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# FUNDAMENTAL CHALLENGES IN DEVELOPING INTERNET OF THINGS APPLICATIONS FOR ENGINEERS AND PRODUCT DESIGNERS

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## Abstract

Decreasing cost for computing power, connectivity and electronics arouse potential for a variety of Internet of Things (IoT) applications but the development of value-adding IoT applications evolves still relatively slowly. To foster their realisation, IoT application development must be approached holistically. The identification of development challenges is a necessary groundwork for a holistic design methodology. This paper presents the development of an IoT application based on an existing mechatronic product as case study and derives challenges faced by developers with an engineering design background. An IoT add-on device is integrated into a mechatronic system. The use of actuators can be monitored in real-time. The identified challenges relate to the identification of added value, making of design decisions, understanding the target physical object, keeping iteration cycles equally short and learning of new skills. The identified challenges inhibit the realisation of IoT applications and must be addressed to foster IoT applications in industry. In future, methods to identify value-adding IoT applications and tools to efficiently realise such applications must be developed.

**Keywords**: Design for X (DfX), Digital / Digitised engineering value chains, Innovation, Internet of Things, Case study

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# 1 INTRODUCTION

Various media channels, the *World Economic Forum* (Schwab, 2015) and researchers (Brynjolfsson and McAfee, 2014) claim a technology driven revolution is taking place and thereby changing the way mankind lives and rules the economy. The revolution, also known as *Industry 4.0* in German-speaking regions, is designated to be the fourth industrial revolution (Kagermann et al., 2011). The backbone of this revolution is the merge of physical and digital spaces as cyber-physical systems (*"Cyber-physical systems (CPS) will transform how humans interact with and control the physical world."* (Rajkumar et al., 2010)). The term is defined as: *"Cyber-physical systems (CPS) are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core."* (Rajkumar et al., 2010). The communication capabilities of such systems drive the technological revolution because they allow to connect multiple systems and create in this way the *Internet of Things* (IoT). The IoT is a paradigm which is the result of the convergence of three perspectives: (1) A thing-oriented, (2) an internet-oriented and (3) a semantic-oriented perspective (Atzori et al., 2010). In other words, physical things can be sensed or sense data automatically (1). The data is then automatically communicated to other things or humans (2). The data is interpreted and evaluated automatically to derive meaning (3). These three perspectives allow the vision of an internet containing information about the physical world which is not depending on human input (Ashton, 2009).
Technological progress in the domain of information and communication technology (ICT) and hence decreasing cost for computing power, connectivity and electronic components enable the IoT to become more and more reality and arouse potential for a wide range of promising applications. Not surprisingly, there is a lot of hype about IoT (Burton and Walker, 2015). In fact, the development of IoT applications evolves relatively slowly, even though the IoT paradigm promises high potential. Clearly, several IoT applications are popping up in domains such as smart home, wearables or smart cities. Well-known IoT applications are often consumer gadgets nice to have (e.g. colour changing light balls or fitness trackers). Known applications with a positive economic or ecological impact are still rather rare (e.g. parking or bin fill level monitoring). In enterprises of the metal, electrical and machine industries (MEM) even less applications are known despite the opportunities offered by a variety of technological enablers.
IoT application development deserves the attention of engineering design and design methodology must be adapted to fulfil the requirements of IoT application development. To exploit the full potential of the IoT vision in the MEM industries, companies and their developers must be empowered to develop and realise value-adding IoT applications. At first sight, this seems easy achievable by putting the right people with the right knowhow together and let them build such applications. But development of an IoT application is much more challenging because it is not just about combining sensors with an embedded system, equipped with communication technology and linked to a cloud platform. The development of IoT applications is a multidisciplinary product and service development task. IoT application are mostly based on yet existing physical products. The development of physical products belongs traditionally to the domains of mechanical engineering and industrial design which traditionally lack ICT competencies. IoT applications must satisfy the needs of a broad spectrum of stakeholders. IoT applications will not only have impacts on its primary users but also on society, economy or politics (Feki et al., 2013). In addition, the ecosystem of IoT enabling technologies is highly volatile and evolves quickly. All this makes the development of IoT applications highly demanding, especially for developers with a traditional and non-ICT background.
A holistic treatment of IoT application development along the entire value chain of new product development (NPD) is missing. Seeking for literature on IoT application, product or service development and design does not lead to much results at least not with respect of design or innovation methodology. Single aspects of or isolated perspectives on IoT application development are discussed in literature.

- Westerlund et al. research on design tools for IoT business models (Westerlund et al., 2014). The part of realisation and implementation of IoT applications is not covered as it is typical for management or business research on IoT.
- Hodges et al. present tools for rapid prototyping of IoT applications which is an essential element in the design process (Hodges et al., 2013). The main focus of this or similar contributions is the realisation of functionality. Business aspects then again are not covered.

- Hribernik et al. suggests an approach for co-creation of IoT applications to cover needs and requirements of a broad set of stakeholders (Hribernik et al., 2011).
- Patel and Cassou provide a development framework for IoT application software development (Patel and Cassou, 2015). The framework supports partial automatic generation of code and iterative development. Only software development is covered by this framework.
- The 23rd CIRP Design Conference focuses on smart product engineering. The conference proceedings promise to describe processes, methods and tools for the creation of these smart products (Abramovici and Stark, 2013). Most of the contributions do not fulfill the promise.
- The contribution of Kiritsis treat closed-loop product life cycle management (PLM) under the aspect of IoT and intelligent products (Kiritsis, 2011). The development of IoT applications is not directly addressed but indirectly by illustrating how intelligent products enable information feedback on the product lifecycle, especially product design.

A holistic approach allows to bridge the gaps between physical, digital and business development to effectively and efficiently develop value-adding IoT applications. Such a holistic approach aims to foster the realisation of IoT applications in the MEM industries.

In order to design and validate a holistic development methodology and approach suitable for efficient and effective IoT application development in the MEM industries research must identify the specific development challenges for IoT applications from the perspective of engineering design and product development. This paper contributes to the identification of IoT application development challenges based on a case study. The case study aims to answer the following three research questions:

1. What are relevant aspects and considerations when developing an IoT application based on a given physical object?
2. How is the technical realisation of such an IoT application implemented as a prototype?
3. What are challenges faced by developers with a traditional, non-ICT background when developing IoT applications?

The case study adds connectivity and smartness to an existing physical product and creates thereby an IoT application.

An integral definition of the term *IoT application* is needed to treat the topic of IoT application development holistically. The understanding of the term *IoT application* varies depending on the working field of authors. In the research field of enabling technologies an IoT application is understood as the added value resulting from the use of technology (e.g. *"IoT will not be seen as individual systems, but as a critical, integrated infrastructure upon which many applications and services can run."* (Stankovic, 2014)). Some research on the business aspects of IoT tend to declare an IoT application as the implementation of middleware functionalities which are necessary to offer a certain benefit or value proposition (e.g. *"[...], IoT applications enable device-to- device and human-to-device interactions in a reliable and robust manner."* (Lee and Lee, 2015)). Interestingly, the term application points away from the core activities and expertise in each field. It is used to declare that this is the part of which someone else will take care of. The perspective of product development brings in a third part which is the medium carrying IoT functionalities: physical products and goods. A definition consisting of three parts is used to cover all three aspects: (1) physical objects, (2) data processing functionality and (3) added value (Figure 1). This definition is partially congruent with the five value-creation layers in an IoT application (Fleisch et al., 2015) but simpler and more applicable to the perspective of product development and engineering design.

The document illustrates the research design and case study setup (Section 2), provides answers to the formulated research questions (Section 3). The results are further discussed (Section 4) and a generalised conclusion is derived (Section 5).

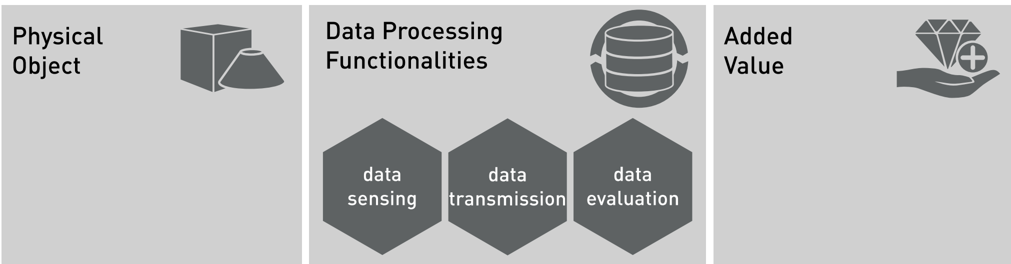


*Figure 1. Definition of IoT application consisting of three parts*

## 2 RESEARCH DESIGN

Develop and build an IoT application based on a physical object (product) in order to learn about challenges of development for the IoT and present it in form of a case study is the fundamental approach of this work. A case study is chosen to gain first, practical experience and to identify potential directions of impact. The case study serves as a basis to plan future, more explicit research. The case is more specified by the strategy of development, the classification of the physical object and the description of the selected object in the following paragraphs.

### 2.1 Strategy of Development

An existing product is chosen as the physical object for this development case and it is complemented to create an IoT application in this way. There are basically two strategy options: develop a new IoT application from scratch with a new physical product or build an IoT application based on an existing physical object. The choice can be motivated by the fact, that development activities in industry more often focus on incremental advancement of existing products rather than on complete new development, e.g. shown by an empirical survey in Germany with 159 participants (Albers et al., 2015). It is relevant to understand the challenges of transforming an existing product towards intelligent and smart product.

### 2.2 Classification of the Physical Object

A mechatronic system is the physical object chosen to become smart in this case study. Typically, a mechatronic system consists of mechanical, electrical and information technology elements. A mechatronics system's physical components are an embedded system, actuators, sensors, power supply, moving parts, housing (static parts) and often a user interface. Mechatronic products are widely spread through all kind of industries and applications, especially in the MEM industries. It shows yet a certain degree of intelligence but is not compulsory a thing in the IoT. Products can be classified on four levels of intelligence (Kiritsis, 2011). A mechatronic system like a car for example belongs to the third level of intelligence: *"physical products with embedded sensors, memory and data processing capabilities."* (Kiritsis, 2011). In order to reach the fourth level of intelligence and meet the requirements of an IoT thing, identification and communication capabilities must be added. With respect to Atzori's IoT paradigm (Atzori et al., 2010) semantic elements are also missing in a typical mechatronic system.

### 2.3 Physical Object Selected

The mechatronic product selected for this case study is the so-called Jarvis Mechatronics Kit (JMK). The field of application of this product is project based engineering education (Heinis et al., 2016). The JMK allows students to realise and operate their own mechatronic systems. It is a consumer good with students as direct users. 100 units of JMK are used in engineering design projects at (ETH Zurich, 2015). The JMK is constituted by a computing unit called myRIO by National Instruments, a power electronics board with an enclosure and connections for peripherals, actuators and sensors (Figure 2, (a)). Even though a specific product is selected for this case study, the implemented solution claims to be general and transferable to other mechatronic products, at least to some extent.

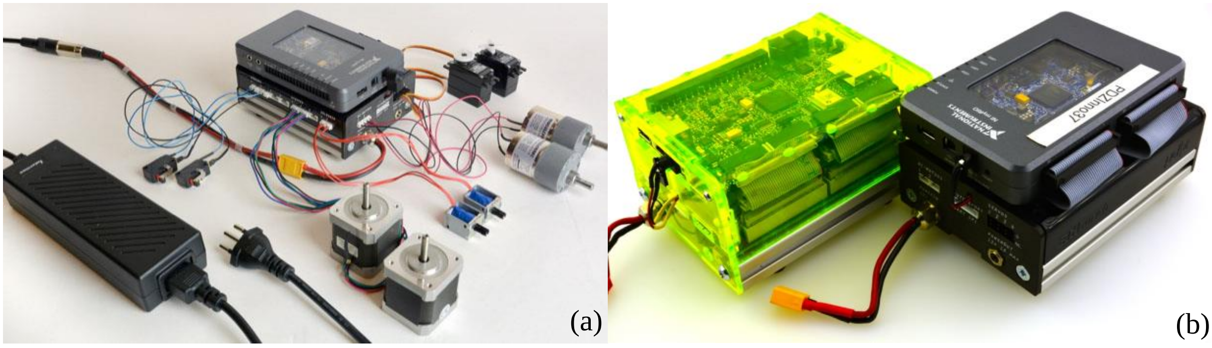


*Figure 2. (a) Initial JMK with actuators. (b) IoT version and initial version of JMK*

# 3 RESULTS

The result section answers the three research questions stated in the introduction (Section 1), one in each subsection.

## 3.1 Aspects of IoT Application Development for a Mechatronic Product

Relevant aspects and considerations for IoT application development based on a mechatronic system emerged from the case study. Based on the suggested definition for an IoT application where the physical object is defined by the research design, the two main tasks are to develop and design the data processing functionality and to define the added value. Single aspects of the two main tasks are explained in the following sections by showing the solution approach chosen and by reasoning the choice and the importance of an aspect (Table 1).

*Table 1. Overview or relevant aspects for IoT application development*

| Task | Relevant Aspects | Critical Questions |
|---|---|---|
| added value | user orientation, valuable meaning | *Who is the user addressed with an IoT application? How does he benefit?* |
| | data security, privacy | *How to avoid drawbacks on added value due to unsecure data or privacy?* |
| data processing funtionalities | integral vs. add-on solution | *How do the data processing functionalities influence the physical object?* |
| | data sensing | *What kind of data needs to be sensed? What is the approach to get the data?* |
| | data transmission | *How is the data communicated? How is an internet connection established?* |
| | data evaluation | *Where is the data collected? How is it evaluated to derive meaning?* |

### 3.1.1 Added Value: User Orientation and Valuable Meaning

To define the stakeholders or users and how they benefit from the IoT application user stories are used. The students are the main users of the JMK. Others are the educators and the developers of JMK. To create added value three user stories are addressed with this case:

- "As a student I want to reflect on my prototyping activities with the JMK and compare it to others in order to accelerate my learning progress."
- "As an educator and researcher I want to compare the performance of the students with their mechatronics prototyping activities to check for correlations."
- "As the developer of JMK I want to see how the product is used and when it fails in order to improve it."

How the connectivity and the smartness of a product delivers valuable meaning to users or stakeholders is an important and challenging question which is essential to be answered for every IoT application: *"It's exciting to envision futuristic scenarios in which previously analogue products come to life. [...] make sure you're focusing on a problem to which customers want a better solution"* (Hui, 2014).

### 3.1.2 Added Value: Data Security and Privacy

Data security and privacy concerns are not yet addressed in this case due to its academic purpose. The topic of data security and privacy is very sensitive and important to be considered for IoT applications (Weber, 2010). According to the *privacy calculus model*, users do only allow data access if the benefit of sharing a certain information is superior to its downside and they are confident that their privacy is protected (Dinev and Hart, 2006).

### 3.1.3 Data Processing Functionality: Integral vs. Add-On Solution

An add-on device with its own embedded system, a single-board computer, is retrofitted into the JMK. Therewith, the add-on device is decoupled from the student's application of the JMK. From developers point of view this approach is preferred over an integral solution for two other reasons. First, the add-on device does not affect the functionalities of the initial product. The risk of impairing the performance of the product is almost negligible. Second, development iterations become larger when the entire product is modified. The add-on allows to modify and complement the product's functionality within short iterations. Only when the add-on delivers the intended outcome and functionality, the development of an integral solution can be approached as a next step. Often, existing products have a long development history which is not always well documented. In this case the development of an integral solution is even more challenging.

### 3.1.4 Data Processing Functionality: Data Sensing

The user stories define what kind of data needs to be sensed. To track the activities of the students with the JMK and its usage data, the IoT add-on device senses whether JMK is on or off and the activities of the actuators (e.g. motor speed or torque). JMK provides four different actuators: DC-motors, servo motors, stepper motors and solenoids. The simplest option to get the data is over a *universal asynchronous receiver/transmitter* (UART) interface from the computing unit myRIO. This requires a built-in piece of software on the myRIO, which would limit the the student's freedom of programming. So, this is not a real option for this case. Besides, there are are two options to get the actuator's data: The first option is to install sensors (e.g. encoders) directly to the motors and the second is to wiretap the signal cable from the myRIO (embedded system) to the power electronics of actuators. The second option is chosen because adding sensors to the actuators results in additional wiring and serious geometry changes of the actuator. Wireless sensors solve the wiring issue but cause the problem of power supply. Energy harvesting or batteries would be needed, which requires even more space.

### 3.1.5 Data Processing Functionality: Data Transmission

The IoT add-on device communicates over mobile network connection (3G UMTS). There are several options to establish a data connection: Local Attached Network (LAN), wireless LAN (WLAN), mobile network connection (UMTS or LTE), low power wide area network (LPWAN) or low range wireless connections (e.g. Bluetooth, Zigbee or Z-wave). Crucial for the selection of the mobile network connection is the application location of the JMK and the power supply available. The JMK is generally used stationary but at different locations with different network infrastructure. The students work at different places with the JMK (e.g. at home, university or outdoor) Therefore, a long range mobile network is preferred. LPWAN is suitable for small data packages and is energy-saving. As power is available and higher data volumes are expected a connection over UMTS is selected in this case. Local networks (LAN, WLAN) would be suitable for stationary mechatronic products such as production machines.

### 3.1.6 Data Processing Functionality: Data Evaluation

To centrally collect data for data analytics and for device management an existing, web based cloud *application enablement platform* (AEP) called *deviceWise* by Telit is used in this case. The AEP provides an application programming interface (API) which allows other software applications to access the collected data. An own web based AEP could be developed. But as, the market provides a selection of established AEP solutions, the development of another one is not required.

### 3.1.7 Data Processing Functionality: Power Supply

In this case, the IoT add-on device gets the power from the JMK and the JMK gets it from the power grid. In general, mechatronic systems do have any sort of power supply. Most of them get the electricity from the grid. So, power supply is not a critical issue. Only if the mechatronic system is battery driven or harvests the energy from its environment power supply of the add-on device must be considered specially in order not to impair the host system's performance.

## 3.2 Technical Implementation of Data Processing Functionalities

The IoT add-on device is realised and implemented for one JMK (Figure 2, (b)). The data processing on the JMK is driven by a single-board computer (SBC) called *Raspberry Pi* (RPi) *Zero* which is built into the housing of the JMK (Figure 3, (a)). The RPi Zero offers a full featured Linux operating system based on a System-on-Chip (SoC) with an ARM Processor by Broadcom Corporation and 40 general purpose input/output (GPIO) pins. The software running on the SBC is written in the language *Python.* The code can be provided on request (Gomes Martinho, 2016). The software consists of algorithms for data sensing and transmission to the cloud AEP. The implemented software streams data every five seconds to the AEP. It executes the following steps.

1. *Establish the connection*: the software establishes the connection to the AEP.
2. *Enter the main loop*: main loop is executed while no AEP method request exit the loop.
   - *Collect desired data*: execute methods to get values (data) of objects (e.g. motors).
   - *Stream the collected data*: execute methods to stream data to AEP.
   - *Execute AEP methods*: execute instructions coming from the AEP.

3. *Terminate measuring*: delete variables, disable sensors and shut down AEP connection.
4. *Exit*.

The execution of the software starts automatically when the SBC boots by calling a shell script in the *rc.local* file (/etc/rc.local). The SBC boots whenever the JMK has power supply. The software running on the RPi Zero is compatible to other SBCs running Linux. The software has a modular architecture. Therefore, the IoT add-on device can be integrated into other mechatronic systems and tracking of additional objects (e.g. motors) can be achieved with little extra effort.

### 3.2.1 Implementation Data Sensing Functionality

The main challenge of sensing the motor usage data is to convert the wiretapped control signal from the JMK into a digital signal which can be read by the SBC. Seven different variables are measured with one signal tapped per variable (Table 2). Four of the signals are digital signals already. The digital signals can be measured using the GPIOs. Counting the steps of the stepper motor is challenging because the signal changes unpredictable and at high frequencies (up to 2.5 kHz). Polling of the step signal results to the risk of missing single steps and to high processor load. To avoid this risk and high processor load, the signal is detected using interrupts (edge detection). With interrupts, not the value of the signal is detected but its change. Two of the signals are pulse-width modulation (PWM) signals where the duty cycle determines the variable. A second order low pass (RC) filter is used to measure the duty cycle as analogue voltage. The current which characterises the torque on the DC-motor is sensed by the motor driver (MC33926) and returned as analogue voltage. The analogue voltage is converted to a digital signal using an MCP3008 analogue-to-digital converter (ADC) which passes the signal via *Serial Peripheral Interface Bus* (SPI) to the SBC.

*Table 2. Sensed motor data and its signals and signal processing*

| Motor | Variable | Measured Signal (wiretapped) | Signal Manipulation | Signal Reading |
|---|---|---|---|---|
| DC-motor | direction | digital state (HIGH/LOW) | none | GPIO using polling |
| | speed | PWM (duty cycle, 5000 Hz) | – 2nd order RC filter – ADC – | SPI |
| | torque | analogue voltage (525 mV per amp) | – ADC – | SPI |
| servo motor | position | PWM (duty cycle, 50 Hz) | – 2nd order RC filter – ADC – | SPI |
| stepper motor | direction | digital state (HIGH/LOW) | none | GPIO using polling |
| | steps | digital impulses (LOW) | none | GPIO using interrupts (edge detection) |
| solenoids | activation state | digital state (HIGH/LOW) | none | GPIO using polling |

### 3.2.2 Implementation of Data Transmission Functionality

The data is communicated to the AEP using the MQTT protocol. MQTT works based on a publish-subscribe principle using a broker for message distribution. The broker is part of the AEP. The IoT add-on device uses a *device ID* and an *application token* provided by the broker to authenticate. The MQTT protocol has a smaller data footprint than the HTTP protocol and uses less energy. It can deal with slow networks and network delays. A MQTT library from the Paho project by Eclipse is used.

The physical connection over the mobile network (3G UMTS) is established using a USB stick from Huawei model E3531 and a subscriber identity module (SIM) card. The stick simulates a LAN-over-USB connection and works with devices providing an USB interface. A software package called *usb-modeswitch* is used to have the stick recognised as modem by the SBC. An alternative to the USB modem is a chip based modem (e.g. Adafruit Fona 808) connected to the SBC via UART. The chip based modem allows better integration but requires a higher effort for implementation.

### 3.2.3 Implementation of Data Evaluation Functionality

In the case study, a dashboard which is part of the AEP is used to visualise the collected data and to create semantic content and meaning (Figure 3, (b)). The data evaluation is done with the AEP and not directly on the IoT add-on device because the AEP offers more computing power and data evaluation tools out of the box. The dashboard is an interactive, customisable, widget based website. The usage of the JMK and its motors can be monitored real-time. The widgets are gauges, graphs, lamps and other figures to display collected data or buttons and switches to interact with the JMK or its primary user using cloud methods (e.g. activation of motors or LEDs). More advanced data analytic methods (e.g. machine learning algorithms) are not applied because usage data of only one JMK is collected so far. Larger data sets from field tests are required for this.

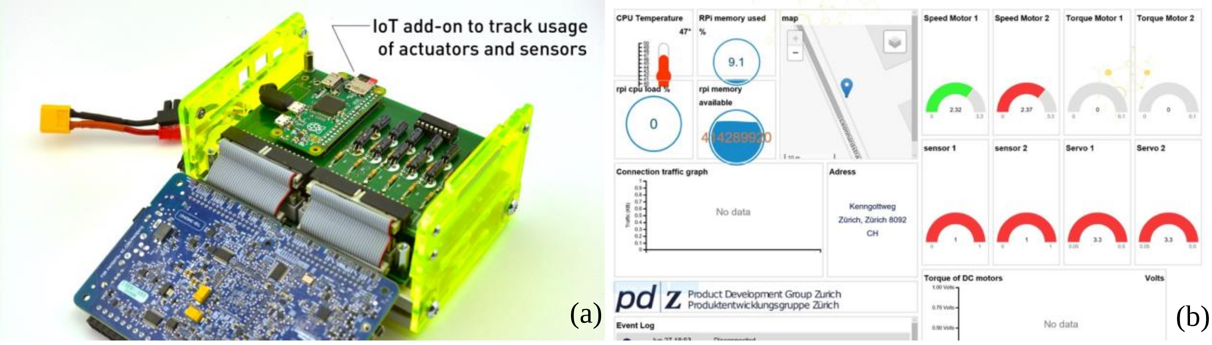


*Figure 3. (a) IoT add-on device in housing of JMK. (b) Dashboard with actuator usage data*

#### 3.2.4 Integration into JMK

The housing of the JMK is adjusted and an additional printed circuit board (PCB), containing all electronics hardware necessary for data sensing, is installed into the JMK. Not changing the outer dimensions, mounting points and connections is essential to guarantee the habitual use of the JMK. The new trackable JMK provides the same functionalities like the initial one but can interact with and stream its usage data to the cloud AEP.

### 3.3 Identified Development Challenges

Five challenges for IoT application development emerge from this case study. They are described in the following subsections.

#### 3.3.1 Identify Value Added Which Outweigh Development Effort

Starting with an existing product and identify the added value generated by an IoT application is a challenge. A prediction whether the IoT version of JMK adds real value to the users cannot be made at this time. Methods to make added value by IoT applications measurable or tangibles before they are fully launched are missing. The effort of development and implementation outweigh the value added. The ratio between effort and benefits is in an economic imbalance.

#### 3.3.2 Make Design Decisions

Due to missing standardisation fixing the right design variables at the beginning is a challenge. As in many development projects several design options exist to solve certain sub tasks of the overall task. Deciding on one option for one sub task limits the options for other sub tasks/problems due to solution compatibility. For example, defining the material of a part limits its manufacturing possibilities. Because the field of developing for the IoT is relatively new, technology is quickly evolving and standardisation is missing, experience about the dependencies between single sub problems is rare. Therefore, design decisions must be made without knowing the impacts on other sub problems. This is challenging. Selecting the cloud AEP and the RPi as starting points are the first design decision made in this case study. These decisions shape the course of the project.

#### 3.3.3 Understand the Physical Object Targeted

Understand the architecture of the target product is a challenge. Even though the JMK has been developed only recently and product documentation is available, understanding the structure of the electronics and the software (labVIEW) was demanding. Without understanding the architecture of the target product, developing an add-on device is hardly possible. The initial developers of JMK are accessible for questions only to a small extend.

#### 3.3.4 Keep Iteration Cycles Equally Short

Applying the concept of short iteration cycles equally on all elements of IoT application development is a challenge. Generally, iterations have positive impacts on development projects but they are resource intensive (Wynn and Eckert, 2016). Short iterations intend to keep the cost of an iteration low without foregoing the benefits. The execution of designing, building and testing in sequence can be seen as one iteration in development. For the software part of an IoT application all three execution steps necessary for an iteration loop can be conducted within a short period of time at relatively low cost: write code, compile it and test it. Iterations for the physical elements of an IoT application demands a higher effort. When digital parts have to interact with the physical ones, the inequality in lead time of iterations complicate a smooth project course. In this case for example, the availability of electronic parts and design and manufacturing of the PCB delay the project course.

#### 3.3.5 Learn New Skills

In order to start developing for the IoT with a non-ICT background one need to build up new skills. This is a challenge. Programming skills are fundamental. Good documentation about technology and code libraries are essential to develop new skills. Tutorials help to get things done.

## 4 DISCUSSION

Sensing actuator usage data by wiretapping signal cables comprises the risk of unintended manipulation of the signal itself. Unwanted actuator actions are possible. They are not a serious issue in the case of the JMK but for mechatronic systems with larger and more powerful actuators, they pose a risk for users or the environment. In addition, wiretapping the control signal of an actuator does not give a feedback about the actual actuators state but only about the intended state. Nevertheless, wiretapping is a pragmatic approach when absolute precision and certainty is not required.

Even though the case study claims to present an IoT add-on device which is modular and can be attached to various mechatronic systems, a generalised solution is not fully achievable. The size of the target physical object (mechatronic system) for example brings some limitations and design restrictions. Also, power supply (voltage and current) of a mechatronic system determines whether the IoT add-on device can be used to track its actuators usage. Besides, the maturity of the IoT add-on device is on a prototype level but the technology used allows upscaling and further integration.

The research method of conducting a case study is suitable to identify challenges of IoT application development but does not guarantee to identify a set of collectively exhaustive challenges. In fact, the validity of the identified challenges holds true only for this case and its developers. Compared to other cases, which are based on toy technology, e.g. LEGO Mindstorms (Anderl et al., 2013), this case is based on technology which is also applied in industries. Still, the presented case has an academic character. Multiple cases with a stronger industrial character could confirm the validity of the results.

## 5 CONCLUSION

This contribution answers the three research questions formulated in the introduction (Section 1): (1) General aspects relevant for IoT application development for a given physical object and product (mechatronic system) are outlined. Given the physical object of an IoT application, the aspects can be distinguished into two categories: added value and data processing functionality. Relevant aspects in the category of added value are user orientation, valuable meaning of data, data security and privacy. In the category of data processing functionality, the aspects are integral vs. add-on solution, sensing, transmission and evaluation of data and power supply. (2) An IoT add-on device is developed and integrated into the given mechatronic system and a data stream to a cloud platform is established. The integration of the IoT add-on device has no negative impact on the initial functionality of the mechatronic system. The add-on device enables actuator usage monitoring in real-time for the mechatronics system. (3) Challenges faced by a developer with a non-ICT background when developing an IoT application are identified. The challenges are related to the identification of added value, making of design decisions, understanding the target physical object, keeping iteration cycles equally short and learning of new skills.

The aspects of IoT application development covered by this case study can serve other developers as guideline for a holistic development approach. Further, the presented solution can serve as example for a possible technical implementation. With little effort, the developed IoT add-on device could be integrated into other mechatronic systems and thereby allows to track the actuator usage other systems. The development challenges identified in this case study inhibit the realisation of IoT applications. They point out a research direction for design research for IoT application development. Addressing the challenges means fostering the realisation of IoT applications in the MEM industries.

In the future, effective methods to identify added value generated by IoT applications must be developed and developers must be equipped with tools to efficiently realise promising IoT applications in order to make the added value of IoT applications tangible.

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