the size of the company – big mining companies with well refined operations and technological solutions were much more interested in investing into and testing new ideas, while small companies felt they had their hands full with just the traditional automation.

2.3. Internet of Things

Internet of Things is a huge concept, which can be used to advantage in numerous different ways. This is emphasized by the fact that since the birth of the term “Internet of Things” in 1997 it still does not have a universally accepted definition [21]. Mostly IoT refers to connected things, which can be for example sensors used for data acquisition, that are then used to provide information for different services in nearly real-time. The rapid growth of IoT is closely related to developments on several other areas, namely energy efficient sensors and transmitters, wireless networks, databases, cloud computing and data analytics.

By utilizing Internet of Things and wireless sensor networks, previously unavailable or unused data can be collected, analyzed and then used to optimize processes or detect problems early. Big data enabled system-level analysis may reveal problems or optimization possibilities that were never found before [2]. Cloud storage and computing make it possible to easily combine data from different sources and locations and to process the huge data flow [1], [9].

More straightforward benefits are gained from identification and locating possibilities: individual sensors can be used to identify objects automatically and at the same time expose their location. The use cases for this technology are nearly endless – for example, it can be used in smart warehouses, smart cities and factories, hospitals, retail storages, tracking humans or items for safety and security reasons or for providing individualized service [1], [2], [22], [23].

The sensors and the data generated by them can also be used for more complex control, monitoring and simulation purposes [24]. Machine learning is a hot topic, where previously obtained data is used to teach the software how the system should behave and afterwards the software can notice abnormal situations from the current data or it could be able to optimize it better than other methods [25], [26]. Digital twins use the data to simulate or estimate the behavior and state of the system, which makes advanced control methods and testing possible [24]. Therefore, IoT often acts as an enabler for new, higher level technology, by acquiring data in such amounts or physical places that were not achievable before [24].

IoT was made possible mostly by the developments of wireless sensors and wireless sensor networks (WSN). New technology allowed reliable wireless operation and very low energy consumption, in some cases even so low that the sensors can be powered by energy harvesting [27]. The advancements allowed installing sensors in locations where they could not be previously installed and being low cost, they could be installed in great numbers, creating networks [24]. New networking solutions, such as ZigBee and publish/subscribe protocols allowed efficient communication for WSN [28].

One of the main drivers of IoT has been radio frequency identification, RFID. Low cost, passive RFID tags can be installed on objects and then used to identify them with unique electronic product codes (EPC) of the tags [29]. The passive tags don’t require other power source than the radio signals from the RFID reader device, thus making them energy efficient, small and long lasting [9]. There are numerous commercial solutions that can be very simple to implement and use. RFID allows automatic, wireless identification of tagged objects as well as locating them, making them valuable for all kinds of industries [24].

Other technologies, especially wireless communication, have been drivers for the rise of IoT as well. NFC (Near field communication) is based on similar radio frequency communication as RFID, but it functions at much shorter distances, only up to 10 cm and the communication can be two-way [9]. The energy efficiency and performance improvements of Wi-Fi and Bluetooth (and its Bluetooth Low Energy (BLE) version) as well as newer LPWAN (low power wide-area network) technology, such as LoRa, now offer a wide range of sophisticated options for wireless IoT communication [9].

As the IoT and information technologies have already matured, the research and development investments to these systems are on a more acceptable scale and commercial solutions can speed up the implementation. However, an IoT system always depends largely on the specific case, which means that engineering and testing is always needed for IoT projects, even with extensive use of already existing solutions.

2.3.1. Cloud and Fog Computing

With the massive increase of sensors and data created by them came the need for increased storage and computing capabilities. At the same time, the sensors needed to become cheaper and wireless, which meant low energy consumption requirements. Low energy consumption in turn puts a limit on computing capability. Huge data flow as well as low-power sensor hardware meant that new ways to process and store the data were needed to be developed and few companies would have the capital and knowledge to build the required datacenters [30]. The answer to this need was cloud storage and computing – huge datacenters that are sold as a service and accessible online [9], [30]. Some of the currently widely used cloud services are Microsoft Azure and Amazon AWS.

With the cloud services, customer who wants to use them can simply rent the needed storage capacity and processing capabilities [30]. The customer gets access to the industry leading algorithms and hardware immediately and for an affordable price, which cuts the development time and investments and leaves the cloud service customer to focus on their own core business [31]. The service is also scalable: the needed storage space and processing power can be adjusted automatically based on the customer's needs [9], [30]. As shown in Fig. 2.3, the cloud services support the numerous IoT systems by efficiently storing and processing the data. The sensor networks are connected to nearby gateways that are less energy-restricted and with higher transmission capabilities than the sensors [9]. The data from the sensors is transferred to the cloud data centers through the gateways. With this kind of hierarchy, the cloud service providers can operate at a great scale, and only few data centers are needed compared to the number of IoT devices and systems.

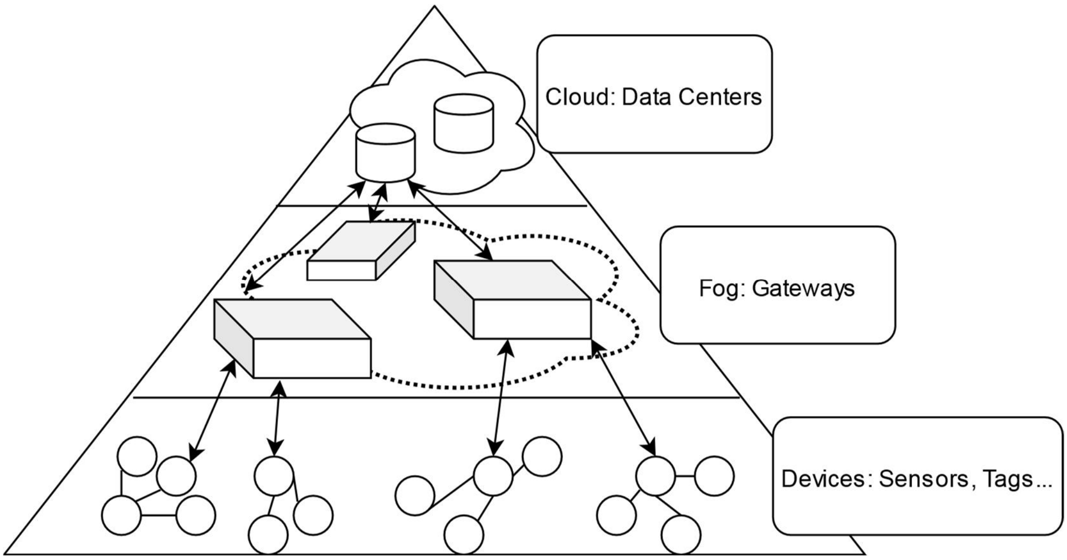

Fig. 2.3 The role of cloud and fog layers in IoT systems and the data flow from IoT devices through gateways to cloud service data centers. The pyramid shape illustrates the number of objects on each level: according to Al-Fuqaha et al. the scale could be hundreds of data centers, thousands of gateways and millions of IoT devices [9]. Figure adapted from [9].

Additionally, the cloud service is normally accessible from any location. This way, all the data from different sensors from different locations can be transferred to the cloud storage and processed there. Finally, the cloud service can provide easy to access web user interfaces, which can be completely tailored for different user accounts.

While the cloud services revolutionized data storage and processing, they still require internet connection. Transferring data to the cloud, then processing it and transferring results back to a machine or operator that needs the input takes time and a reliable connection [30]. This is fine for results that are not very time sensitive, for example performance analysis or condition monitoring reports over long time periods. However, results that are needed immediately cannot utilize cloud services reliably and instead need to be processed as close to the sensor and machines as possible [24]. Therefore, for example fully cloud based real-time process control is still not fast and reliable enough for most cases.

Other factors discouraging cloud service usage are data security and regulations. A self-managed private cloud can be an answer when there are enough resources for it, or alternatively a hybrid cloud. Hybrid cloud combines private and public cloud systems, so that sensitive data and applications can be stored and run locally on-premises, while less sensitive data can be uploaded to the public cloud, that is owned by a third-party cloud service provider [32].

Cisco company created the term and standard called fog computing for representing computing that takes place outside of the cloud, close to the data origin [33]. This computing itself has an older term edge computing, that simply means processing that takes place at the edge of the network instead of sending it elsewhere to be processed [9], [33]. In IoT systems, fog or edge computing commonly takes place in gateway modules or computers, as they are situated where they have direct access to data from the sensors, as shown in Fig. 2.3. Fog computing standards aim to present the best ways to implement edge and cloud computing so that the time sensitive data can be processed immediately and other data in the cloud [9]. Fog computing and hybrid cloud manage similar cases, with the difference that one uses traditional computing units and the other local, private cloud computing.

As a summary, the main advantages of cloud services that have made the quick growth of IoT systems possible are accessibility, scalability, outsourcing IT infrastructure investments and management and industry standard algorithms for data storage and processing. Challenges include real-time process compatibility and data ownership, privacy and security.

2.3.2. Examples of IoT Use Cases

IoT has potential in widely different settings and scenarios. Some of the most common purposes for IoT systems are identification and tracking, for which small, cheap and wireless sensors or tags are ideal. Another common IoT use case is to leverage the same features to deploy a large WSN for monitoring purposes. The data produced by the mentioned methods provides numerous possibilities by data analytics.

Some examples of IoT use cases from different industries have been collected in Table 2.1. It can be noted how the similar methods (e.g. object tracking) can be useful in completely different environments and create value in different ways.

Table 2.1 Examples of IoT use cases in different industries.

Industry	Methods	Use cases	Reference
Automotive	Tracking, Management	Identification and tracking of components in manufacturing. Production management based on demand and component supply.	[6]
Packaging Manufacturing	Monitoring, Predictive Maintenance	Detection and prediction of low-quality production cycles or failures, predictive maintenance.	[26]
Pharmaceutical	Tracking	Tracking of products and their origin. Quality assurance.	[34]
Lumber	Tracking	Tracking of products and their transportation and origin.	[5]
Agriculture	Tracking, Monitoring, Locating, Optimization	Farming optimization and automation. Livestock feeding and growth tracking. Product tracking for transportation & distribution management. Product quality assurance (e.g. temperature monitoring).	[35], [36]
Nuclear energy	Monitoring, Safety	Monitoring radiation levels with WSN.	[37]
Retail	Identification, Tracking, Monitoring	Loyalty cards (customer identification), monitoring product stock levels, real-time pricing, easy product information queries.	[36]
Oil & Gas	Monitoring, Predictive Maintenance, Locating	Pipeline condition monitoring, predictive maintenance, locating broken components or breaks in pipelines.	[38]
City Management	Monitoring, Management, Optimization, Safety.	Flood monitoring and warnings. Smart city: traffic management, energy consumption optimization, etc.	[35], [39]

Based on the examples in Table 2.1, most IoT systems concern item identification and tracking in manufacturing, transportation or warehouses. The systems are often used to provide quality assurance, improved management as well as operation optimization. Additionally, the systems enable individual services as well as services for all citizens.

Likewise, some IoT solutions have already been designed and implemented in mining industry as well. The first solutions were improving or introducing new monitoring capabilities that make the plants safer for the workers. Also plant wide monitoring and tracking networks have been planned and tested. Large scale projects have included autonomous hauling trucks, trains and drilling [40].

One example of new safety monitoring measures is IoT rock bolt, that is used in tunnels to transfer the load of the tunnel wall further to the untouched rock [41], [42]. The rods could be damaged by seismic activity, so sensors and communication network have been introduced to monitor the condition of the rods [41].

Tailings dams are huge pools for collecting tailings slurry, which is process waste material that cannot be used or is not worth the cost to use. The dams are perhaps the easiest and cheapest method for disposing of the tailings, but the mass of the collected slurry is a safety threat to everyone and everything nearby them. During the recent years, several disastrous tailings dam accidents have happened, causing hundreds of human casualties and destruction to nearby infrastructure and environment [13]. To prevent these accidents, the dams are monitored, but manual monitoring might not always be possible and is prone to human error. An IoT based WSN has been designed to measure pressure and surface levels as well as deformations to give continuous information on the condition of the tailings dam [43]. Alarms can be given if any measurement crosses a set critical level and it is also possible to give the alarm to civilians living nearby the dam by mobile phones.

A personnel and equipment tracking system has been designed and tested in a smelter shutdown operation [8]. It allowed locating personnel at all times to ensure their safety as well as qualification and permission to enter high-risk areas. It also made possible to optimize the routes that the personnel travelled, turning time spent in travelling through the plant to productive work and their locations could also be used to later figure out which project they worked on. Even worker fatigue could be estimated from the distances the workers had walked during the day. Tracking the equipment also improved the productive working time by ensuring that the personnel could always find the correct tools for the task.

Autonomous trucks and trains have been deployed by Rio Tinto mining company and Caterpillar manufacturer, among others [8], [40]. The data gathered from hundreds of sensors in each vehicle makes it possible to model and monitor them digitally in real-time. By using cloud services, the terabytes of daily data can be processed and stored quickly [8], [40].

Equipment manufacturers are developing IoT systems directly into their products. Most of the new systems concern asset tracking and product condition monitoring to provide better information for the operators when the equipment is in use or to get information on their maintenance needs. Big data and machine learning are also gathering interest to better optimize the processes as well as to notice early signs of possible problems with the equipment or the processes. One noticeable difference between the IoT systems designed by manufacturers and mining companies is the scale: mining companies are often more involved in plant wide systems, while manufacturers deal more with single machine or equipment type and eventually their integration to bigger systems.

2.3.3. IoT for Mining Companies and Manufacturing Companies

One consideration for importing IoT into mining industry has to do with the two different parties, manufacturers and mining companies. While plant wide IoT projects are mostly designed and closely monitored by the mining company, implementing IoT into the mining devices and machines is done by the manufacturers themselves. It is not sensible for the mining companies to install IoT products into these devices as they would risk voiding any warranties and service the manufacturers give. Therefore, getting the benefits of IoT relies largely on manufacturers and the cooperation between the two parties.

From the manufacturers point of view the most important metrics are competitive differentiation, customer satisfaction and acquiring knowledge for improving the products and services. On the other hand, the mining company customer is usually interested in the performance and efficiency, delivery times, product prices and maintenance.

Controversies appear when manufacturer is looking to improve their knowledge, but mining company wants to keep their business a trade secret. If the manufacturer wants to gather data from the machines sold to their customers, they need to be reliable and trustworthy and have secure technology. Internally the manufacturer must have good data handling policies and trustworthy employees. The manufacturer may need to show great transparency and methods to prove these to their customers.

On the other hand, letting the manufacturer collect data from their devices is beneficial for each party. Direct benefits for the mining company would be service from the manufacturer that helps them to adjust their processes to optimally use the devices. This way the performance and lifetime of the devices can be maximized quickly, by using both the data and the expertise of the manufacturer.

Another benefit from the data collection is the possibility for the manufacturer to improve their products. The improvements can later be implemented as upgrades or modernizations or in the form of new devices if the mining company wishes to expand their business. The continuous improvements could also help with the previously mentioned service to improve and adjust the processes.

In a larger scale, the plant data could be compared against other similar plants to fix problems and to improve processes – solutions would not only rely on the manufacturer’s expertise but also on the actual data from other plants around the world. The manufacturer could create their own comprehensive database of all their products and quickly find solutions for the mining company customers. This however requires great care and confidentiality from the manufacturer – even though the benefits are obvious, the data must be secured and strictly only about the device itself in order to not risk leaking information and breaking the confidentiality.

2.4. Reference Architectures

Architecture design is the central idea that combines all the components of the system together. It determines the functionality of the system, the core elements and the topology of the communication network. IoT system architecture is closely related to traditional industrial network architectures, but the nature of the sensors (and their network) creates big differences. When looking at an IoT system, there can be hundreds of sensors creating data, which needs to be handled efficiently. Another common feature in IoT systems is wireless communication, which requires its own protocols and devices.

There are numerous IoT architectures for different cases that often share many common factors. For a long time, a common problem has been the struggle to design architecture for each different IoT case from the ground up, and many have hoped for a standardized reference architecture. Nonetheless, every IoT case is somewhat unique, as the sensors and their requirements differ as well as the requirements for the communication, such as efficiency, bandwidth and reliability. Since IoT has such a wide range of completely different use cases and the technology is progressing at a very quick pace, standardization has not been very successful. This has led to numerous different standardization efforts, architecture designs and redundant development, as companies and organizations have developed their own systems to answer the problems [44], [45]. It has gone to the point where there are even too many standards, and the current efforts are concerned to unify the standards by using same terminology, definitions and other collaboration [45].

Developing standards takes time; another way that allows faster standardization is open source frameworks, that are being developed by alliances of numerous companies and research groups. Open source frameworks allow collaboration, security through peer-reviews from other collaborators and the finished frameworks are free or low cost to use, therefore a good open source framework can be expected to become widely adopted in the near future. One example is Open Connectivity Foundation (OCF) that has over 300 members, including Microsoft, IBM, Cisco and Qualcomm [45].

One notable example project that created an IoT architecture reference model (ARM) is IoT-A, completed in 2013 and funded by the European Council [44], [46]. The project produced guiding material for the design process that helps to gauge the scale of the system and the important factors in it as well as unifying the terminology and design choices – however, it is very high-level and abstracted in order to apply for different IoT applications.

IoT-A approached IoT architecture modeling by considering the system in different contexts to understand the case problem and how the architecture could be built [46]. Some of these contexts are physical interactions, information flow, functionality, communication and security. Main part in IoT-A is IoT Domain Model, which includes all physical and virtual objects that affect the system and how they are connected. Each context model, called view, are representations of specific aspects of the architecture and illustrate how the architecture addresses different concerns [46].

IoT-A was also one of the reference architectures that IEEE used in their research and report on definition and key concepts of IoT [21]. According to the report, there is a set of “minimal architectural components that an IoT system must possess”:

- User: a person or a digital entity, e.g. application, that interacts with the system
- Physical entity: a physical object that is of interest to the user. Their digital representations are called virtual entities, and together they form an augmented entity
- Device: sensor, tag or other device that is used to associate physical objects with virtual objects
- Sensor operating system: software that operates the sensor
- Middleware: software between the sensor and enterprise software, that configures and manages the hardware
- Resources: software components, such as databases, that provide the information about the physical entities
- Service: provides the interface that exposes the system functionality and resources for the user. [21]

Another take on the IoT architectures are layered stack models, that are well known in the telecommunication science. Traditional telecommunication network architectures have been commonly divided into protocol stack layers, where information moves through the stack and each layer has a specific function that is not dependent on the other layers. The most used standard is OSI reference model with seven layers, starting from the physical connection and ending to the application layer [47]. More recent take on the layered architecture is a three-layer stack, which includes Link, Network and End-to-End layers [47]. Applications are their own layer on top of the others.

Similarly, protocol stack models were common in the studied IoT architecture models. Although the models had similar goals, they had different focus areas as the models ranged from three to seven layers: some focused more on the sensors, some on the applications and others on the middleware. Some of the common models are shown in Fig. 2.4 and discussed in [9]. The main differences in the IoT architectures compared to OSI and three-layer network model were higher importance of the physical connections, service and device discovery and lighter messaging or transmission protocols due to energy saving and bandwidth limitations [48]. As a result, IoT architecture stacks often included a perception or sensing layer for physical interactions, network layer for connectivity between nodes, gateways and server or cloud layer, discovery layer for detecting other nodes and services and messaging or application layer for transferring information between servers and clients [48], [49]. As an example, IEEE categorized three layers: Physical Layers, Interrogator-Gateway Layer and Information Management, Application and Software Layer [21].

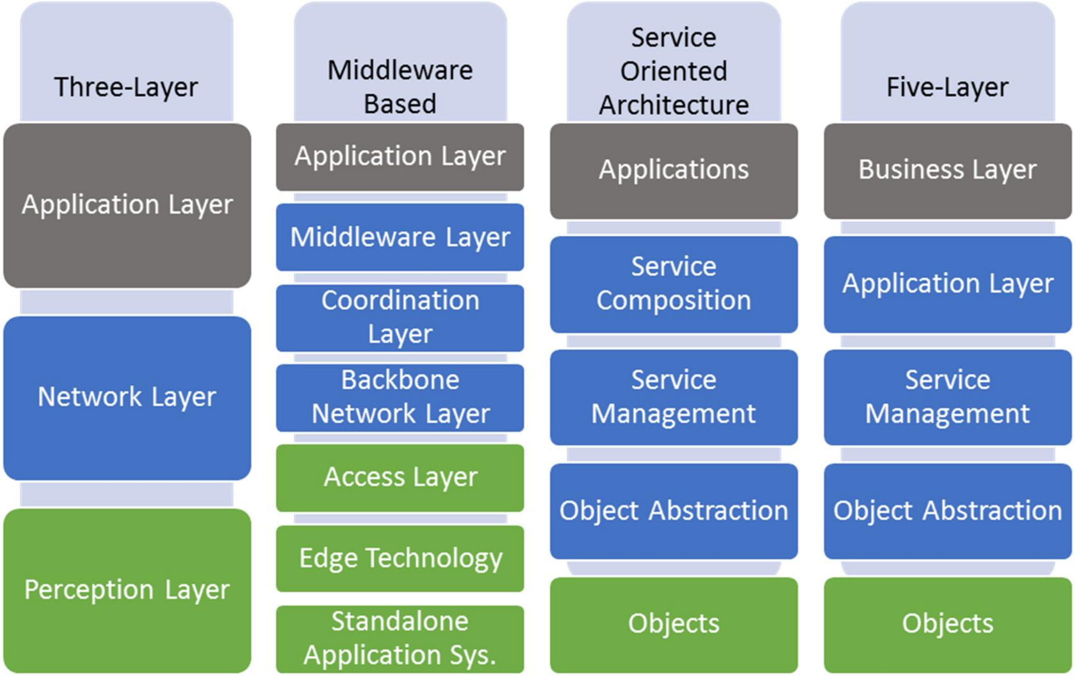

Fig. 2.4 Examples of IoT system architecture models. The models have similar structures and shared features, as indicated with the colors, but they differ depending on the focus of the frameworks they were built on. Figure adapted from [9].

The division to layers is useful in the higher-level design, as it allows designing the different modules independently, but how they perform their function is left to the architecture designer. As shown through the number of different IoT models, it is not straightforward to design an IoT architecture, as different systems (and their designers) have different concerns.

2.4.1. IoT-A Reference Architecture Model

One of the most popular IoT reference architectures is IoT-A. It provides guidance and tools to understand and design IoT system architectures in a general level and adapting them to specific cases. In other words, the project aimed to provide a common ground for every IoT domain architecture. Therefore, it is a good starting point, but much is left to the designer when adapting the architecture reference model (ARM).

The main product of IoT-A ARM was the IoT Reference Architecture itself. Additionally, the project produced material regarding the usage of the reference architecture, as well as the concepts and definitions related to it. The reference architecture consists of different models, each describing a certain concept and how they relate to each other. The central model is IoT Domain Model, which “describes all the concepts that are relevant in the Internet of Things” [46]. Other modules are Information Model, Functional Model, Communication Model and Trust, Security and Privacy Model [46]. The information model describes the information structure and interfaces as well as the attributes and services. Communication model aims to identify protocols and gateways needed for interoperability of the elements. Functional model explains the functions of the elements in the system, divided into functional groups: Management, Security, Communication, Service Organization, IoT Service, Virtual Entity, IoT Process Management and additionally Device and Application. Lastly, Trust, Security and Privacy Model describes the methods that are taken to ensure the module’s namesake properties.

To help creating the models the project introduced architectural views, which are used to find the components and actors that influence the specific view and how they relate to each other [46]. The views include:

- Physical Entity view
- Deployment view
- Operational view
- IoT Context view
- Functional view
- Information view.

As an example, the Physical Entity view includes all physical objects that affect the system. Such objects can be devices (sensors, tags, actuators), humans, mechanics, etc.

Finally, perspectives are used to guide the architecture design process. A perspective in IoT-A is a qualitative aspiration and as such may concern several views [46]. IoT-A considers the most important perspectives for IoT to be Evolution and Interoperability, Availability and Resilience, Trust, Security and Privacy and Performance and Scalability [46]. The simplified IoT-A architecture design process is presented in the Fig. 2.5.

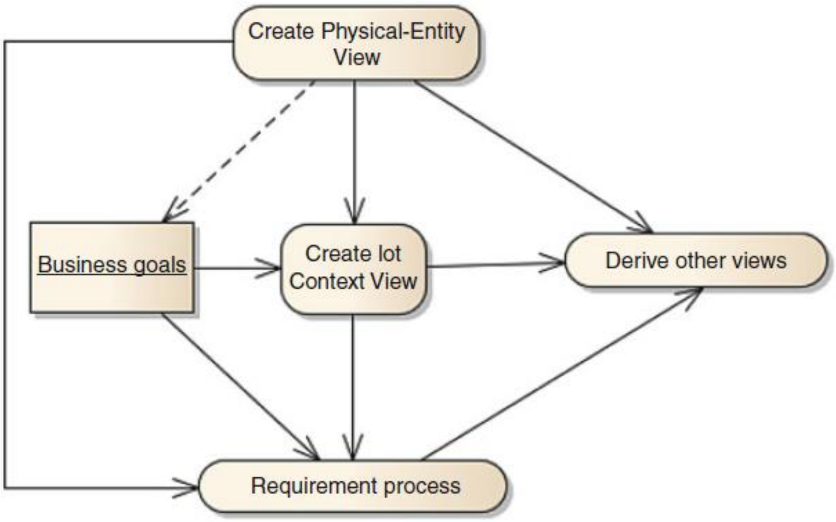

Fig. 2.5. Simplified IoT-A architecture design process. The process starts by creating Physical Entity view and then IoT Context view. The views and business goals are used to form the architecture requirements. Lastly, other views are created to complete the architecture. Figure from [46], published under Creative Commons license.

When creating an architecture by the example of IoT-A, the first task is to define the Physical Entity view, as shown in the Fig. 2.5 – in other words, defining every physical thing that affects the system. Continuing from Physical Entity view and with the guidance of business goals, Context view and then IoT Domain model can be created. These form the basis for designing the architecture. With these views and the business goals, requirements can be defined by various requirement engineering methods, threat analyses, perspectives and other design choices. Finally, other views including Functional, Information and Deployment views can be derived to complete the architecture.

Context View and the IoT Domain Model included in it can be considered the heart of an IoT-A architecture. They explain the key concepts that the system tries to achieve and link the physical and virtual entities and show their basic interactions. A skeleton example of a Domain model is given in [46] and shown in Fig. 2.6.

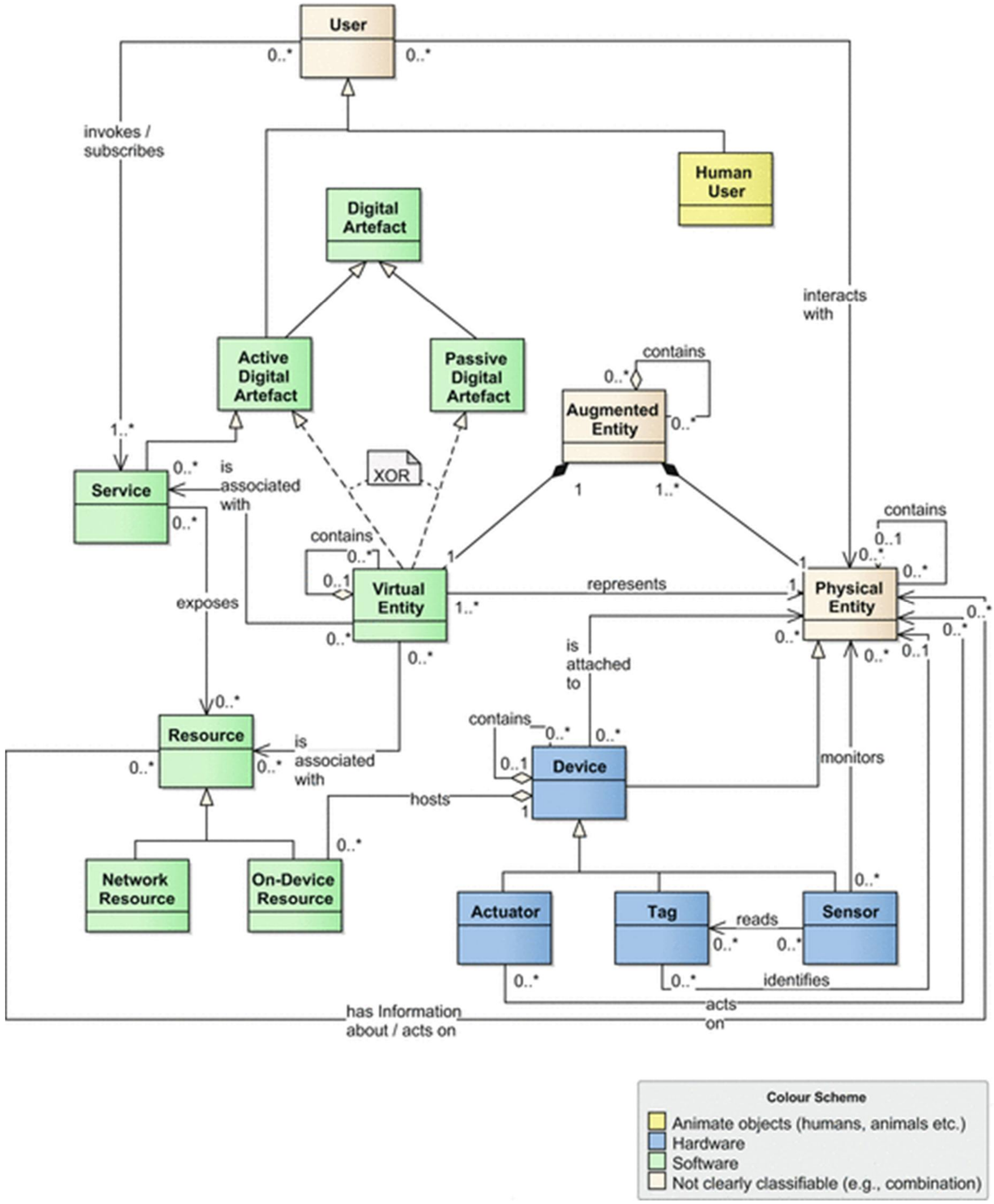

Fig. 2.6. IoT Domain model example in UML (Unified Modeling Language). Figure from [46], published under Creative Commons license. In UML, a hollow triangle depicts a generalization (the tip points to a general classifier), diamond depicts aggregation, arrow navigability (object at the end of a line can see/reference the object the arrow points at) and dotted lines dependency or abstraction.

As shown in Fig. 2.6, a user interacts with software service, that is a part of a digital artefact. The digital artefact consists of virtual entity (which represents a physical entity) and software resources, that are gathered from IoT devices or from elsewhere through network resources. The devices interact with the physical entity.

With the physical entity and context views, as well as business goals, the system requirements can be defined with any requirement engineering method. IoT-A divides the requirements into three categories: view, design constraint and qualitative requirements. View requirements are mapped into their respective views to guide their design and design constraints set the constraints for the views and the whole system. Qualitative requirements usually affect the complete system and are mapped as perspectives or tactics created by the architect.

Next, functional view is created. IoT-A provides a functional model, that divides functions to different groups. Inside the groups, different functionalities are divided into functional components. View and constraint requirements are mapped onto specific functional groups to aid their design.

Lastly, other views, such as information view, can be generated to form the architecture.

2.4.2. Main Architectural Considerations

Perception or sensing layer, the lowest level of the IoT stack architecture, is the core element of any IoT architecture, as can be observed from Fig. 2.4. However, the actual implementation is nearly always case specific and depends greatly on the chosen sensors, objects and environment.

Firstly, there are the devices, such as pressure and thermometers or RFID tags and antennas. Next, middleware (gateway) is needed – middleware is the components that are needed to connect to, use and read the sensors and to transmit the acquired data further. A common example is RFID reader, that activates the antennas, reads the tags, upkeeps a tag inventory and finally transmits the information further.

Next architecture decision is about the connection of the sensors or middleware: wired or wireless and the requirements depending on the sensor network size. In a wireless network the protocol must be decided, often by the choice between energy consumption, signal strength, transmission distance and bandwidth. For higher performance protocols the network can be clustered for different gateway components. IoT specific protocols, such as ZigBee, can be used to reduce the needed gateways and the energy consumption. For wired connections, switches or gateways can be used to cluster big networks, but smaller networks may have direct connections.

When the data is collected from the sensor network, it needs to be stored and processed to gain useful information. For that the first option is to implement a local database and processing unit. The main question is, should the system be local only or in the cloud. Both options have their pros and cons.

The most important benefit in a local only system is the complete control and ownership of the system. This makes security management easier, as the system does not need a connection outside the plant and the access to the system (software and hardware) can be well monitored and restricted. There are also less legal worries about the system or data ownership – everything belongs to the system owner. On the other hand, costs for the local only system can be high. The owner is responsible for all initial investments, maintenance, development and security, including the knowledge and experience required for the tasks.

In a networked solution, the data is sent to a central database that may be owned by another party. The central database therefore is inherently worse security wise, because it requires trustworthy partner who has the knowledge, skills, capital and equipment that can ensure the performance and security. However, it also has several desirable advantages. Firstly, it removes the need for technological knowledge that is required for maintaining the storage and processing servers as well as the investments in them. The server provider may also offer stability and redundancy by having many data centers across the globe, which would be a huge investment for any company.

3. IMPLEMENTING IOT IN MINING EQUIPMENT

In this chapter possible ways to implement IoT in mining equipment are considered as well as the reasons why (or why not) it could be an improvement.

Firstly, the benefits and problems of IoT are considered for mining equipment. This is done by comparing IoT features and possibilities discussed in chapter 2.3 to modern distributed control system (DCS) and programmable logic controller (PLC) based machine automation. Additionally, the value of IoT features is considered from two different point of views: equipment manufacturer and mining company.

Secondly, IoT system architecture design for industrial filters is considered. IoT-A reference architecture is used as the base and the key design questions for filters are investigated. As a result, a general idea and guidance are formed for the IoT architecture design process.

Together, the benefits of IoT and the architecture considerations for filters form the grounds for identifying and developing new IoT system designs for industrial filters.

3.1. Benefits of IoT in Mining Equipment

The push to develop IoT systems has been huge, and some may develop it simply because everyone else does. In business, technology cannot be developed only for the sake of the technology and hype; there should be benefits and value in new technology and development investments.

3.1.1. Modern Automation and How IoT Fits in It

Modern automation is often modeled as in Purdue Enterprise Reference Architecture (PERA), where the enterprise systems are divided into five levels, as presented in Fig. 3.1 [50], [51]. The levels 3 and 4 in Fig. 3.1 include higher level systems, such as manufacturing execution system

(MES) and enterprise resource planning (ERP), that are concerned on subjects like production output, targets and scheduling and make the higher-level decisions that the lower levels act on.

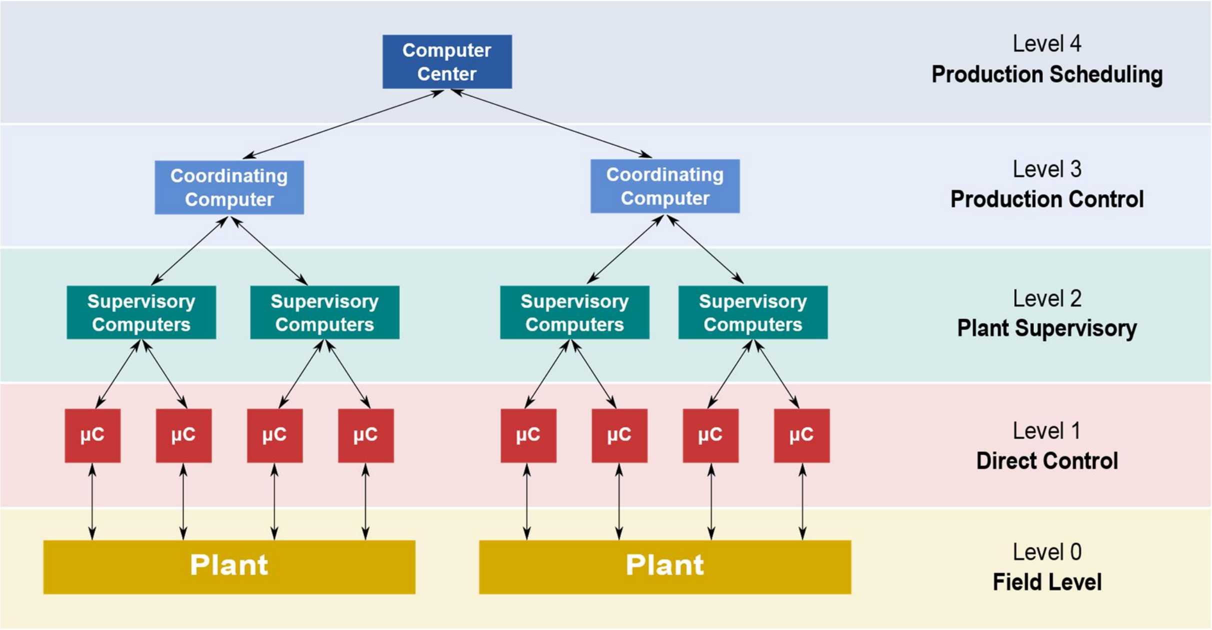

Fig. 3.1 Functional levels of a DCS, based on Purdue Enterprise Reference Architecture. Figure from [52], published under Creative Commons license.

The lower levels contain plant automation system. A plant, such as a mineral concentrator plant, consists of numerous different complex machines that need to function together in the process. To accomplish that, distributed control systems (DCS) are commonly used. In DCS, controls of different machines are divided to their own grouped systems, as in level 1 in Fig. 3.1. The groups are then connected in a DCS to a larger controller unit (level 2). The controller units are used for process control, that also provide overall monitoring and control capability for the operators.

DCS may also include SCADA (Supervisory control and data acquisition) system. Earlier, DCS and SCADA used to be two different ways to implement plant control systems, but modern technology has blended and combined their features. SCADA (or DCS control center) is used to present necessary information such as the process or plant state for the operators. In a sense, it is an early form of IoT: it acquires great amounts of data from the plant sensors, analyses it and displays the information. Some general differentiations in IoT are larger sensor networks, smarter sensors and internet connection for cloud services. More importantly, the goal of SCADA and DCS is to control and monitor, while IoT focuses in the analytics part for extracting more information. Ultimately, DCS and SCADA can be one part of a larger IoT system.

When considering the scope of equipment manufacturer in mining industry, the automation usually deals with the lowest three levels – instrumentation, machine automation, and connection to plant DCS. In projects that are larger than delivering machines, or when the product itself is higher level automation, the higher levels are also included.

In this scope, IoT can mean addition of new sensors, such as wireless sensors allowing their installation in new locations, and larger sensor networks. IoT can have a cloud service connection and integrate more enterprise systems there for data analytics purposes. The IoT system can also help advanced process control.

The first level includes PLCs that are used to interact with the sensors and actuators in the lowest level and to take care of controlling single discrete parts of a process. PLCs normally manage the operation of a single machine, such as a filter in a mineral concentration process, based on the commands from the DCS control unit. IoT has less direct effect on the PLCs, because analytics are generally performed on the higher levels. IoT may still enable usage of new features by changing the way DCS or other higher-level systems function.

On the other hand, small IoT systems may run locally alongside PLCs as well. New industrial PCs (IPC) are becoming more and more common, and they can offer complete PLC or soft PLC functionality and, at the same time, run for example a Windows operating system that is close to the usual office PC operating systems. Therefore, some IoT systems could run alongside PLC controls and store, analyze and display information right next to the equipment or use it for the control. A separate IPC could also be used for small scale IoT systems as both, a gateway for transmitting data for further processing as well as an immediate, local system. When separated from the actual control system, it is also much easier to ensure that control system keeps functioning as intended and the IoT system can be easily added to existing equipment.

The differences of PLC, DCS and SCADA systems were clear when they were first used some 50 years ago. Today, their definitions are blurry, as each of them can do similar tasks – the main difference becomes the focus of the system. Addition of IoT will blur the lines even further by making information available to all levels. IoT can also include the higher-level systems more in the automation decisions.

3.1.2. IoT Value Proposition – the Benefits, Problems and Feasibility

What value IoT can bring, when it is implemented into mining equipment? There are many benefits, but an important note is that the benefits can be different for the manufacturer and the customer, sometimes being a benefit for only one of them.

The main product of IoT is large amounts of new data. How does that data transform into desired business values and features, such as lower costs, faster operation and higher quality and efficiency? The first thing that the data can be used for is increased and enhanced monitoring capabilities. With better and automatic monitoring, problems can be found earlier, safety can be improved, data-based process improvement is possible – overall, there will be less unwanted surprises.

A further use of the monitoring data is predictive maintenance. After collecting data during normal operation and comparing new measurements to it unusual behavior can be detected, and for example component lifetime estimates can be calculated. Predictive maintenance allows the customer to plan the maintenance in advance and execute it before the component’s lifetime is over. The result is less downtime due to preparation and avoiding possible additional damage caused by a broken part.

Predictive maintenance can be complemented with location and identification data. Then the specific component that requires maintenance can be immediately located, reducing greatly the time needed for the maintenance when there are several similar parts or when they are in hard to reach locations.

The equipment monitoring can also give operational security for the customer. The customer buys equipment based on the information given by the manufacturer. With the monitoring capabilities, the equipment performance can be validated, essentially either proving that it works as promised or not. This would promote quality and increase trust to the manufacturer. The information could also be used to at least partly automate ordering new spare parts when needed - avoiding the need to manually estimate the amount of parts needed, checking the existing stock levels, finding the correct ordering numbers from the manufacturer's catalogs. When done predictively, it would also give the manufacturer time to prepare for the delivery and ensure that everything runs smoothly. On the other hand, the system might face several problems, such as the integration with the customer's enterprise resource planning (ERP) system and data sharing policies and is therefore mostly applicable for large management solutions or long service contracts.

Data collection, when combined with cloud technology, can be used to deploy big data analysis and other computational methods like machine learning and artificial intelligence (AI). All these can be used to find completely new information, patterns that happen rarely or that are too small to notice but can still impact the performance or lifetime. They can also be used for automated maintenance and fault prediction.

The cloud technology gives other benefits for IoT systems as well. Any necessary updates can be done on the background and the customer does not need to think about acquiring, running or maintaining the hardware. The cloud system can provide one simple user interface (UI), where all the different equipment and services can be integrated, eliminating the problems that arise when multiple software programs are needed. Having all the data in one place also makes it easier to run AI, machine learning and big data algorithms across different equipment and even the whole plant. Lastly, the cloud connection can allow access from any location, minimizing the network complexity and problems with plant firewalls.

For the manufacturer, all the previous benefits result in increased customer satisfaction, leading to increased chance of returning customers, increased spare part and service sales, more options for upgrade sales and increase in overall good reputation.

If the customer allows the manufacturer to use the collected data, it provides the best possible grounds for product development. Remote support cuts the costs of travelling and allows faster response times, again helping the customer and increasing the customer satisfaction.

When done properly, all these features provide great competitive advantage. Additionally, by integrating multiple products and services in the cloud-based user interfaces, the customer may get used to one tool and ecosystem, which promotes the manufacturer for future contracts with them.

However, as mentioned, there can be crossing views on some of the features. Most conflicted are the data collection, data ownership, its use and the connections. Plant production data is often confidential, and external connections not allowed. The manufacturer must have the trust from the customer and make the IoT system product as transparent as possible for the customer, so that the customer can make a fully informed decision on giving access to the equipment data and to get all the features.

It is also possible to create a local cloud and a completely local system. The system could provide most of the benefits of IoT, and mainly lack in the cloud-based computing unless large investments and development work is done for it. Remote support and monitoring are another area that would suffer from local only system, but the connections or data transfers could still be arranged as needed. Updates and integrating new equipment would also need more work.

3.2. Architecture of an IoT System in Industrial Filters

Designing the initial overview of the architecture may be easiest with the protocol stack models. The first step in architecture design is then defining the perception layer, the lowest level in the three-layer protocol stack model, as in Fig. 2.4. The most suitable technology for measuring, identification or other actions needs to be decided along with the devices and objects to accomplish them. This includes for example RFID tags and smart sensors.

In the network layer the required gateways, computing units and other devices need to be defined for the purpose of transmitting and preprocessing the data gathered in the perception layer. Examples are Wi-Fi and Bluetooth transmitters, as well as routers that can be used for cloud connections.

Lastly, the Application layer defines hardware and software needed to perform data analysis and to establish the services that the system is made for.

After the designing the initial overview of the architecture, a more detailed basis for IoT system architecture design can be defined. Next, IoT-A reference architecture is followed to create a general architecture for IoT systems in industrial filters. The purpose of the general architecture is to present the most important aspects and design choices that the environment and the filters create.

IoT-A Reference Architecture

IoT-A reference architecture provides steps to produce the architecture by dividing it into contextually separated parts, that are called views and models. The most important parts of the IoT-A architecture are Physical Entity view, IoT Domain model and Information model. The IoT-A architecture generating process is shown in Fig. 2.5 and followed to generate the general filter IoT system architecture.

Physical Entity View

In the Physical Entity view, the obvious core physical object is the filter itself – a mechanical structure with motors, pumps, moving parts and numerous components that affect the filtration. However, the whole filter is not relevant for most IoT system architectures. Instead, specific components of the filter should be considered as the relevant physical entities. These can for example include components whose operation affect the system, those that are being measured, as well as those where other IoT system components might be installed on. Additionally, the process material (before and after filtration) may also be a relevant physical entity, when the system is directly related to it. For example, a moisture measurement system is directly related to and in contact with the process material.

A general Physical Entity view is formed around the filter. As the view is most dependent on a specific case, it cannot be modeled precisely – it merely helps to identify the important entities for the IoT system. A general Physical Entity view is presented in Fig. 3.2.

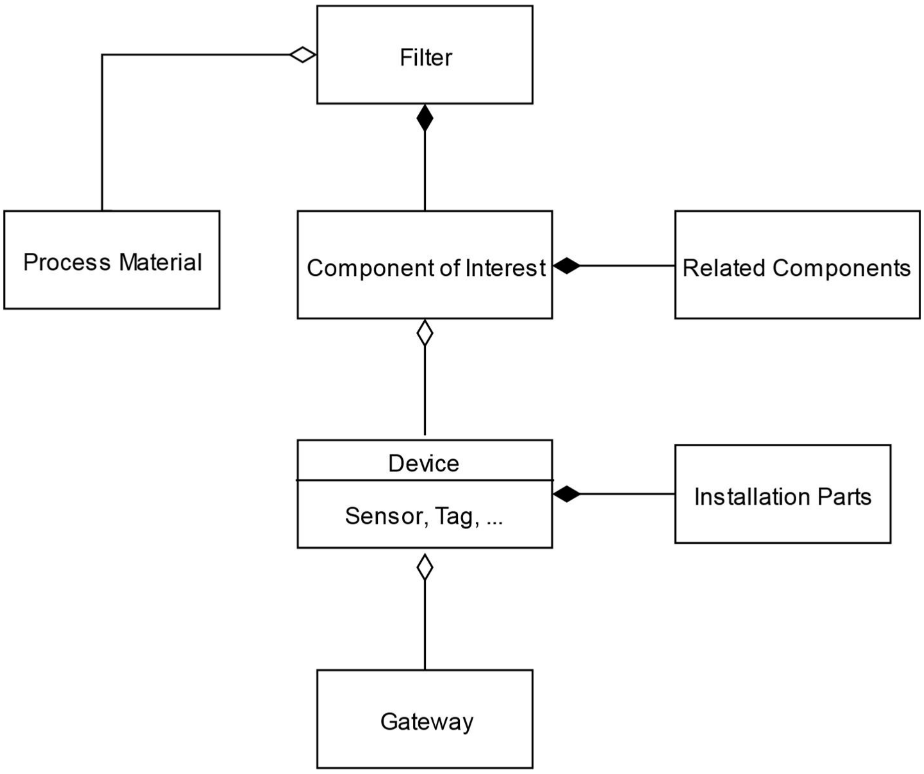

Fig. 3.2 General Physical Entity view in UML for industrial filter IoT system. It includes the physical objects that affect the system.

As shown in the Fig. 3.2, the filter as a whole is considered the top most entity, because on this general level it is impossible to rule out any parts of it. Component of interest is the component that is measured, tagged or otherwise interacted with in the IoT system. Related components are other components of the filter that physically affect the component of interest and thereby the IoT system as well. Device is the sensor, tag or other physical device in the IoT system connected to the component of interest. The device is physically installed with installation parts that may affect the device or the component they are installed on.

The device requires a gateway for communication, that may need to be modeled as a physical entity, depending on the case. For example, an RFID system requires a reader gateway and antennas and their installation locations can change the system behavior. After the gateway there may be numerous devices for communication, data processing and storing, but they are normally not concerned in the physical entity view.

Finally, the process material that goes through the filter is potentially a part of the Physical Entity view, as any system component that is in contact with it must be able to withstand it physically and chemically.

IoT Domain Model

IoT Domain model is based on the Physical Entity view and shows how virtual entities are related to the physical entities as well as to other virtual entities, as in the example in Fig. 2.6. In practice, the Domain model shows the overall system architecture that the other models complement. General IoT Domain model for industrial filter IoT systems is shown in Fig. 3.3.

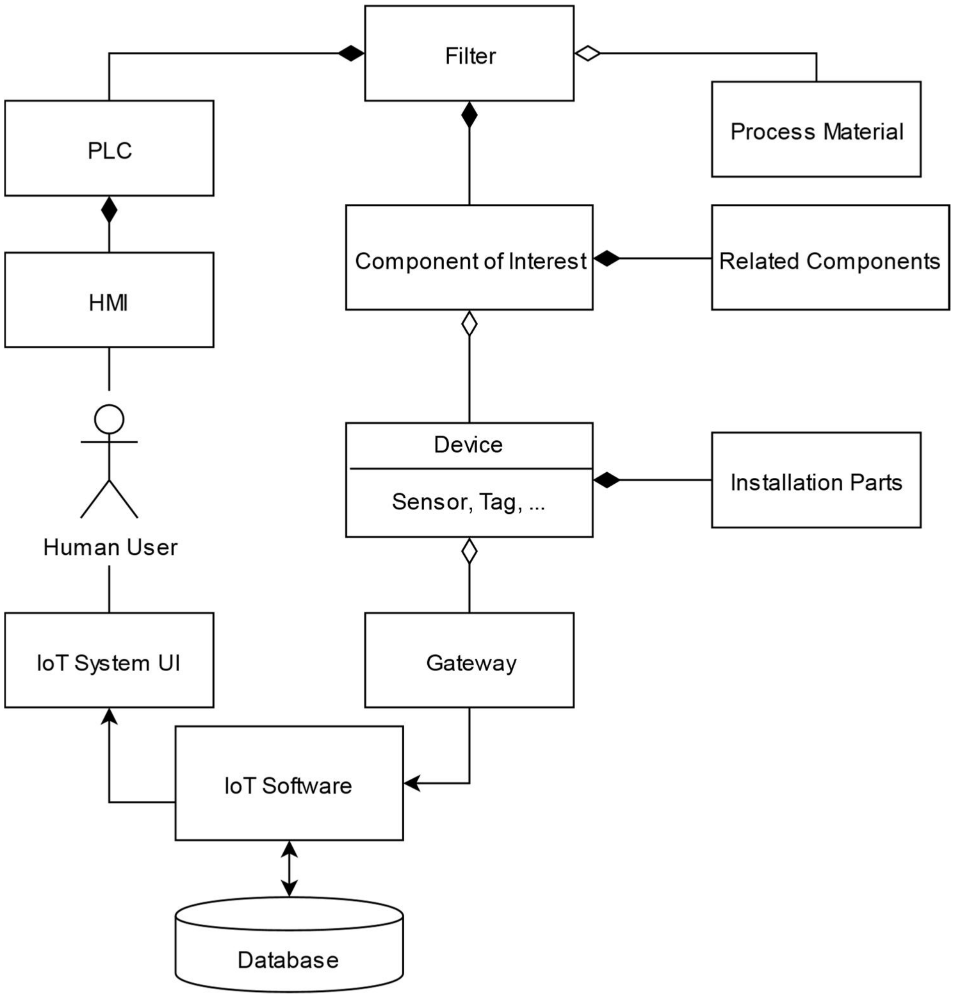

Fig. 3.3 IoT Domain model in UML for industrial filter IoT system. The Domain model shows the relations of physical and virtual entities.

The data acquired with the IoT device and transmitted through the gateway is processed in software. The software normally has a database resource for storing the data. Information gathered from the data is shown to a human user through user interface (or in some cases to a software user, if human interaction or monitoring is not needed for the system). Human user may interact with the filter through human-machine interface (HMI) that sends the commands to filter automation PLC.

Information View

Information view explains the information flow in the system. It may also include information on attributes, values and types that different virtual entities have in the Information view. In the general model, shown in Fig. 3.4, the data is acquired by the IoT device, such as a sensor. Data is firstly processed and transmitted further by the gateway to the IoT system software as well as to the filter automation PLC if needed. PLC can show the information to user through HMI.

The IoT system software processes the data and acts on it as programmed. Information and commands can be exchanged with the user through UI. Data is stored in a database.

If cloud service is used, the local software will send either raw or preprocessed data to the cloud. Data is processed in the cloud service, shown in the cloud user interface and stored in remote cloud storages. If both local and cloud systems are used, they should have similar user interfaces and possibility to operate simultaneously.

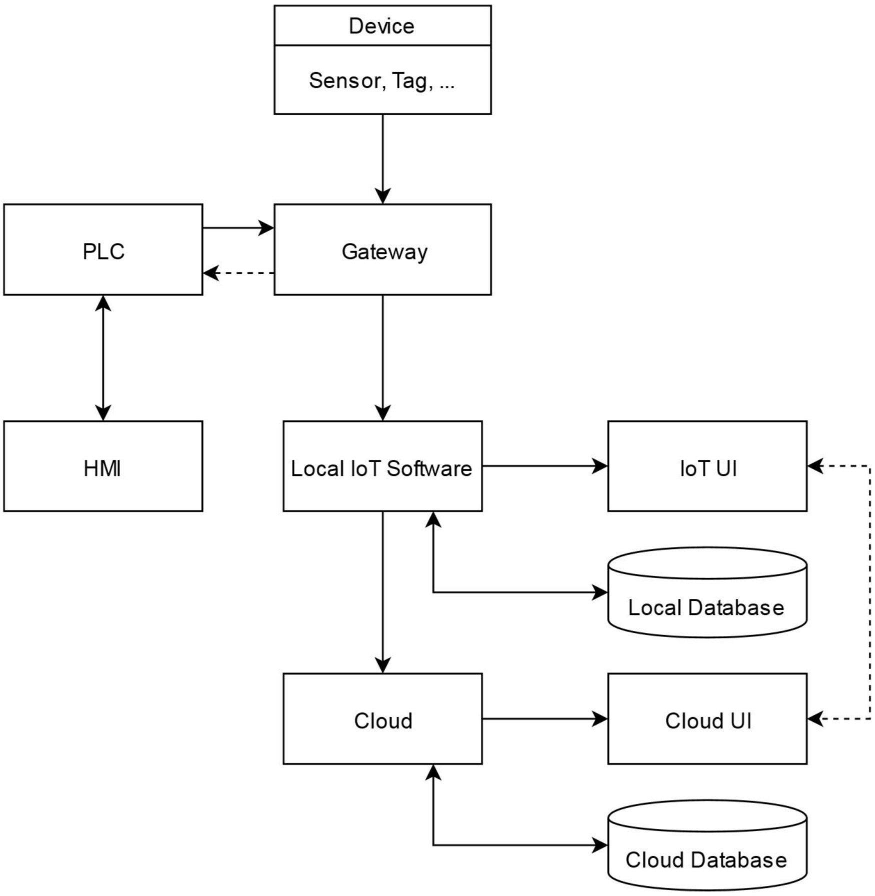

Fig. 3.4 Information view for general industrial filter IoT system architecture.

The Information view in Fig. 3.4 is very generalized, and there are many options to implement it. The main question is where the data processing takes place: local only, cloud only or both. As discussed in the chapter 3.1, each option has its pros and cons. The Information model here presents a system that uses both local software and cloud service that are synchronized. A local-only solution is achieved simply by removing the cloud services. In a cloud-only solution, the local IoT software could be a light edge service, that may perform light preprocessing, have a buffer data storage and send the data to the cloud service. Local UI would not be needed and local database only in a small buffer scale to ensure that data is not lost if there is a network problem. On the other hand, with more integrated and advanced systems the gateway may already be able to handle sending the data to the cloud, eliminating the need for additional local software completely.

System Requirements

In IoT-A, system requirements are defined based on the Physical Entity view, Context view and business goals. IoT-A does not define any methods for requirement engineering, only how they are mapped into the architecture.

Generally, in industrial filters, the first requirements concern safety – any new technology must be thoroughly designed and tested for safety. This is especially important for anything that can affect the automation and filter control. The most straightforward step is to ensure that any IoT system that does not take part in controlling the filter should be separated from the automation. Existing information from PLC can be received with hardwired IO signals or data buses with very minor changes, but information to PLC and acting on it needs to be carefully designed.

Another safety concern worth mentioning is mechanical moving components, as they have many possible points of failure and need to be controlled according to the filter automation state. Therefore, for the simplest system designs fixed components should be preferred.

Second important general requirement is security. IoT devices, gateways, locally running software and cloud services must be protected from external connections and with appropriate access rights for the users.

Other requirements need to be defined for each system based on the case and their business goals. The requirements may deal with mechanical properties, such as sustaining harsh environment, as well as with what data is collected, where it is stored and processed.

Similarly, Functional view or other remaining architecture views are not possible to be derived for a general level architecture, without specific business goals and system requirements.

4. CASE STUDY: FILTER CLOTH TRACKING SYSTEM

Outotec, a mining equipment manufacturer, wanted to implement an automatic cloth tracking system in their Larox FFP pressure filters [16]. In this case study the architecture of the system is designed based on the findings of the thesis literature review part, IoT-A guidelines and when possible the existing technological solutions that Outotec has.

Outotec Larox FFP contains several consumable components: cloths, membranes and plates. They are in direct contact with the slurry to be filtered, receive wear and tear and need to be changed regularly. In the largest FFP filters, there can be 98 plates, 97 membranes, and cloths on both sides of each plate, totaling in over 180 cloths. If any of the components breaks, the filter needs to be stopped to avoid damage to the other components as well as the impact on the production.

Previously, tracking the condition and lifetime of the components has been a task left for the operator, resulting in manual follow-up or simply not tracking them and stopping to change them whenever needed. It is a perfect case for deploying IoT system for identifying and monitoring the components and enabling predictive maintenance: the components can be changed before breaking when their filtration cycle count approaches a lifetime prediction based on the tracking data. Cloths were decided to be the first component to track, being the easiest component to access and the fastest to wear out.

Additionally, Outotec wanted to assist maintenance procedures by providing location data of the installed cloths. With the location information, the oldest cloths can be quickly found in the filter, instead of manually locating each cloth. This promotes efficient use of the cloths, as they can be easily changed individually when needed, instead of the all-at-once approach.

4.1. Benefits for the Customer and the Manufacturer

The benefits of the tracking system are clear for the customer. First and foremost, the system allows condition estimation and predictive maintenance of the consumable components. After monitoring the cloths over one or more cloth lifetimes during normal filter operation, the acquired lifetime data can be used for estimating and predicting future cloth lifetimes. The prediction can then be used to plan maintenance before the cloths break, which minimizes downtime. Further, with the location information the time for the maintenance can be reduced when only specific cloths need to be changed, and these quick cloth changes can be performed during downtimes (planned or unplanned), caused by other reasons.

The lifetime data can also be used for adjusting the process to extend the lifetime of the components: for example, the effect of different pressure levels on the lifetime of the components can be derived from the data. When combined with other data, such as tons produced or the moisture levels of the product, the customer gets performance information for evaluating the most suitable components.

A shorter than expected lifetime can also be a sign of problems, again allowing predictive maintenance – or a documented reason for component quality checks. The data provides valuable validation for the customer about the quality of the cloths or other tracked components they have bought.

With data over long time and analytical measures, other improvements can be found. For example, if cloths in a specific part of the filter have on average different lifetime than those in the other parts, this information could be used for improving the filter operation.

The most important benefit of the tracking system for the manufacturer is the increased customer satisfaction and loyalty. As the consumable parts are a significant expense in the filter operation, the tracking system provides important and valuable competitive differentiation. Further customer satisfaction and loyalty can be gained by integrating the system into a customer portal, where the customer can easily access information about the filters as well as any other machines in their plant.

Another important benefit for the manufacturer is the data itself. Just like the customer can use the data to optimize the lifetime of the components and fix possible problems, the manufacturer could use it to improve the lifetime and the performance of the filters and their components. The data can also help the manufacturer to increase their knowledge on how to maximize the lifetime of consumable components in different processes, allowing them to offer better service in the future. With a large installation base, the tracking system could provide extensive guidance on optimization and cloth type selection.

4.2. Description of the System and System Requirements

The tracking system needs to be able to identify the installed components and their installation location and to keep track of their lifetime (measured in filtration cycles). This must be automatic to make the system fast and easy to use as well as to remove any possible operator errors.

The tracking should be wireless, as cables would be vulnerable to break due to continuous movement in the filters. Connecting and disconnecting cables would also increase the installation and maintenance times when cloths are changed. Additionally, mechanical moving elements should be avoided to keep the system simple, durable and safe for operation.

The information shown to the customer must include how long each component has been in use (time from installation and filtration cycles) and where it is installed in the filter (place number and visualization). Further information can be given for example on the age distribution, processed material amounts and moisture levels on relation to the component age. The information should be accessible near the filter for maintenance reasons (especially the location information), for example on the filter’s HMI panel, but also in the customer’s offices for employees responsible for operational planning, component stocks and orders as well as process control and monitoring.

There are normally several filters in a plant, and the same system must be scalable for all of them. In the future, scalability could include all the plants of the customer, enabling global maintenance management and monitoring.

The price of the system must be low enough to encourage customers to try new technology. More importantly, the impact on the prices of the consumable components must be as minimal as possible to keep the prices competitive. Data security must meet the company and customer standards.

4.3. Defining the Core Technologies and Design Choices

RFID technology was chosen for identifying and tracking of individual cloths. RFID allows wireless and automatic tracking and the tags have unique electronic product codes (EPC) that are easy to use for identification. Only the tags need to be in contact with the slurry, while antennas and other components can be installed on the outer filter structures. Industrial passive RFID tags cost only few euros per piece, are installed in durable enclosures and they are easy to install on each tracked component. On the downside, RFID technology may have problems when the cloths get dirty over time from the slurry residue, containing liquids and metals that attenuate or block the radio frequency signals. The metal structure of the filter is another challenge for RFID equipment as it reflects and blocks the signals, which results in multipathing and possibly undetectable tags.

Alternatively, active RFID tags could have been used to reduce signal attenuation risk caused by the slurry and to deploy different localization methods. However, their cost is too high, especially when considering the cloths. They could be used for other components like the plates, that generally last much longer than cloths. Additionally, some active RFID tags could be permanently installed as reference tags to improve localization.

Other wireless tracking and identification methods were considered as well. NFC (Near Field Communication) could be more reliable than RFID from the computing perspective, but its short range makes automatic reading of the moving tags nearly impossible within the existing structure. Other wireless communication methods, namely Bluetooth, Wi-Fi and LPWAN, could work better for identification than RFID tags in the given environment, but they are again more expensive than passive RFID tags and using them for locating purposes inside the filter wouldn’t be as straightforward.

The produced data contains the component ID (tag EPC), installation date, removal date, number of filtration cycles in use and the installation location in the filter. To acquire this information, data is needed on every cycle: component ID, location, cycle count, time stamp. To detect the location, several data points are needed, resulting in hundreds of data entries for each cloth for each cycle.

The user interface should be accessible both at the production as well as the offices. To easily avoid difficulties created by plant firewalls and to allow viewing the information anywhere with different user access levels, a cloud service is used for the user interface. Additionally, cloud service enables scalability and easy integration of other filter tracking systems or even completely other IoT products under one customer portal. The cloud service can be updated remotely for improvements and new features, like more advanced data analysis. External cloud connection makes it possible for the manufacturer to also analyze the data for troubleshooting and product development.

On the other hand, the system must have the option to disable external connections completely, should the customer wish so. Therefore, a complete local version is needed. The resulting system resembles a hybrid cloud system, where data and software can be on-premises for security reasons or in the cloud when needed.

4.4. Tracking System Architecture

The central physical entity in the architecture is a cloth. Other physical objects of interest are the filter structure, where the RFID antennas need to be installed, and the slurry that can be in contact with the tags.

RFID tags (devices) are installed on the cloths, together creating a virtual entity of a cloth with an ID and an installation location. Other virtual entities are the local software and cloud software.

The software needs resources to function: a database where the data is stored. Local database needs to hold large raw data that is necessary for the RFID location detection. However, once the locations of the tags are found, the data can be reduced to a single row for each tag that are updated after every cycle. Therefore, locally there are two different database tables and, in the cloud, only the compact database is required. On the other hand, a decision must be made on should the location detection algorithm run locally or in the cloud – local processing requires computer that can process the data from multiple filters efficiently, cloud processing requires much more data to be transmitted. Initially, the local processing option was chosen for easy offline development.

User interface services are needed for displaying the information for the operators. For the remote cloud connection, Outotec remote connection solution is used, which creates a secure VPN connection to the cloud with a 3G router.

Filter run information is needed from the filter automation PLC to signal when to turn on the antennas. Otherwise, the antennas would have to stay on continuously, creating loads of useless data and hiding the useful data. With the chosen hardware, the run information can be given simply with a hardwired input/output signal directly to the RFID reader. Other data, such as production tonnage, can be received from the automation PLC over Ethernet.

Local software can run in a single IPC and it is tasked to configure and control the RFID readers and store data. Each filter needs their own RFID system, which can be connected through an Ethernet switch to the common IPC, that performs data analysis and hosts UI.

The proposed hardware architecture is presented in Fig. 4.1. It is still up to decision whether there will be separate IPCs for each filter to control their respective RFID readers, connected to the common IPC for data analysis and UI hosting, or if the common IPC would also be used for controlling every RFID reader. With only the common IPC, hardware could be reduced, but software and the single IPC need to be able to handle the configuration and management of the readers of *n* number of filters, as well as simultaneously receiving and storing the data from the readers.

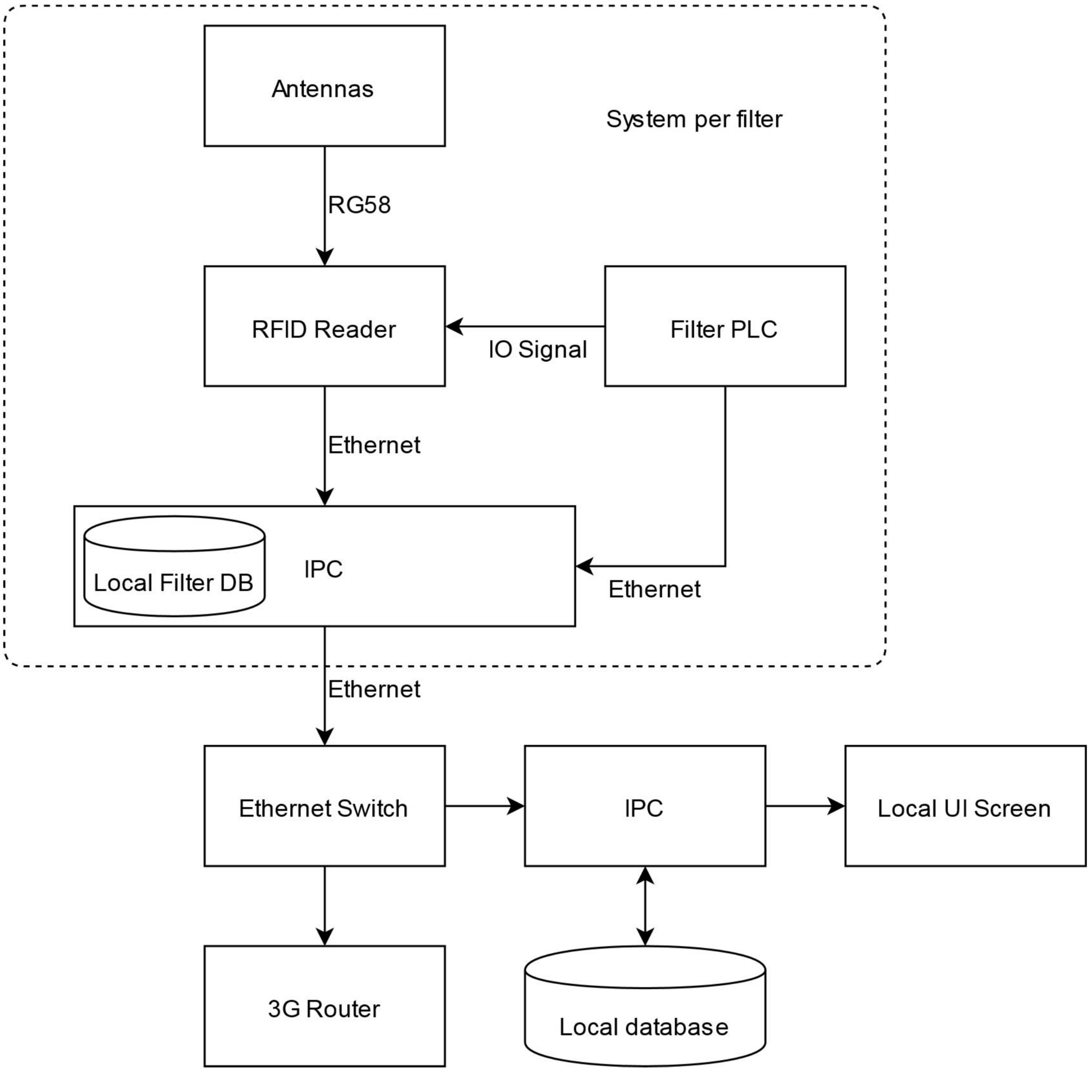

Fig. 4.1 RFID Tracking system hardware architecture initial proposal.

The software architecture is presented in Fig. 4.2. RFID reader is controlled with the local software. The software also manages storing the acquired data to local database, performs the needed data analytics and hosts local UI. When cloud services are used, the data is transmitted to edge device, that consists of a small IPC and 3G router, that are used to create a secure VPN connection to the cloud service for uploading data. Cloud service stores data and performs similar analytics as the local software. In the cloud service, additional analytics can also be performed, and the service can be updated remotely with new features. The cloud service hosts its own UI, that is similar to the local UI.

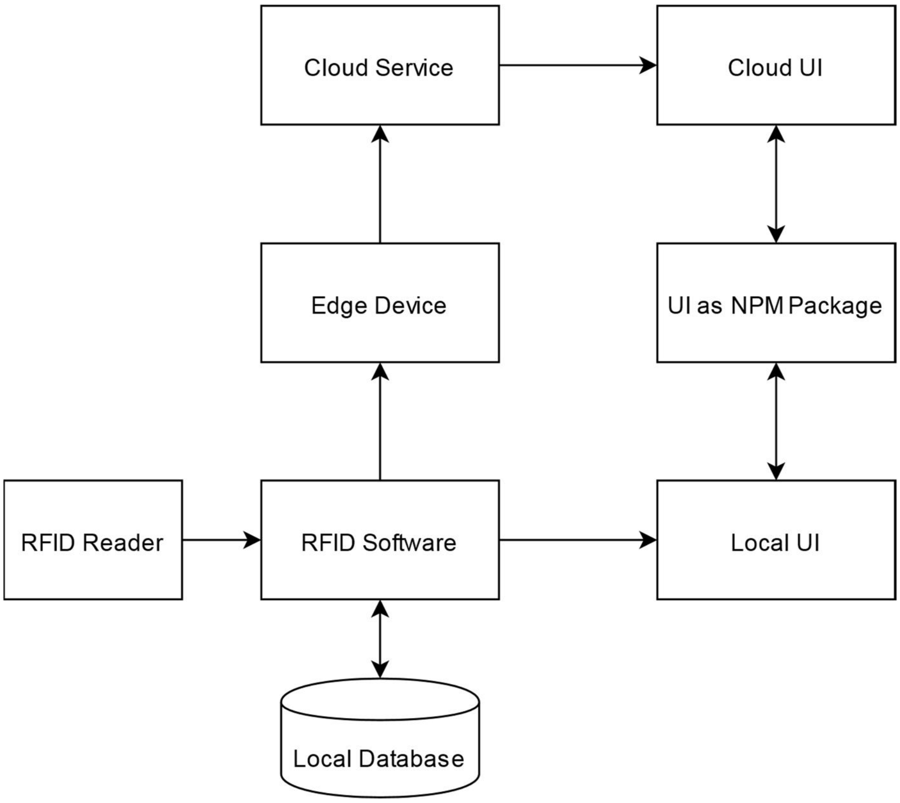

Fig. 4.2 Software architecture initial proposal.

The local software and the cloud service use REST API that allows the user interfaces to request data from them. Therefore, the data source (local or cloud) does not matter to the user interface package allowing flexibility for the backend deployment. To match the user interfaces of the local system and the cloud system, the UI is made as an NPM package. This way, the cloud and local systems can easily have the same user interface and be kept updated.

4.5. Case Results

At the end of the thesis project, the tracking system is still work in progress. So far, individual components have been tested: RFID tags and readers have been tested in a purpose-built test bench, along with the local software controlling the reader and storing data locally. Test bench PLC has been used for start/stop IO signals. Outotec remote connection over 3G network is a company standard (hardware and software) and used in other projects as well. Cloud service is also used and in development in other projects, which boosted significantly web based UI creation and configurations needed for uploading test data to the cloud.

Architecture wise, the remaining work mainly concerns completing the software features and testing all the components together, especially the case of multiple filters.

5. DISCUSSION

Based on the thesis results as well as the articles discovered during the research, the following key topics were discovered:

- IoT and Industry 4.0 visions are strongly shaping the current development of the mining industry
- Numerous efforts to standardize IoT have been made, but without much success
- There is a clear difference in the development and opinions on IoT between small and large companies
- Mining companies and manufacturing companies have different development possibilities and reasons
- Industrial IoT alongside DCS and MES systems
- Role of cloud services for developing and integrating IoT based systems.

Due to the social, environmental and economic factors discussed in the chapter 2.2, mining industry is strongly investing in new IoT systems. The vision of lights-out plants would greatly improve the reliability, efficiency and safety. At the same time, the vision seems far-fetched by most mining companies and manufacturers, with only the largest companies interested in it currently. However, the vision comes closer with each improved monitoring and predicting system, digital model and automated process and machine. IoT enabled data acquisition can improve almost any machine equipment or their operation. With the enhanced data acquisition and networking, integrating systems from the plant DCS to MES to ERP may also take a step further.

The IoT reference architectures and standards discussed in chapter 2.4 and [9], [21], [45] show how nearly impossible it is to create one unified reference architecture or model for IoT systems. IoT can be implemented with so many different technologies and ways that there simply is no single answer for everything. On the other hand, with enough abstraction a single architecture model can be used for many different cases, but the value of the reference model will decrease as more work needs to be done in each case. Designing an actual IoT architecture requires therefore careful problem analysis, researching the most suitable technology for it, and simulating and testing that. Especially the perception layer, which includes for example the sensors, is always case specific. Some parts, however, may be reusable in the architectures. In the case study architecture, the 3G remote connection and many parts of the cloud service architecture can be reused in future projects as well. The knowledge and software that were acquired and created for the RFID system can also help future RFID systems.

Despite the number of different reference architectures and their level of abstraction, they are very helpful for those who are designing IoT systems for the first time. They teach the essential terminology and help dividing the system into manageable pieces. With the current research work that aims to unify the terminology for the reference architectures, it will become easier to find the best suiting reference based on the project goals and focus, which will result in faster development. On the other hand, it may still be more beneficial to research specific technologies and case studies instead of reference architectures, when designing a new IoT system.

One finding was that there are different opinions between small and large mining companies regarding IoT. Big companies are generally more interested in investing into IoT development, while smallest companies may struggle with traditional automation. Reasons are obvious: the big companies have capital, benefit from the large scale even with small improvements, as well as wish to keep their place as market leaders. For the manufactures, this may mean that big mining companies are looking for partners to develop new systems, while other companies can be offered ready-made IoT products, services and ecosystems that can create long-term relationships with the customers.

In the case study, it was found easier to implement IoT systems as additional services separated from the machine automation when possible. Developing is simpler when there is less need to touch existing, refined systems and components, and additionally, the new system can be sold as additional feature or as a modernization for old products. With tracking and monitoring systems this can often be done, but new systems aiming to improve control and automation will need to integrate with the existing system. Additionally, the less the IoT system depends on other systems, the easier it is to retrofit to old, existing machines. Mining equipment is normally designed to operate even for decades, so the possibility to offer IoT system as a modernization upgrade is valuable for manufacturers.

As IoT systems are often very case specific, they are also being built mostly for specific machines by the manufactures. The logical next step is integrating all the different systems into one service, where each system and service component can be individually activated for each client, depending on which machines they have bought, and which features they want. This service could function on its own to provide information for different operators and needs, or it could be integrated further for example with the existing control systems and ERP, slowly progressing towards the previously mentioned vision. Therefore, an important aspect in IoT system design is thinking about future integration and scaling possibilities from the beginning.

Cloud services seem strong choice for the integration of IoT systems. In a large-scale system or several integrated systems, the storage and processing of data gathered from the sensors requires data centers, which is no longer the core business of mining or manufacturing companies. Data storage algorithms, power management, computing power assignment are all tasks that would take huge resources from a mining company or a manufacturer, while they could focus on using the technology to provide more information and improve the mining operation. But the role of cloud services is still controversial due to data security risks and question of data ownership and the manufacturers must work to gain the trust of the clients for using cloud services. Most important steps for assuring the data security are continuous evaluation, checking and monitoring and keeping up to date with new technology. It would be good for the manufacturers to partner with cloud providers to show their commitment. The cloud service provider must be trustworthy and actively research and develop their systems, monitor and protect from attacks, as well as inform and teach their clients (manufacturer) on best practices and system configurations. All of this must be proved and transparently informed to the customers to show that their data is secure.

On the other hand, it is common that equipment on a mining site comes from many different manufactures. If every manufacturer has their own IoT solutions and cloud services, the mining company ends up with the problem of numerous different systems and user interfaces, which becomes hard to manage and operate. Manufacturers with largely integrated systems have a clear advantage over other similarly performing equipment, as customer would gain better value from one service instead of many separate and different services. Alternatively, systems that allow integration with other manufacturers' systems may also have an advantage due to flexibility. They would also promote open and faster development in the industry, where the competition would be at the service features instead of service portfolio size and vendor lock-ins.

Cloud services still have clear advantages in the smaller scale as well, which especially manufacturers can use to their advantage. The cloud services keep the system scalability at hand, the service is widely accessible, and it still offers the same IT management benefits mentioned before – and for smaller companies, the cloud service management done by the service provider may be even more important than for big companies. By designing IoT systems with the cloud support in mind, the systems are easier to integrate into larger management systems. This is especially important for manufacturers with a diverse product portfolio: often the products are developed independently, which leads to poor information exchange between them. By designing them to work with cloud service, they can be easily integrated later.

6. CONCLUSION

In this thesis the suitability of Internet of Things and its architecture design process for mining equipment were researched. The main contributions include investigating the benefits and values of IoT for manufacturing and mining companies, considering how IoT fits into the existing automation and management systems in the industry, explaining IoT system architecture design process by using reference architecture as a tool and giving the case study as an example of an IoT architecture. The benefits and feasibility of IoT in industrial filters were investigated and considered from the point of views of a manufacturer and a mining company. The findings can be used for estimating the possibilities for new IoT systems as well as supporting material for learning about IoT in mining environment. The system architecture research can be used as a guideline and starting point for developing new IoT systems in filters or other equipment. The case study functions as an example for future projects as well, especially for the use of RFID.

In mining industry, IoT research and implementations are gaining more and more traction due to exhausted price competition, decreasing ore deposits and quickly increased efficiency and environmental requirements. Technological development is usually done by the equipment manufacturers based on the customer needs or by strategy to gain competitive differentiation with product development. IoT in combination with data analysis and machine learning are used to improve the processes and equipment efficiency, as well as to deploy higher degree of automation, condition monitoring, object tracking and predictive maintenance.

One of the most important design choices is the usage of cloud services, especially in the industrial setting. Cloud storage and computing are common in IoT systems due to the limited resources of the IoT nodes and the huge amount of data created by them. Cloud services offer easy scalability, possibility for machine learning and heavy algorithms and a well accessible platform for creating user interfaces for different projects and users. Cloud service also enables easy remote diagnosing, updates and other service options. On the other hand, using cloud service means that data may need to be transferred out of the plant premises which is a data security risk and may not be accepted by all clients, despite the security measures taken by the manufacturer and cloud service provider. Therefore, in industries like mining where the data is often confidential it is good to consider a hybrid option of cloud and local-only systems. A hybrid offers the benefits of the cloud service, but is also possible to be run only locally, giving flexibility for its marketing and deployment and reaching wider customer base. The hybrid solution presented in the case study shows one architecture option for achieving such a system.

Although the benefits of IoT are clear for acquiring new data and creating new information or services with it, IoT and cloud services most likely will not have direct impacts on machine automation, since most data analytics are done in higher level systems. On the other hand, new IPCs running Windows or Linux operating system alongside PLC functionality make it possible to add IoT systems to the low level as well. It may also be required eventually, as the vision of a fully automated lights-out plant would require extensive sensor networks and connectivity, for which IoT technology is a key element.

Due to the numerous different technologies and use cases of IoT, designing an IoT system requires lots of research as well as trial and error. Many different reference architectures have been made to simplify and guide the process of designing an IoT system, but the wide implementation possibilities have led to overwhelmingly many reference architectures. Modern research projects are aiming to establish a common ground and terminology to overcome the problem. Nonetheless, the reference architecture models help to understand the key elements of the systems and their different needs and requirements.

One popular IoT reference architecture project is IoT-A. The model breaks down the architecture design process into manageable blocks called views based on their context in the system. Main views considered the physical objects in the system, information flow and functionality, resulting in an overall IoT domain model and the supplementing models.

By following the IoT-A reference model guidance, a general (reference) model was created for IoT systems in industrial filters. Industrial filters are commonly used in mineral concentration process to remove excess liquids from concentrated ore slurry and to achieve the highest dry particle content. The main elements to consider were the components of interest and their location in the filter, which dictates the possible technologies for measuring or actuating them.

The devices that perform the chosen technology vary greatly in IoT systems – as an example, in the case study several RFID antennas and tags were tested, with extremely different results. The need for separate gateways must be investigated and numerous different solutions may exist with very different features. Other filter specific considerations include the protection of the devices in case they are in contact with the slurry or water and the communication with the filter automation or plant automation.

Important finding was that IoT architecture design is very case depend, as also shown by the number of different reference architectures. The general level filter IoT system architecture could also work for many other machines as it is, because it leaves many aspects undefined. Therefore, when researching architecture design for new IoT systems, it is more important to look for specific technologies and case studies instead of reference architectures – although the reference architectures provide a good guideline and starting point for development.

As the thesis concluded that creating a universal reference architecture for IoT systems is nearly impossible, the future research on the topic should focus on specific industries and processes, where the environment is uniform enough to allow creating reference architectures. When there are multiple reference architectures available, there is also need for detailed surveys that would examine their differences and help finding the most suitable reference for new projects.

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