Remote Data Collection Motivational Drivers, Challenges, and Potential Solutions in Industrial SME Companies

Teemu Mäkiaho(✉), Topias Kallio, Henri Vainio, Jouko Laitinen, and Kari Koskinen

University of Tampere, Tampere, Finland
{teemu.makiaho,topias.kallio,henri.vainio,jouko.laitinen,kari.koskinen}@tuni.fi

Abstract. Data collected from industrial machines enable companies to pursue new servitization offerings such as machine health condition monitoring as well as to monitor the machine behavior for research and development purposes. In this study, qualitative data was collected from four different industrial SME companies to create a better understanding of the motivational drivers industrial companies may have to create remote data collection systems. The results will discuss the initial motivational drivers for data collection setup construction as well as the challenges companies were facing along the way in designing and implementing their systems. Based on the empirical research results, the recognition of internal motivational drivers and data utilization targets should be clear before proceeding to further development of data collection infrastructure. Generally, the research results recognize various areas that an automation industry company needs to consider before planning and implementing an online data collection system, what challenges they may face as well as generalized proposed solutions are presented.

1 Introduction

Machine system availability has a significant role in the overall profit making in the industrial environment and technology-advanced business models are emphasizing the importance of technology and data analytics in overall value creation (Schroderus et al. 2021). The profit margins can be increased using advanced condition monitoring techniques where machine condition can be accurately monitored and its current operation condition assessed based on the monitored parameters such as temperature, humidity, thermography, motor current, electrical inductance, electrical capacitance, acoustic signal, vibration, or pressure (Hashemian and Bean 2011). The broad use of sensors, data collection with real-time transfer capabilities, and data fusion technologies with advanced visualization may contribute to more effective results (Wang et al. 2018) when discussing machine system reliability monitoring and performance optimization. However, the infrastructure of machine system data collection is no longer limited to machine system parameters monitoring. The Industrial Internet of Things (IIoT) connected mass data can be composed by utilizing various data sources, such as condition and operation data (Ehret and Wirtz 2017), failure history, production process data, machine features

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(Bertsimas et al. 2019; Ehret and Wirtz 2017), operating conditions (Liu et al. 2019), repair history data (Kong et al. 2020), and operator attributes e.g. the attributes of the operator who uses the machine.

Data collection for enhancing machine system maintenance or availability are only samples of motivation factors the SME's may have to establish remote data collection capabilities. Increased competitiveness requires new business model approaches, therefore forcing companies to search for better ways to serve their customers as well as to make their products more cost-efficient and reliable. This qualitative research reveals the motivational drivers that the four industrial companies have towards the establishment of a data collection system as well as identifies the challenges industrial SME's may encounter when designing or implementing a remote data collection system. By identifying the possible challenges in advance, companies will be more ready to create solutions and perform risk mitigation actions in advance (Kallio 2021). For the companies, the main driver of establishing remote data collection capability is to offer remote condition monitoring services for their customers. As a result of this study, the motivation for data collection planning and implementation is addressed. The last part of the results illustrates the challenges and identified potential solutions to how such obstacles could be alleviated or minimized in comparable companies or industries.

2 Methodology

The research methodology is empirical qualitative research in the form of semi-structured interviews. Semi-structured interviews follow a list of predetermined questions under previously determined themes to form a general structure for the interview. Also, additional questions and talk are allowed during the interview in a controlled manner (Kallio 2021). This allows exploring rich background information about the studied topic (Saunders et al. 2019). Interviews for this study were conducted with four Finnish machine building small and medium size (SME) companies in the field of the automation industry. All the companies have their main operations in Finland, but all the companies are operating their businesses on a global scale. The companies were selected due to the following criteria: the size of the company corresponds to the small and medium-sized company definition from the machine building industry sector, and the company is currently developing or using remote data collection systems. One of the four companies is already performing data collection whereas the other three are in the design or implementation phase of the data collection system.

3 Motivation for data collection

All the case companies share a common interest in developing remote data collection systems to create added value for their customers in the form of servitization. Grubic states that enabling novel servitization of industrial machine systems requires remote data collection (Grubic 2014). Companies are targeting to improve their data collection capabilities to enhance their data-based service offerings such as condition monitoring agreements. Common nominators of the industrial SME case companies, in addition to company size and industry sector criteria, are interest in servitization of machines, remote data collection, and condition monitoring to support maintenance activities and servitization. Another commonality between the companies is that the machines and machine systems are delivered around the world including no mass-produced products, and all the company products contain machine automation systems embedded in their main products with off-the-shelf industrial Personal Computers (PC's) and Programmable Logic Controller (PLC) functions. Three of the four case companies can collect process-related control and operation parameters data on a local level, and one company has continuous remote access to their machine- and process-related data with remote diagnostics capability included.

Based on the interviews, the case companies are driving towards servitization of their products while, at least partly, retaining ownership of the machines delivered to the customers. This creates a great incentive to keep machines in good condition. To reduce the risk associated with this type of availability-based contract, Grubic and Peppard illustrate that remote monitoring is crucial as it can result in higher availability and reliability of the machines (Grubic and Peppard 2016). From a technological perspective, built-in industrial PC's enable data collection and partial processing capabilities from the machines with ease. However, in many applications, external sensors are needed to increase data collection capabilities about the machine's health status or behavior that cannot be originated or are not available from the internal information systems. In many cases within the case companies, the initiatives for adding external sensors are often set by the customer demand of monitoring machine behavior to support their local maintenance planning and decision-making more precisely. Also, customer demand for remote data collection capability is recognized as being one of the top motivational drivers within the case companies. Based on the interviews, product marketing and selling are becoming substantially harder without any integrated data collection. On the other hand, the remote connection also enables companies to develop, tailor-made, and update their products continuously over their lifecycle which may also result in substantial benefits for the customer e.g. in the form of process optimization. Similar products are frequently operated in distinctive and dynamic surroundings and such information offers the product manufacturer enhanced capability to calibrate their machine operation to meet the customer demand and increase overall satisfaction in the customership. The motivational drivers for the companies to pursue remote data collection are listed below:

- Increased customer demand and satisfaction
- Predictive capabilities to avoid faults
- Remote diagnostics and technical support capability
- Continuous development of products. Learn about products and their deterioration during use in different environments
- Product servitization and additional services with data
- Optimal wear part changes
- Maintain and improve quality
- System control and tailored operational optimization for customers
- Troubleshooting and certain maintenance remotely
- Reduction of traveling for instance in warranty cases through remote fault finding and maintenance
- Safety improvements in condition monitoring

From the customer perspective, remote data collection and condition monitoring is deemed valuable, especially when considering the high price of the machine or the cost of maintenance, machine exposure to wear, and machine criticality to the overall production process. Consequently, remote condition monitoring may result in more stable and predictable operation, and availability increase of a machine (Grubic and Peppard 2016). Machine long-term operational data and the knowledge gained through the data can be further utilized for machine diagnostics, predictive and prescriptive maintenance capabilities to enhance machine uptime and reduce unnecessary operational stoppages (Wang et al. 2018). Additional servitization possibilities, machine optimization, continuous development of products, and better risk management controllability for instance in warranty cases are also recognized motivational factors for data collection within the case companies. Online diagnostics and machine accessibility also offer a sustainability perspective in terms of reduced need for traveling, where certain troubleshooting, system control, technical support, or maintenance can be performed from a distance. Safety issues are also improved when condition monitoring of devices requires fewer onsite measurements and inspections.

4 Selecting Data to Collect

The selection of adequate data collection system components is highly dependent on the machine features and their connection to the operational environment. Certain usable data parameters can be obtained directly from the machine-integrated systems and sensors, but most importantly the collected data needs to support the goal of what type of information is requested to be conducted from the raw data. In addition to pure machine operational parameter-related data, other data sources such as machine condition (Ehret and Wirtz 2017), failure history, production process data (e.g. ERP and CMMS systems), machine features (Bertsimas et al. 2019; Ehret and Wirtz 2017), operating conditions (Liu et al. 2019), repair history data (Kong et al. 2020), and operator attributes e.g. the attributes of the operator who uses the machine also may be considered as data sources. Soft sensors i.e. virtual sensors are also deemed as an interesting source of data to replace some physical sensors, especially in applications with high physical stress, such as applications where high amplitude vibration or temperatures are present. Kabaday et al. describe that virtual sensor combine sensed physical sensor data and provide measurement results of abstract conditions that are not directly physically measurable (Kabadayi et al. 2006). According to the companies, by reducing the number of physical sensors, many sensor failures could be avoided thus resulting in better reliability and cost-effectiveness.

Once planning sufficient data to collect, utilizing domain knowledge of the machine system operational features, individual subsystem or component level fault modes and effects, as well as the system interrelation to other process components is essential. In the case companies, the primary source of data acquisition was through integrated industrial PC's or other integrated controllers due to already existing embedded capability. External sensors e.g. vibration sensors were used only if more accurate information about the machine or component condition was needed, or if the information supporting the use of the selected business model.

Different data collection motivators may require different process steps for successful implementation. For instance, collecting data for research and development needs may differ from steps if the data collected is used in remote condition monitoring or process optimization. Simplified and generalized steps of initiating data collection planning and implementation for condition monitoring purposes are addressed as follows:

1. Identify business drivers and customer value
2. Identify machines or components to monitor based on their criticality, failure modes and root causes. Perform FTA or FMECA type of analyses when necessary.
3. Identify representative measurement parameters for root cause
4. Determine measuring and signal processing techniques and analyzing methods. Use primarily integrated technologies and add external sensors or data collectors if adding value. Evaluate the needed data properties 4V's (Volume, Variety, Velocity, Veracity) (TechAmerica Foundation's Federal Big Data Commission 2012).
5. Collect, save, analyze, and understand the data. Use various domain knowledge sources to find correlations from the data to create additional information or knowledge.
6. Decide if the data and technologies are sufficient, find development needs and iterate the process if necessary.
7. Implement a continuous data collection and monitoring system

After the data has been collected, correct resources are needed to interpret and convert the received raw data into the desired form of information or knowledge. Contextualized technical understanding of machine system operation, fault behavior, normal component level operational feature and behavior knowledge, condition monitoring expertise, and interrelation to other processes to name a few are of the essence to understand when analyzing the collected data. Condition monitoring specialists, machine operators, maintenance technicians, and other professionals working with machines daily operational routines and challenges often hold the required domain knowledge for the correct data selection process and such domain knowledge is vital to utilize when selecting the correct data to collect.

Identifying value-adding data before creating the data collection system proves to be challenging. Therefore, a strategy of collecting all the available data was seen as dominant within the companies leaving most of the challenges to find appropriate parameters for the data processing and visualization phase. However, initiating the data collection process quickly and improving the process over time -approach was seen as the most efficient way of starting data collection within the companies.

5 Implementation Challenges and Potential Solutions

Generally, implementing IIoT based remote data collection system is considered challenging within the companies. The challenges are divided into two different categories as follows:

- IIoT system and technology-related challenges, and
- Resource and data-related challenges

Implementation of new technologies and systems requires resources. Due to their smaller scale, SME's have more limited financial and knowledge-related resources available compared to larger companies. There are plenty of system technology providers in the market from sensors to communication and data storage providers, making the selection of correct partners and value-adding technologies demanding. Based on the study, it is recommended to utilize existing off-the-shelf products or embedded technologies as data sources yet remembering that all the IIoT system implementations require some level of customization. Despite this challenge, collaboration and teamworking with other similar companies, partners, or research institutes would significantly help companies in resource-related challenges. Designing the data collection system to meet possible future requirements such as updating communication protocols or gateways as well as scalability are identified challenges that must be accommodated in the system selection phase. Table 1 content consists of IIoT system and technological challenges with an identified potential solution both from literature and results from the interviews.

Table 1. IIoT system and technological challenges with potential solutions

IIoT system and technological challenges	
Challenges	Identified potential solutions
• Great variety of different IIoT products and solutions available • No standardized structure for IIoT platforms • Difficulty to get reliable and objective information to compare alternatives	• Discussions with providers • Specifying own objectives and needs • Experimentation and test trials
• Selection of IIoT platform and services (Contreras-Masse et al. 2020)	• Defining criteria for cloud-based IIoT platform selection (technological, economic, and social) and comparing different solutions based on needs (Contreras-Masse et al. 2020)
• Difficult to get specific costs of cloud and IIoT platforms	• Discussions with providers • Specifying own objectives and needs • Experimentation
• No ready off-the-shelf solutions available	• Understand your system requirements to prevent unnecessary customization
• Difficult to make a system with IIoT system characteristics: scalability, security, etc.	• Find trustable, certified, and scalable subsystem platform partners from each of the needed areas.
• Poor Internet connections and transmission restrictions in some locations	• Verifying that connections are enough • Use of local data storage • Use dual communication protocols e.g. LAN as primary and cellular network as a secondary connection method

(continued)

Table 1. (*continued*)

IIoT system and technological challenges	
Challenges	Identified potential solutions
• Selection of proper technologies	• Having clear objectives • Data requirements are specified • Recognize internal skills and purchase the needed knowledge for instance by using external consultant services
• Determining required data sources, acquisition, transmission, and storage at the beginning of development	• Collaborate with peers, University co-operation, Training of staff, Consultants
• Specific component information can be hard to acquire	• Collaboration with component manufacturers for instance joint development projects based on the collected data
• Compatibility of device interfaces to allow data transfer	• Development in collaboration with system manufacturers
• Project-based deliveries make it hard to standardize data collection solutions, calculations, and interfaces	• Standardization of monitored products or components
• Verifying that remote data collection solutions work in customer's facilities	• Train internal resources such as sales representatives to recognize potential issues and propose risk mitigation

Resource- and data-related challenges differ from the challenges related to technological infrastructure design and build-up, while there may be overlapping activities for instance when selecting proper data sources. Despite the selected motivation to remotely collect data, companies are struggling to recognize how to utilize the collected data and identify what knowledge and expertise are required for the purpose. Also, the case companies are aiming to start data collection rather quickly to start building the historical database of their machine behavior in a contextual environment. Another challenge may occur as SMEs begin to collect data from the machines that are in customers' facilities. Customers may not be willing to share data from their factory for security or privacy reasons. If this is the case, it came up in interviews that it is helpful to negotiate and point out the benefits of data collection to convince a customer to accept it. Also, early-stage internal training on related technological or business strategy level change management would narrow the scope and reduce unnecessary overlapping of needed work steps, especially at the beginning of the data collection process. Collaboration with similar companies or partners is also considered beneficial for SME companies with limited resources. Resource and data-related challenges with identified potential solutions are presented in Table 2. The table content consists of challenges and identified potential solutions both from the literature and results from the interviews.

Table 2. Resource and data-related challenges with identified potential solutions

Challenges	Identified potential solutions
Resource challenges	
• Hard to identify what knowledge and expertise is required and whether does company have it	• Collaboration with partners and needed external resources e.g. consultancy companies • Building internal experience and knowledge
• Limited financial and knowledge resources	• Limiting the scope of the project based on (Omri et al. 2020) • Use existing data collection systems • Limit data to be collected
• Lot of important knowledge focuses on only one or few professional	• Teamwork and collaboration inside the company and with partners • Enhance internal documentation processes
Data challenges	
• Identifying relevant data and its properties	• Detecting knowledge needs from a business perspective and selecting a database on them • Based on analytical needs derived in preparatory activities e.g. criticality analyses • Collect data, and learn relevant parameters by studying and analyzing with contextual knowledge
• Missing data: context and historical data	• Use external data sources with PLC data • Knowledge of maintenance personnel • Gradually build a historical database
• Getting access to data from the machine in customer facilities	• Negotiate and show benefits of data collection to customer • Include data collection and accessibility as a prerequisite to sales contracts • Obtain external security certification for your data collection system • Create joint data usage ownership agreements and benefits maps
• Small volume or poor quality of data can result in poor analysis (Omri et al. 2020)	• Collect more data with better properties (Omri et al. 2019) • Think about the 4 V's of data: volume, variety, velocity, and veracity (TechAmerica Foundation's Federal Big Data Commission 2012)

6 Conclusions

Different business opportunities and cost savings through remote data collection are more obtainable due to recent development and reduced prices of information and communication technologies. Short and long-term data collection combined with condition monitoring and data analytics knowledge will enhance service-based contract capabilities from single machine operation monitoring to accurate machine availability, predictability, and overall fleet management prognostics. The results of this study highlight the initial motivational factors for setting up a data collection system and challenges encountered in the design and implementation process within SME case companies. The motivational factors presented in this paper are collected from companies working in rather homogeneous automation-related business environments and cannot be generalized to all business sectors. However, the listed motivators could act as an initiator for an industrial company processing possibility, why a remote data collection system could be established for their own business. Following, the research results represent related challenges industrial SME's may discover when intending to move toward data collection-based service contracts such as remote condition monitoring. Challenges are complemented with identified potential solutions which could help industrial players to consider recognized areas early in the process and therefore mitigate design and implementation-related risks.

Utilization of the data and determining its value can take time. Establishing a remote condition monitoring system also requires a rather significant resource allocation from human and capital perspectives. The value potential and benefit may also be difficult to showcase in advance for the internal organization as well as to potential customers. Once the system is operational, it is advised to monitor and collect improvement-related information from the system to demonstrate the received benefits.

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