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Integration of a smart 5G clamping pallet in a learning factory environment

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Abstract

With an increasing number of smart networked devices being used for data acquisition in production, reliable connectivity and fast communication are becoming increasingly important. Since mobile networks have been developed accordingly, 5G technology is also being used more frequently for machine-to-machine communication. The main advantages of 5G are very high data rates combined with low latency, which are essential for appropriate data acquisition in production. Although 5G is widely used in mobile phones, users are not familiar with 5G communication within the production domain. Also, companies that want to use 5G devices in their production environment often lack knowledge regarding implementation, connectivity issues, or best practices. The smart clamping pallet presented in this paper demonstrates the current possibilities of industrial communication with 5G. Various sensor systems such as GPS, acceleration sensors, and force measurement are installed in the pallet, enabling precise localization and in-process control of the production process. The fully automatic vice integrated into the pallet, which works independently from any wired connection, represents the basis for future highly flexible and collaborative manufacturing processes. Particularly concepts of distributed manufacturing can be implemented based on this. This setup enables a knowledge transfer for users and companies and hands-on training within the production domain. In the future, the pallet will be used in the TU Wien Pilot Factory Industry 4.0 (TU PF) to demonstrate and familiarise learners and other interested individuals with the possibilities of today's industrial communication. In particular, networking and digitization can be understood based on this industrial use case for 5G. This use case meets the three pillars of the TU PF concept: (1) product piloting, (2) demonstration, and (3) knowledge transfer and education.

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1. Introduction and state of the art

For new technologies like 5G, there are hardly any experts in the industry, especially among Small and Medium Enterprises (SMEs). Trained personnel is needed in the companies directly to improve investment decisions. This paper presents an industrial use case to familiarise industrial companies with the possibilities of 5G. The first hurdle is

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to demonstrate this new technology to companies and make it tangible in a demonstration factory. In order to generate a use case close to the manufacturing industry, a prototype product is required that clearly demonstrates the application and benefits of the technology (use as a pilot factory for prototyping). The last stage is the use as a learning factory, in which companies can specifically deal with the possibilities, technical implementation, and application of 5G campus networks or private networks. The presented paper describes these individual stages based on the prototyping of a smart clamping pallet as a demonstrator for 5G applications in manufacturing, its application in a demonstration factory and the insights gained in the process so far.

1.1. Overview of the 5G technology

The world is currently experiencing the fourth industrial revolution, which is marked by a range of new technologies that combine digitization and automation of industry [16]. This new era of industrial innovation is known as Industry 4.0. One of the main targets of Industry 4.0. is to provide a communication layer for automation technologies such as remotely controlled and autonomous machinery [10]. New wireless connectivity solutions like 5G are required to meet the stringent industrial requirements for ultra-reliable, low-latency communication while providing high-speed connection in real-time applications.

The innovative communication system of the fifth generation (5G) meets the high requirements of industrial applications. In contrast to 4G or earlier networks, 5G offers a high-speed ultra-low latency (uRLL) solution, enabling vast amounts of data to be transferred between connected devices, systems, and infrastructure in real-time. Remote-controlled autonomous machines are mission-critical applications in the communications field. Fast communication between the machine and the decision-making entity is of crucial importance. A fatal error can occur if communication fails or data reception is delayed. Hence, the main challenges of such applications are the need for a (1) secure connection, i.e., the high reliability of communication, the need to (2) send and receive data with extremely low latency, and the need for (3) high bandwidth, resulting in a high data transfer rate.

1.2. 5G in manufacturing

Most activities in the manufacturing industry take place in dynamic environments in which manufacturing processes, the necessary machine technologies and production systems require the continuous motion of humans and machines. Wired communication is not feasible in such dynamic environments because it cannot adapt quickly to changes and does not support user mobility. Hence, the use of wireless communication is indispensable in these environments [9]. Among various wireless technologies, the use of wireless cellular networks can be beneficial due to the ubiquitous and seamless communication, the support of user mobility, as well as the utilization of the licensed spectrum, resulting in a higher level of security and QoS (Quality of Service) [2]. Although both throughput and latency are limited, making them unsuitable for critical use cases or high bandwidth use cases, the innovation of 5G technology improves the performance and can provide a transfer rate of 100 times over previous technologies, 1 ms communication latency and 99.999 % reliability [1].

1.3. Campus network

The innovation of 5G technology enables for the first time the realization of independent, standard-based private wireless networks, the so-called 5G campus network. This in turn enables a wide range of demanding applications across various vertical industries. In contrast to a public mobile network, the 5G campus network is limited to users who are restricted with the campus organization and versatile in industrial locations of all sizes, e.g., an industrial campus or a defined local campus, a university or individual buildings. These campus networks cover a restricted, prescribed geographical area, operate in dedicated frequencies, can be used as a so-called 5G non-standalone network (which requires access to the 4G spectrum) or as a 5G standalone network (without 4G Spectrum) and thus offer a high level of reliability and data protection, as well as an additional level of security and control [17]. This helps wireless network operators and enterprises to meet the demands of industrial automation due to the flexibility, modularity, and programmability of the 5G system architecture. For this reason, the solution of 5G campus networks is envisioned to enable applications of robot control that require delay-sensitive industrial communication [14]. Furthermore, the authors show significant differences between non-standalone and standalone 5G networks in industrial environments.

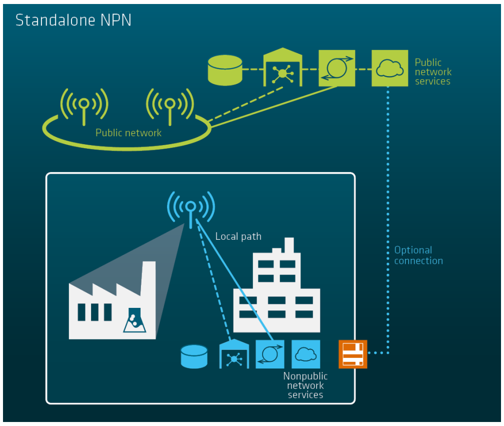

Fig. 1. Structure of non-public standalone 5G network [5].

Therefore, we aim to set up a private 5G standalone campus network in our industrial research laboratory at TU Wien to materialize and validate the specific properties of 5G technology in advance. Fig. 1 shows the structure of the non-public campus network. The network operation is not affected by the external public network, which ensures that no data leaves the campus, thus improving the enterprise production management efficiency and communication scheduling level and improving the overall work management efficiency. In the course of this project, the first 5G standalone campus network in Austria is to be implemented at the research laboratory at TU Wien together with Hutchison Drei Austria and ZTE in order to materialize and validate the specific properties of 5G technology in advance and develop industrial use cases to show novel approaches for industrial wireless communication. In this test environment, the construction and function of 5G standalone networks will be demonstrated, and potential future users from the industry will be familiarised with the 5G technology. The smart clamping pallet presented in this paper will be fully integrated into the 5G infrastructure in the future and used as the basis for specific learning programs.

Kundel et al. [13] describe how to setup a 5G standalone test network as a basis for research activities. They point out, that the used network hardware plays an essential role regarding performance.

1.4. Clamping systems in machining

One key factor for achieving the desired accuracy in machining is to properly clamp the workpiece and provide a high degree of repeatability for precise results at high part output. High clamping forces are applied by the clamping device, in most cases a machine vice, whereby different types are available (e.g. with force enhancement). Zero-point clamping bolts are directly attached to the mating surface to quickly equip machines with such vices.

Zero-point clamping systems are widely used, especially in high-demand applications for fast mounting and repeatability. They act as a rigid link between the machine table and the workpiece holder, for instance, a machine vice. They also enable the fixture preparation parallel to the manufacturing process, leading to significant time savings. The connection is established by clamping bolts inside the clamping pot houses. Depending on the manufacturer's design, the bolt is pulled in with high forces and positioned by a form-fitting mechanism actuated by springs. The unlocking process applies compressed air to push back the spring-loaded locking system. Current developments focus on the implementation of sensor technology for in-process data acquisition [6].

2. Development of a 5G-based technology demonstrator for discrete manufacturing

To illustrate what 5G technology can be used for in an industrial environment, Hutchison Drei Austria and the TU Wien developed an industrial use case for manufacturing components. A smart clamping pallet was developed, which consists of a state-of-the-art machine vice with an electro-mechanical drivetrain, which enables the vice to control the clamping force during the manufacturing process. Thus it is possible to safely modify the applied force while machining if required. Especially for thin-walled workpieces out of light metals, this is beneficial because of

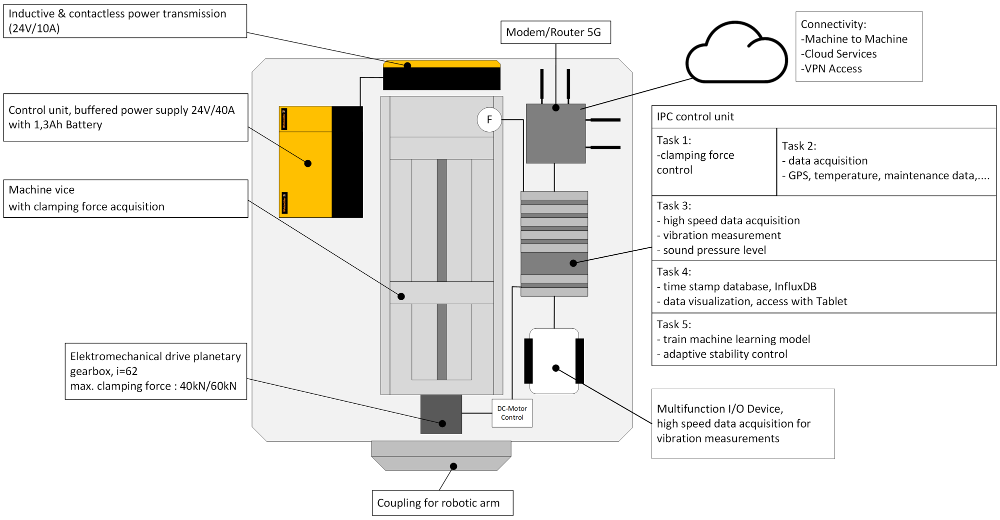

Fig. 2. Schematic structure of the smart clamping pallet.

the avoidance of unwanted deformations. In addition, a loss of clamping force can be detected, and thus, component rejects can be avoided well in time. The clamping vice is attached to a pallet with a robot-coupling system for handling. The pallet is equipped with a zero-point clamping system to be quickly loaded into machines. Integrated 3-axis acceleration sensors can detect vibrations and chatter during machining, which can be compensated in real-time by the NC controller due to the 5G connectivity. There is a computing unit on the pallet that allows local calculations to be made and the data to be made available via the web interface. GPS sensors allow the current location of the pallet to be identified at any time. For energy supply, the system is equipped with a 24V battery system with the possibility of wireless, inductive charging [12]. Fig. 2 shows the schematic structure of the smart clamping pallet.

In wireless communication systems, improving indoor coverage is a critical design requirement that ensures that deeper coverage is provided as the equivalent of the signal penetrating a wall or floor. This is because the resulting radio signal combines several signals transported on different paths. The mechanisms that influence radio propagation are complex and diverse [18, 3]. They can generally be attributed to free space path loss, reflection, scattering, and diffraction. Path loss can be defined as the signal attenuation that the type of environment would mainly cause, the medium of propagation, the distance between the transmitter and receiver, and the height and position of the antennas [15]. For this purpose, special care has been taken in choosing the housing while implementing the pallet. Carbon-aramid fiber material was used to build the housing to achieve low signal attenuation.

3. Industrial use case for distributed manufacturing

Ellwein et al. [8] mention four topics as currently relevant in recent manufacturing technology: mass customization, shareconomy, digitization, and cloud manufacturing. The authors evaluated the impact of these trends on manufacturing paradigms and identified three possible paradigms: (1) separation of design and manufacturing, (2) collaboration across organizational boundaries, and (3) on-site manufacturing. Separation of design and manufacturing empowers customers for the product and enables true mass customization, involving customers in the product description process. Collaboration across company boundaries empowers customers in terms of process and allows them to choose their contractor for each production step. Subsequent on-site production focuses on throughput and delivery time by moving production to the end customer's daily action area. Especially in countries like Austria, where 99.6% of all companies have SME status, companies can benefit massively from distributed manufacturing in the future through cooperation with other specialized companies (Joint Manufacturing) [4].

The integration of wireless cellular connectivity into the clamping pallet offers a wide range of possibilities to implement the idea of distributed manufacturing. Regardless of where the pallet is used, data can be transmitted to other instances in real-time or processed on the pallet itself. Thus, the functions of 5G can be demonstrated, and the use for distributed manufacturing in multiple locations can be shown to potential users from the industry. Highly specialized small companies often do not have the infrastructure to cover all production steps. Parts are often manufactured at several locations, which usually means much organizational and logistical effort. The technology of the clamping pallet greatly supports and facilitates such processes through (1) data generation for monitoring during the process and (2) live tracking data, which enables simple localization and tracking of the clamping pallet. This allows live data to be integrated into order management and react to it dynamically, enabling more efficient use of resources. In addition, the client can keep an overview of the production progress even in the case of external production.

4. Integration in TU Wien Pilot Factory Industry 4.0

The TU PF makes it possible to develop, test, and improve new value creation strategies for the industry in an area of approx. 900m². For this purpose, it represents a realistic production environment equipped with various state-of-the-art production facilities and offers the industry a safe testing environment [11]. TU PF can fully represent value chains from design and production to assembly and quality management. It is also a platform for research education and combines learning, experimentation, and the demonstration of production in one place, helping to understand how knowledge from current research can be transferred into future production processes. TU PF is intended to be available not only for students but also for advanced training of industry professionals. Furthermore, the TU PF supports the visualization of the impact of Industrie 4.0 and understanding the structure of the Reference Architectural Model Industry 4.0 (RAMI 4.0). As a three-dimensional layer model, RAMI 4.0 represents a fundamental architecture for Industrie 4.0 using a sophisticated coordinate system. The coordinate system of the cubic layer model consists of three axes that symbolize the three-dimensional space and on which the hierarchy levels of a manufacturing plant networked via the internet, the life cycle of plants and products, and the IT representation of an Industrie 4.0 component are described [7].

In the TU PF it can be shown how a 5G campus network is structured, which components are involved, and how it operates (demonstration factory). The pallet is to be fully integrated into the production process in TU PF, to show the use of the network with its current possibilities for production. In Fig. 3 the pallet is shown on an AGV in the TU PF. The sensors integrated into the pallet make it possible to record data during machining processes and use this data to control the manufacturing process. Commissioning and configuration of the 5G campus network is currently in progress. When this is completed, the integration and interaction with higher-level automation concepts will be demonstrated in future. This includes communication with robots that load the vice and control it (pilot factory). Moreover, the effects of vibrations and chatter in the process can be shown in the future directly before the real-time compensation is activated. By changing the housing parts of the clamping pallet, each made of different materials such as aluminum, plastics, or carbon fiber, the differences in the shielding of the 5G signal can be demonstrated. Speed tests or latency measurements can be carried out to see the differences. Different antennas can also be used to demonstrate the effects. Henceforth, the influence of cooling lubricant on the signal quality can be investigated by switching the feed on and off during the process and data acquisition (learning factory).

Fig. 3. Smart clamping pallet placed on an AGV.

5. Conclusion and outlook

This paper explained how a non-public standalone 5G campus network works and how it could be used in the TU PF in the future to be able to demonstrate its technological possibilities. The smart clamping pallet, which is currently running as a pilot and demonstrator project, will serve as a use case for the learning factory in the future. The network could be expanded to include several locations to illustrate the principles of distributed manufacturing better. It would be interesting to compare the difference between standalone and public networks. Different learning stations could be constructed to train future experts in different stages (e.g,. 5G infrastructure, integration, connectivity, applications).

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