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Supporting the Digital Transformation: A Low-Threshold Approach for Manufacturing Related Higher Education and Employee Training

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Abstract

The technologies of digital transformation, such as the Internet-of-Things (IoT), artificial intelligence or predictive maintenance enable significant efficiency gains in industry and are becoming increasingly important as a competitive factor. However, their successful implementation and creative, future application requires the broad acceptance and knowledge of non-IT-related groups, such as production management students, engineers or skilled workers, which is still lacking today. This paper presents a low-threshold training concept bringing IoT-technologies and applications into manufacturing related higher education and employee training. The concept addresses the relevant topics starting from IoT-basics to predictive maintenance using mobile low-cost hardware and infrastructure.

Keywords: internet of things; predictive maintenance; low-threshold training concept

1. Introduction

The technologies of digital transformation, such as the Internet-of-Things (IoT), artificial intelligence (AI) or predictive maintenance enable significant efficiency gains in all departments of a company and especially of the production [1,2]. They become increasingly important as a competitive factor [3]. Currently often IoT or AI projects are driven by higher management as strategic projects and delegated to the IT-departments for project lead. But a successful implementation and creative, future application also requires acceptance and knowledge of these technologies in non-IT-related groups, such as production engineers or skilled workers [4]. In fact, everybody working with technologies related to digital transformation requires a certain basic knowledge about them for better understanding their advantages and disadvantages [5]. Nowadays, big companies which are already directly faced with the transformation towards e-mobility, e.g. Bosch or VW set up programs to qualify traditional mechanical engineers towards software programming and engineering [6,7]. However, small and medium sized enterprises (SME) producing machines or components often lack the capacity and financial resources to set up own programs and trainings [2]. To support SME in the digital transformation, low-threshold SME-suited employee trainings based on modern training concepts like microlearning or gamification bringing IoT-technologies and applications into manufacturing are a starting point for pilot projects. Furthermore, the current and future generation of students in manufacturing related disciplines such as business engineering, industrial engineering and production technology have to be trained in these technologies and topics enabling them to use them creatively [8,9].

Closing this gap, the paper presents a low-threshold, mobile and low-cost training concept bringing IoT-technologies and applications into manufacturing related higher education and employee training. Special focus of the concept is to use mobile and low-cost hardware and software in order to enable inhouse

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training directly in a company. This enables also the implementation in financially weaker world regions.

2. Related Work

In the past few years and especially in recent times, there have been major changes in the use of media in education although their efficiency varies [10,11]. Nevertheless, the target audience of people with different learning styles and educational backgrounds needs to be considered while developing new methods for training [12]. Particularly in STEM (science, technology, engineering and mathematics) related areas it is important that teaching according to real-life issues and concerns is focused [9,13]. This results in different approaches of teaching topics in IoT-related areas with various focuses. For example, if the target audience reads scientific papers, summarizing the main contents of the IoT in a publication would present applications and influences on society, but neglect practical applications [14]. Another approach is teaching with the use of robotics in schools for children and young adults which supports the understanding of robotics itself. In this case the overarching context of where and how to use robotics would be missing [15]. Teaching predictive maintenance for students in industrial sectors with augmented reality can be used for the visualization of physical and digital content but, in turn, this is dependent on the environment, system complexity and ergonomics of, e.g., helmets or gloves [16]. There are also some models like the MoDiCA-X to test advanced control algorithms which can be used for training purposes [17] or LEAF to train cybersecurity for realistic edge-IoT scenarios [18]. Most of these concepts are based on learning methods, cover industrial use-cases and reflect different approaches on how to teach specialized applications (e.g. programming, robotics, cyber security or maintenance) using IoT-related technologies. It is missing a holistic approach for teaching the basic components of IoT in a practice-oriented manner, with the corresponding devices, networks and applications, so that it can be adapted to manufacturing disciplines and use cases.

2.1. Learning Methods for the Training Concept

To generate a more holistic approach learning methods have been analysed as every training concept is based on one or more different methods. The advantages of the relevant concepts combined for the developed training concept are mentioned below. Action learning is based on learning by doing where the participants work on specific topics while continuously reflecting the learning progress [19,20]. Microlearning as an emerging trend with a predefined processing time for tasks enables direct individual control of learning progress [21]. Gamification uses game elements like high scores, rankings, or awards to increase the motivation of the participants thus allowing to work with complex tasks more easily. In return the educational success is increased [22].

2.2. Implemented Methods and Areas of Application

Nowadays, teaching with a more holistic approach according to the mentioned learning methods usually takes place in educational institutions with specially equipped laboratories. To describe the unique nature of the training concept presented, a distinction is made to similar automation or manufacturing-related concepts already developed.

The first approach uses an annual competition for which students create a robot. The robot parts and a platform are provided which enables the networking of the individual robot modules, whereby the focus is centered around application features such as predictive repair. The objectives are to give students the skills to build and program a functioning mechanism in an IoT-environment as well as to work in a team. Construction and programming of the robot is executed by the students with very little guidance. With this competitive approach designed for several years, one study has shown that pupils can participate in a competition for university students after 3 to 5 years of learning experience [23].

The second approach is theoretical and contains a teaching factory for education based on four steps: Requirements are collected, products are designed, the product is manufactured, and tests are carried out. While developing a new product, students are shown topics like human-robot assembly or augmented reality. The focus lies on teaching features of cyber-physical systems for production lines, product development and showing a whole manufacturing environment where students will work in the future [24].

The third approach is a model factory showing methods of production optimization at an innovation laboratory in Stuttgart which is divided into three laboratory areas: the learning world for information and discussions about future trends, the world of ideas, where new solutions are developed, and the demonstration world with demonstrators to show processes in the value stream. This concept has prebuilt demonstrators and works with many participants. In just three hours they get an introduction in manufacturing related topics based on real life applications. Most of the participants have work experience in related areas [25].

The fourth approach, embedded in the LEAD Factory of the Institute of Innovation and Industrial Management at Graz University of Technology, focuses on teaching through a case study. The learning objectives for the students are, for example, value creation based on digital transformation, dealing with modern interfaces, processing and analyzing data, as well as acquiring competences in information and communication technologies [26].

The fifth approach of the SEPT Learning Factory is closest to the presented training concept. There, the future of manufacturing industries is displayed and engineering students can work hands-on to further their technical capabilities. Besides the learning factory itself, a portable IoT microcontroller-based model is provided where programs like IoT Home Lighting, basic sensors and output devices or Smart Motor Control are integrated. All models can be executed and extended by students even outside the learning factory environment [27].

All the approaches mentioned above are designed either for pupils, students in learning factories with a stationary location or people already working in manufacturing related areas. These concepts include versatile approaches that teach the content and features of the IoT to different learning groups, but so far have not been developed further in the light of a holistic, flexible and mobile approach for teaching IoT basics and network technologies with the possibility to add cloud technologies in a context of predicted future real-world applications.

3. IoT-Training Concept

The training concept enables Non-IT-related groups to understand the basic concepts of IoT and develop a simple manufacturing-related IoT system for predictive maintenance and machine learning applications. Therefore, the following requirements need to be addressed in the development of the IoT-training concept:

- The participants have little or no knowledge in programming, the concepts, and technologies of the IoT
- The approach has to be modular in order to be easily adapted to different technologies, use cases and contexts such as predictive maintenance, shop floor control or quality inspection
- The approach has to be mobile in order to provide training on a non-stationary basis
- Costs for the hard- and software have to be low, ideally open source in order to enable use also in financially weaker world regions

Based on the core idea learning objectives can be derived:

- Participants comprehend concepts and technologies of the IoT and are able to develop simple IoT systems by writing short program modules
- Basic components of data processing, data analysis and visualization are understood by participants and can be applied in a manufacturing environment
- Participants comprehend and can run data processing and simple predictive maintenance applications based on machine learning algorithms and interpret the results

3.1. Training Approach

For the IoT-training a practice-oriented and action-based approach with elements of gamification has been selected, as action-oriented learning environments enable an efficient transfer of knowledge [22,28,29]. Based on the initial decision to action-based training the course is designed as a classroom teaching event with a high degree of practical processing where the participants create their own applications. The participants get little guidance except for the presentation of basics and an introduction to new concept sections. They have to create and test the main part of the applications for themselves. Therefore, the provision of teaching and learning materials for all participants is essential for the proper implementation of the teaching concept. Towards the end, the applications can be

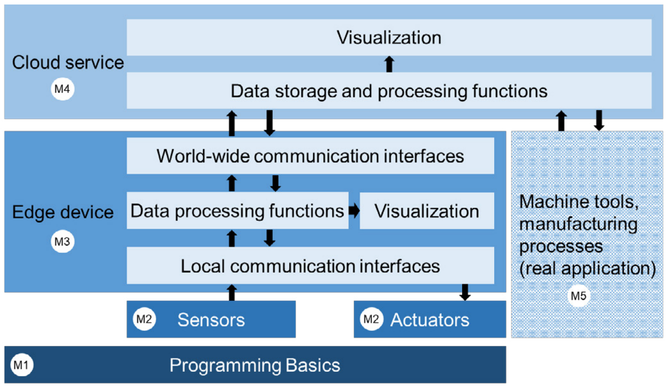

Fig. 1. Content of the training concept

accessed by every participant and datasets have to be created to reproduce real application errors. The best datasets are then used in manufacturing related use cases for working with machine learning algorithms and predictive analytics. Based on a technical IoT reference architecture [30,31] the IoT-training consists of five modules each containing several tasks which are detailed in the following sections. Here, the workload for each task has been created using the microlearning concept, which allows a processing time of around 15 minutes per task [21]. The programs to be developed within the tasks are also designed as logical black boxes, with the corresponding input and output information for a good reusability. Another aspect of the training concept is to provide an industrial application case as a red line, from which the participants can abstract their experiences and gained knowledge ideally to other applications. This reflects the insight that teaching in technical areas must involve a real-life issue centered pedagogy [13]. For the IoT-training presented, the use case of an air filter monitoring and change prediction application is chosen, as air filters are widely used in electrical cabinets of machines in manufacturing and easy-to-understand predictive maintenance applications can be derived. The advantage of this use case is also, that the hardware for training (fans and filters) are cheap and that the solution can be implemented also in real manufacturing to reduce maintenance cost for filter changes. The whole training is designed for the duration of one working day to cover all basic elements of an IoT system. Due to the modularity of the training concept it can be adapted to other use cases and longer events easily.

3.2. Structure of the Training Concept

Fig. 1 shows the structure of the IoT-training concept beginning with a module for teaching the programming basics (M1) followed by the basics of how sensors and actuators (M2) are read or controlled by a local edge device (M3) like a mini-computer using its communication interfaces. Other functions performed on the edge device are data processing, local visualization and communication with other networks. The module related to the cloud (M4) is split in data storage possibilities, data analysis and the evaluation of data. The last module (M5) contains machine tools and manufacturing processes and the associated data generation and transmission possibilities.

3.2.1. Programming Basics

In the first module (M1) basics of edge devices such as mini-computers or microcontrollers are presented to guarantee that every participant is able to physically work with the edge device. Afterwards two approaches of programming are explained: programming with a script language (Python) and flow-based programming with pre-built components like logical black boxes (Node-Red). To learn the advantages and disadvantages of programming with these black boxes, the participants had to convert their Python-Code to a self-built component for Node-Red which could then be freely used in the program. This clarified what happens to the input information in a black box and how an output is produced.

3.2.2. Accessing Sensors and Actuators

With the general knowledge of how to program with Python and Node-Red, in the second module (M2) the participants have to connect sensors and actuators to the edge device. In order to fulfill the low-cost and mobile requirement a controllable cabinet air fan has been chosen. It has the advantage, that easy-to-understand manufacturing relevant use cases can be built such as a temperature control or the predictive maintenance model for air filters. The participants create short and simple programs for data acquisition and control. Once programmed, they are also available as black boxes for further processing. In this context, manufacturing relevant sensors such as temperature, humidity, pressure, RGB and analog-digital converter for light or strain gauges and the local communication possibilities like I^2C are covered. As actuators the displays and analog outputs via pulse width modulation (PWM) are trained, with relations to their use in manufacturing.

3.2.3. Data Processing on the Edge Device

In the third module (M3), the edge device works with sensor data which are processed and displayed locally on a dashboard. Also, to close the loop the data are used to control actuators in examples with an increasing difficulty level. These examples start from visualizing sensor data on a display, to a temperature control with the air fan. Furthermore, to come to the IoT the data are sent to the cloud service (M4). These tasks are performed in the program Node-Red itself, where predefined black boxes are used to speed up the training especially for similar programming tasks. This makes it possible to implement a dashboard without much programming effort and all relevant data can be displayed in a chronological sequence or as a snapshot. In addition, the dashboard can be used to implement a regulator that controls the air fan as actuator. By completing this module, each participant has created a functioning system locally on their edge device in order to monitor manufacturing data and to be able to intervene in a controlling manner.

3.2.4. Data Processing and Analysis in the Cloud

The cloud service in the fourth module (M4) allows the participants to process, visualize and analyze the stored data. Applied in a manufacturing context, an air filter change prediction as a predictive maintenance application has been chosen as main use chase (see Fig. 2). The core elements of the cloud service like the brokers to access data over different networks or a database are running in the background and are not accessible to participants for changes. Only an interface for data visualization, which is Grafana, a free analysis and monitoring solution for databases, can be accessed. Here, the principle of gamification is used, whereby the participants can evaluate and retrieve their own data, but can also work with the data of other participants. A competitive character is created and the results of the participants can be evaluated by others. As a reward, the data set with the most significant results is chosen by the teaching staff for further processing.

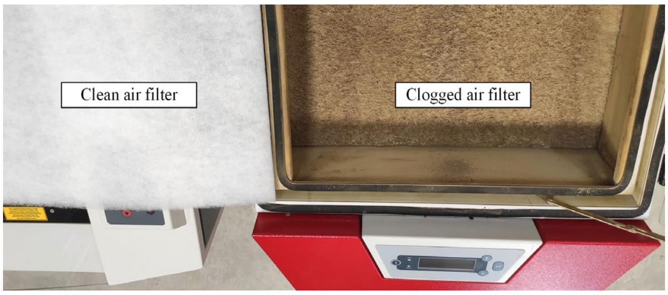

Fig. 2. Real image of a clogged filter of a laser cutting machine

In the predictive maintenance application of an air filter all stages of a predictive maintenance application development can be shown, from data acquisition, to simple degradation modelling and implementation. The degree of clogging of an air filter is dependent on the discoloration, which can be measured by a color sensor. For this purpose, the participants are provided with a modified air filter that has different, realistic degrees of soiling to create time-lapsed different degradation values. Based on their measured values the participants are able to model a simple degradation model of the air filter and implement it on the data processing platform. For the degradation model as introduction into basic machine learning, a linear regression model is used. Then, the participants set a self-defined limit value and receive a prediction of when this limit value is exceeded by scanning the air filter with the color sensor. This example allows participants to understand the influences and impacts of predictive maintenance and machine learning in manufacturing. It is also a base for further training e.g. for predictive maintenance using more sophisticated machine learning algorithms. Possible other use cases are e.g. the automatic acquisition and prediction of throughput-times or product quality data using data from machine tools e.g. via OPC UA or production order data e.g. of an ERP system (M5). The models are developed and executed in the cloud service (M4). In conclusion, the design of the training concept follows one rule namely to keep all possible extensions open without restrictions, for a rapid adaption to different manufacturing use cases.

3.3. Implementation

In many cases, the integration of manufacturing-specific materials or networks limit a teaching event to dedicated stationary laboratories or learning factories. To counteract these restrictions, the training concept is designed to be carried out with only one ethernet connection and an external power supply. The Raspberry Pi is chosen as a hardware platform, as it fulfills the criteria of a good price-performances ratio and is also available in hardened industrial versions such as the RevolutionPi [32] or Netpi [33]. Moreover, it has the advantage that no extra computer for programming is required as it would be the case with microcontrollers or traditional programmable logic controllers (PLC). All materials are transported in one single box and can be scaled easily to the number of participants of one event. The edge devices in use have preinstalled software and libraries for programming and the evaluation process. Also, after each task in the training concept a predefined sample solution is provided to bring participants to the same knowledge level. This allows participants to work at their own pace and still have a working application in the end. To further reduce the processing time of the individual task the proportion of flow-based programming is increased so that participants reach their objectives faster. Basically, the concept is structured in such a way that each module can be seen and used as a black box. A view into the black box is possible at any time and the granularity can be adjusted fluently. It is comparable to a look behind the scenes to get detailed knowledge of how the processes in the background work in a real-world application. Due to these circumstances, modules have to be programmed in a script language (Python) as well as a flow-based one (Node-RED), which makes the development of the individual modules very complex but increases the comprehensibility of the application.

On the Raspberry Pi Docker-containers are running for the teaching staff, implementing a small private cloud environment containing the database, brokers (MQTT), a graphical evaluation program and a stand-alone access point in order to connect the individual devices. To deploy new services, e.g., for different databases, brokers, simulations or machine learning, only a prefabricated docker container must be integrated. For security reasons, the access point allows teachers to assign IP-addresses to the participants and monitor their network activities. Remote control of the devices is also possible, which is a sensible alternative to personal contact, especially in times when the distance is to be maintained [34]. Due to the modularity of the training concept, the content of each event can be adapted by changing the specific materials for the participants.

No stationary computers and expensive devices are needed, enabling the training concept to be used in financially weaker regions. In addition, working in groups of two further reduces costs and encourages interdependent work, while as a negative aspect the practical part is reduced for each participant. If the participants discover missing parts for their specific use cases, these can be added to the training concept in further sessions enabling new creations and implementations of ideas. In general, the opportunity is taken to raise people's awareness of IoT applications in manufacturing, predictive maintenance and machine learning algorithms and thus facilitate their entry into the digital world even if they are not preferring to work in manufacturing-related areas. All provided materials are meant to be tried out and played around with to generate new ideas and applications.

4. Evaluation, Validation and Main Learnings

The evaluation and validation of the concept was done with a group of 16 undergraduate students for production management. They were divided into two groups of eight students each and according to the evaluation of the first group the concept was adjusted for the second one. The length of the course was limited to six and a half hours although the allocation of the sections varied. Both groups had the predefined task of developing an intelligent air filter monitoring system and the programs for each module as well as an example solution of a possible monitoring system. The participants had little or no previous training in programming and little information on automation and predictive maintenance. The evaluation was conducted by observation of the students and a closed-items questionnaire. Participation was voluntary and anonymous. Response rate was 100%. In terms of content, the first group focused too much on programming in Python, which meant that connecting the modules could not be fully carried out. As a result, the concept for the second group was adapted to focus more on the holistic view of an IoT application with reference to predictive maintenance and machine learning algorithms. Despite less explanation of what is behind the black boxes through the focus on programming, the individual modules could be easily understood. The concept was changed according to the participants approach. When observing the two groups, it was noticed that the participants supported each other and solved the tasks independently. After a while, teams began to form that worked individually and completed the exercises. Mistakes were mainly made due to complex formulations, which were adjusted. Compared to the implementation of the training concept in previous years, the modular character of the training concept has made it possible to specifically identify the weaknesses of the individual participants. This allows for an individual shift in the focus of the training in the case of longer events. In summary, the evaluation was designed to get an overview of the direction in which the training concept should be developed in the future. Based on the feedback and general acceptance of the course, the main learnings for the developers of the training concept were:

- The modular approach in combination with microlearning improved the structure of the course and made it easier for participants to follow
- The out-of-the-box character allows quick and easy preparation and follow-up of a teaching event
- The out-of-the-box character reduces the workload and complexity for participants and teaching staff leading to a faster success and increases motivation of the participants
- If a real-world based approach is chosen, a sample solution after every section is recommended to balance the performance levels of the individual participants
- If there is a particular interest in the topic, participants will form groups and work on the content independently

5. Conclusion and Further Development

The demand for trained workers and students with skills and knowledge related to topics like IoT and AI is growing according to their increasing relevance in industry. This leads to new expectations being placed on educational institutions and companies to raise awareness of these topics. A new training concept is required which is easy to understand, adaptable to different circumstances, flexible, location-independent, future-oriented through arbitrary expansion possibilities and adjustable to different levels of education without losing touch to manufacturing applications. In this paper a low-threshold, mobile and low-cost training concept meeting these demands has been presented clarifying the requirements through a modular approach, which includes the character of an IoT system based on an edge device and a cloud service. It can be applied through different learning factories, teaching factories or learning events. Future research activities focus on the development of further use cases for different manufacturing areas such as shop floor management or quality management in order to have a large variety tool kit which can be adapted flexibly on training demands.

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