Beyond Pure Sensing – IEEE 21450 in Digitalization of the Development Cycle of Smart Transducers

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The IEEE 21450 standard family [1] has been developed to ease the use of smart transducers in various applications. The electronic data-sheet TEDS defined in the standards provides descriptions of the sensor and actuator channels in terms of physical quantities, data representation, measurement range, uncertainty, calibration etc. Consequently, such electronic data-sheets can be seen as a specification of a device and might therefore already be conceptually developed in an early design phase.

In this article we illustrate the use of IEEE 21450 TEDS throughout the design work-flow and how this can e.g. support a transition from traditional v-model approach for hardware development toward agile methods, which have been used very successfully in software development. In addition to the refinement of requirements and specifications, the datasheet can also be used as a standard format to retain and exchange information during the design phase. A short introduction to IEEE 21450 is given in [2] and [3], an example implementation of TEDS is shown in [4] and an example of using TEDS to connect sensor nodes is shown in [5] and in [6]. Information on TEDS being used in conjunction with accessing nodes over the internet using Simple Object Access Protocol (SOAP) is shown in [7] and an example of an extended Network Capable Application Processor (NCAP) used as a Universal Plug and Play (UPnP) host for automated access to new nodes is described in [8]

We propose to combine these activities, making the Network Capable Application Processor (NCAP) a central component in the system as illustrated in Fig. 1 and the Transducer Electronic Datasheet a means for supporting easy connectivity and documentation of the process. In this network, a sensor (or transducer) that gets connected to a Network Capable Application Processor (NCAP) via a wireless or wired interface is made available within the network. However, the approach is extended to non IEEE 21451 devices as it allows to add TEDS for such physical or virtual devices as well. This procedure thus enables a unified, fast and dynamic connection procedure for transducers to the network.

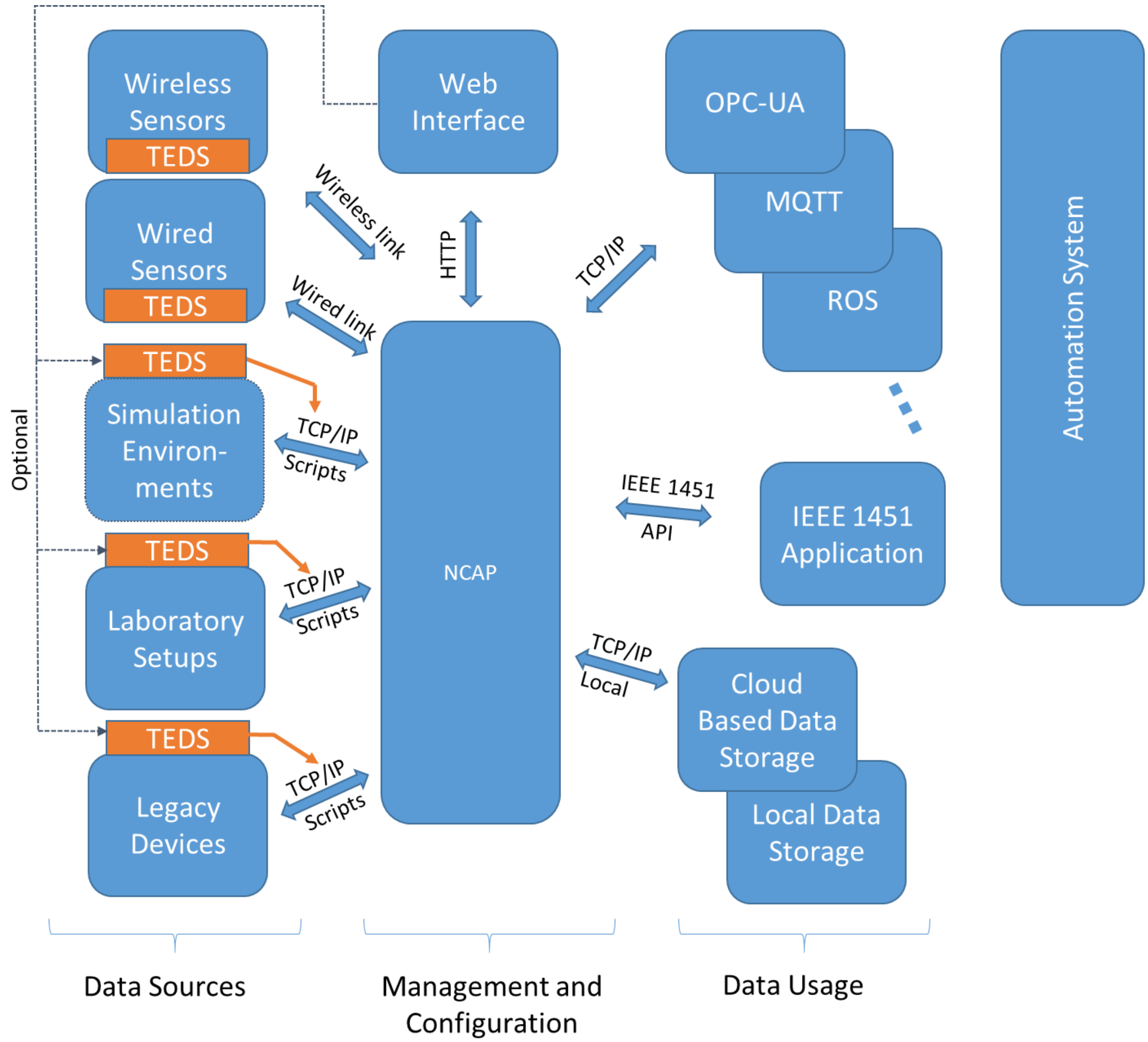

Fig. 1. In the proposed approach, the Network Capable Application Processor (NCAP) represents the core component for configuration and management of a networked measurement setup in both development and productive phase. In order to have one common point for the management and configuration, the NCAP provides a web interface and besides connection to devices also allows connections to legacy devices, simulation environments and laboratory setups. For such connections, the TEDS is not stored in the device and needs to be provided through the web interface or an API. With respect to data usage the NCAP can act as a hub to middleware such as ROS or OPC-UA but can also directly write the data to a file.

Typical Design Process

The way from a first concept of a new product to the final productive system involves many steps. Market studies and feedback from customers can be used to identify the needs of the market for potential new products, functions and services. Once such a need has been identified, the description of what is really needed is usually still rather vague. Consequently, in the next phase it is aimed to define user requirements and derive specifications for a potential solution. However, this is frequently a cumbersome task as the potential user does not yet know exactly what he needs or what would be possible. Furthermore, the sensor system developers/concept engineer may even have more difficulties to correctly understand the needs and match these with possible solutions. Consequently, it is not uncommon that certain functionality within a solution is over-engineered, i.e. the performance in certain respects exceeds the actual needs by far, while other functionality performs poorer than required or is even missing. This may not because there is no suitable solution but due to a wrong emphasize of priorities as a consequence of insufficient knowledge at the beginning of the development. Agile development methods aim to address such issues. One approach that can help in this respect is to early showcase the functionality of the system to the user in form of simulation or model in the loop. This has become possible due to the availability of powerful simulation environments e.g. in the area of automated deriving, robotics and industrial automation and such virtual prototypes or "digital twins" of a system can be used to study the functionality of a proposed sensor system together with the user and to quickly refine the requirements.

Fig. 2 illustrates such an agile design process for sensors systems. In this approach, electronic datasheet as described above are used alike a specification of the device. In each step (and each potential iteration of each step) of the development cycle, information is added to or refined within the electronic datasheet describing the device.

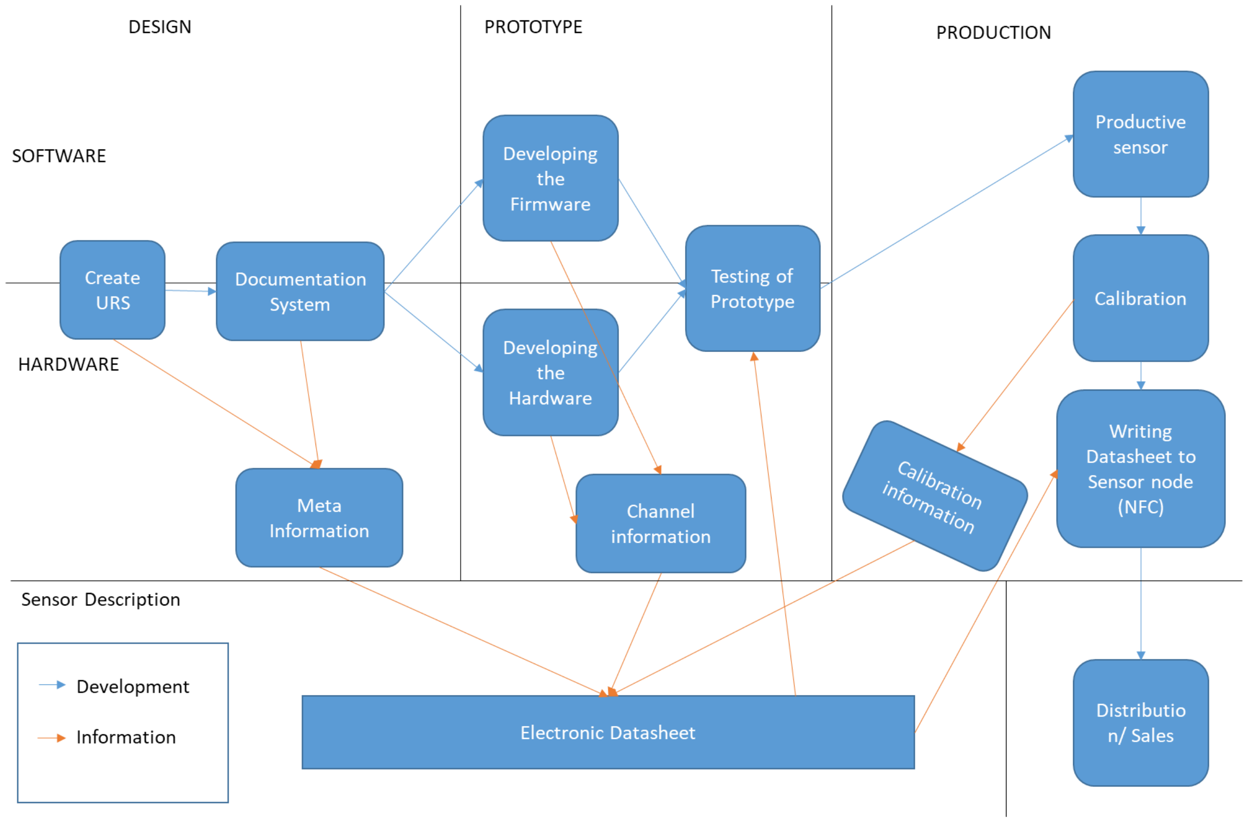

Fig 2. Sketch of a design process for a sensor system. From a User Requirement Specification (URS), an initial electronic datasheet is created. Additional information is added during the prototype phase, e.g. the decision on a specific data format for the transmission of the sensor data. Furthermore, also in the production phase information for the electronic datasheet may be included, usually this will be calibration information. The final datasheet is transferred e.g. by means of Near Field Communication and stored within the device, such that all information required by an NCAP to use the sensor and provide it in the network is available as soon as the device is connected without the need to connect to a cloud service.

The Design Phase can utilize simulation models of the sensor and the overall system to early identify design flaws. In the Prototype Phase, lab prototypes of the sensor are realized to test for feasibility of the sensor and test each required function. In the Production Phase the final sensor product is then created. During all three phases additional information is added to the data-sheet until the last step when a data-sheet is created for each instance of the sensor where individual information like calibration information is added.

The use of an Electronic Datasheet and Virtual Transducers in the Design Process

As described, the electronic datasheet becomes a more and more detailed specification of the actual device during the development cycle. Thus it can be used for documentation and information exchange. However, there is more potential to benefit from an electronic datasheet: As it is already available in the beginning of the design phase, it can also help to ease connectivity and transitions between phases. Such a use of an electronic datasheet is illustrated in an example workflow in Fig. 3. The Network Capable Application Processor (NCAP) plays a central role. Through the web interface of an NCAP with corresponding extension as shown in Fig. 1 it is possible to upload an electronic datasheet (TEDS) to it. The NCAP automatically creates a “virtual transducer” out of the TEDS.

This virtual transducer can already be used as any other transducer that is connected to the NCAP, i.e. one can write to transducer channels or read from sensor channels. The sensor channels of the virtual transducer initially generate random data based on the specification in the TEDS, i.e. within the given range, at given measurement rate, given data format etc. This allows that the automation software can already be implemented and tested with this random data.

In a next step the behavior of the virtual sensor can be refined. One approach is to provide a script for data generation for the described transducer. The NCAP provides a template for this based on the information in the TEDS. The template is than completed with code to generate more realistic data, e.g. by connecting to simulation environments. Similarly, also legacy device can be included into the environment. For example, in our lab we can a include a climate chamber in this way, which becomes a transducer and the controls for temperature and humidity are represented by actuators channel and the corresponding measurements as sensor channels of a virtual IEEE 1451 transducer. An alternative approach to scripts uses an API similar to 1451.4 for connections to simulation environments and legacy devices. This offers several advantages, e.g. with respect to security, and is therefore a focus of ongoing work.

Once developers and users agree on the behavior based on simulated data, a next level is usually a physical demonstrator setup. Eventually, a final productive system gets implemented.

With this process, the developers benefit as it is not necessary to modify the NCAP in any phase of the development cycle. The automation software can also remain unchanged (unless requirements on the side of the automation systems are changed) after the initial implementation and initial tests based on a virtual transducer have been completed. Consequently, switching and cycling between design phases becomes easy and thus this allows for an agile approach. During this process, the TEDS gets more and more specific and the final step from the prototype to a productive system becomes small, the development time reduces and the final results matches the actual user needs.

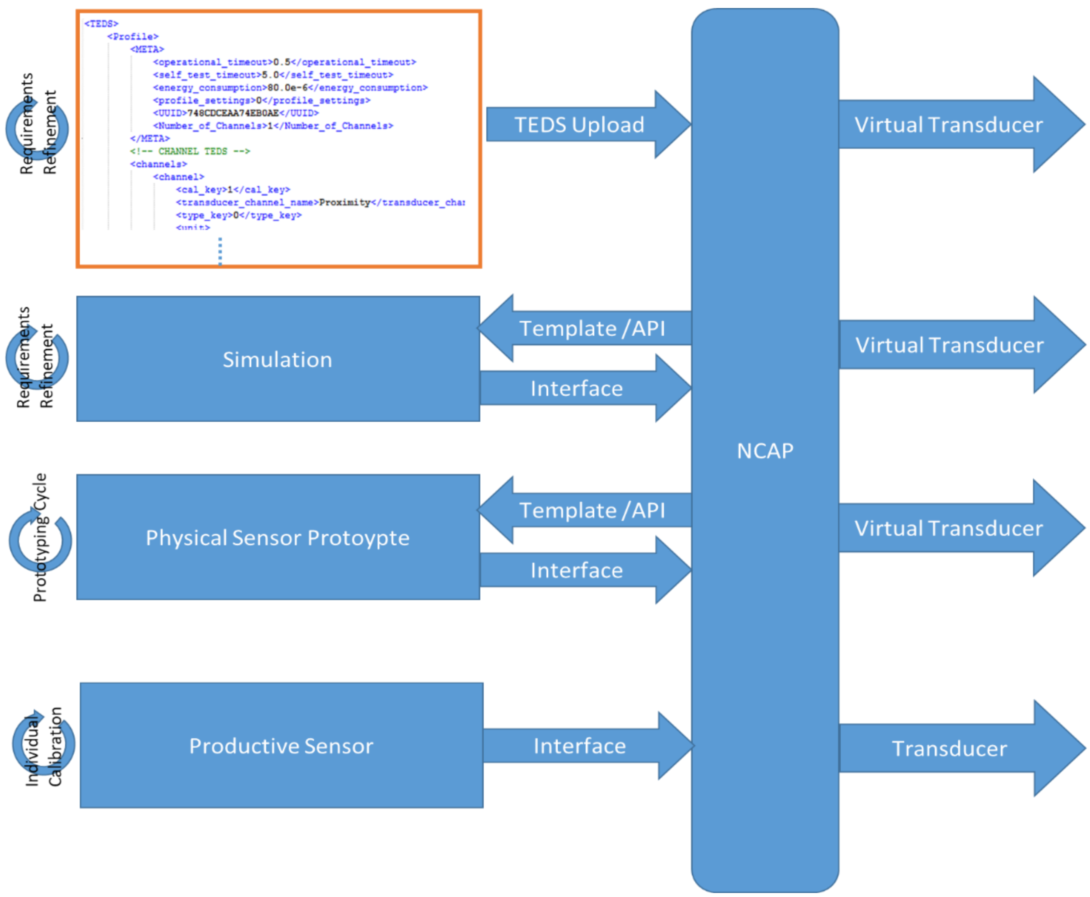

Fig. 3. Illustration of the system connectivity with an NCAP in an agile development process of wireless sensors using Transducer Electronic Datasheets (TEDS). Based on an initial TEDS, the NCAP automatically generates a virtual transducer, which can already be accessed as any other transducer connected to the NCAP, but initially only provides random data, yet in accordance with the TEDS. The NCAP also provides a template/API to connect to simulated data, which can range from simple signal generation or playback from files to advanced real time system simulations. Laboratory prototypes can be connected in the same way as simulations. Finally, a productive sensor or transducer connects to the NCAP in the usual way, e.g. using a IEEE 1451.4 protocol. As virtual and real transducers are accessed in the same way, this allows that the interfaces and software in the automation system developed and tested based on the initial virtual transducer do not change when cycled between simulation in the loop, prototype in the loop etc. and

ideally do not require any further modifications of the automation software due to communication issues, data format, etc.

Use case example - Robot Sensing in Industrial Environment

Our work on the approach and our current implementation of the NCAP with functionality according to Fig. 1 is based on several use cases, ranging from scientific experiments, condition monitoring and industrial test benches to robot sensing.

One such use case is within a research project called AutoLOG - Automatic log ordering through robotic grasping. The project focuses on research towards automating challenging and DDD (dull, dangerous, dirty) tasks concerning the handling of raw material in production lines currently executed manually. Besides artificial intelligence inspired vision based approaches to categorize and segment the raw material and its geometry to subsequently define optimal handling/grasping poses for the automation machinery and robust control strategies, retrofittable sensors are important for seamless and cost efficient upgrading/retrofitting/automating existing infrastructure.

Initial considerations lead to the assumption that such a system would benefit from tactile/proximity sensors integrated within the grasper. From this starting point, an initial TEDS of a transducer, i.e. a variant of a proximity sensor, is created in XML format describing the transducer including the sensor channels with given limits, uncertainties and other parameters. Such proximity sensors can be simulated in environments such as V-REP [10] (in our case in combination with Matlab). This allows for studies of the benefit of the devices in the system and an optimization before an actual device has been built.

The previously described development process starts with the creation of an initial TEDS of a sensor, in this use case example of a proximity sensor. The NCAP can already use this TEDS to generate a virtual transducer. The Overall process is controlled via a Web interface on the NCAP. It allows to create and manage Virtual Transducers from an uploaded TEDS, enables the user to get a list of all active and connected transducer nodes, retrieve TEDS from a specific node, write TEDS to a specific node, create measurement groups consisting of multiple transducers which belongs together within one experiment. The web interface is also used to configure the way the how measurement data is provided to the system once the state of all devices in a measurement group is changed between a configuration and measurement mode. Besides providing the data via a TCP/IP port the NCAP can also be used to connect to certain middleware. In the robot sensing use case shown in Figure 4 the Robot Operation System (ROS) is used as a middleware, i.e. the sensor data is provided in the form of ROS topics and can be used in the common way within the ROS framework. With the connectivity to the automation system through an NCAP, the transition towards the use of lab prototypes and potentially even to a productive system will then be very easy, as no changes in the ROS environment are needed because the initial virtual transducer already provides the same ROS topics and messages as the simulation or hardware realization of the device. Consequently, the benefit of certain sensors, e.g. proximity sensors in the gripper of a forestry crane as shown in Figure 4 can be investigated and optimized in the simulation. Once a physical realization is available no further implementation effort is needed to on the ROS side of the system as the final sensor is connected to the NCAP system and only the TEDS created during the development cycle is complemented with calibration and other individual information of the sensor.

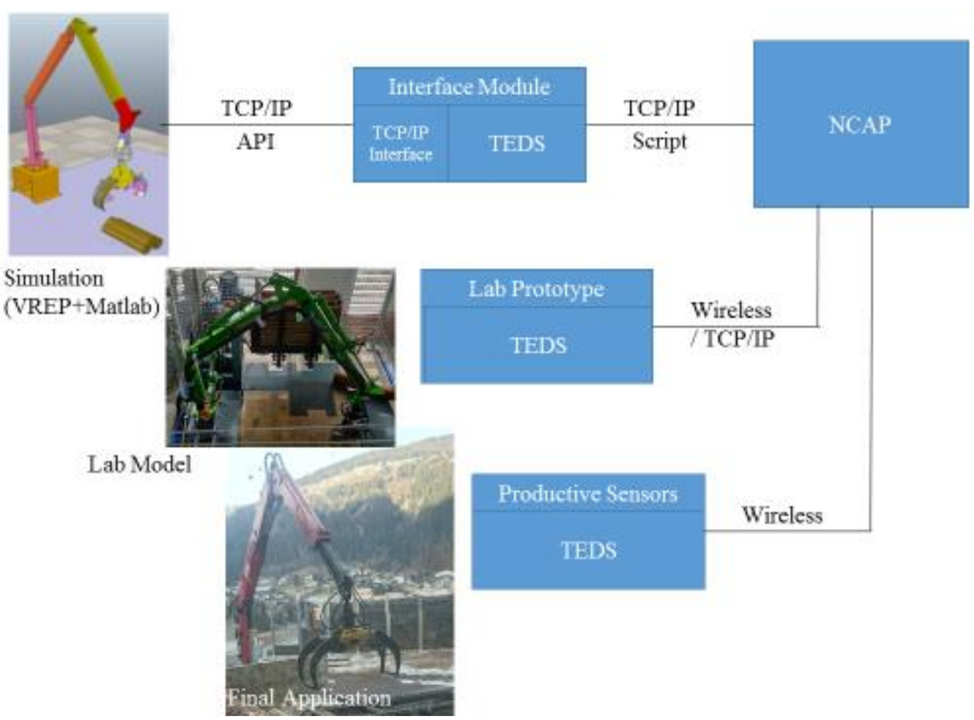

Fig. 4. Use Case Example Robot Sensing. Based on an initial TEDS, a link to the simulation environment, in our case V-REP, is easily created and the real time capable simulation is connected to the NCAP. Utilizing the TEDS, the NCAP can provide the data to the Robot Operating System (ROS) Core and thus to the control system of the robot. This allows to study and optimize sensors early in the design phase [9]. In a next phase, sensor prototypes can be tested in a lab environment for validation and further optimization. Finally, the sensor system can be tested in a field environment. Ideally, most design iterations could be done in the simulation phase and the transitions to the other phases can be done very fast as no modifications of the higher level software would be needed.

Conclusion

In this paper, we demonstrate the potential use of electronic datasheets based on IEEE 21451 TEDS in the design process of wireless sensors. Starting the design process with an initial datasheet allows to automatically generate interfaces and implementations of software on the automation side. With further development in the design cycle, changes of the automation software ideally are only necessary for a change of functionality but not for a change between simulation in the loop, prototype versions and productive sensors.

In order to provide interfacing to simulation environments, extensions to the standard NCAP are needed. This may be achieved using an API that is similar as for other devices that connect to the NCAP, e.g. using IEEE 1451.4 or through the completion of templates provided and run by the NCAP. Besides connecting to simulation environments to allow for simulation in the loop approaches, this approach can also be used to connect to legacy devices or laboratory setups in a unified and simple way.

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Biography

Hubert Zangl is Professor for Sensors and Actuators at the Institute of Smart System Technologies at Alpen-Adria-Universität Klagenfurt. With his research team he addresses topics of robust sensor design and optimization, nearfield sensing and tomography and autarkic wireless sensors for applications in as robotics and IoT.

Tobias Mitterer is a PhD student in the research group of Professor Zangl. Within the project "ZUSE- Electronic Datasheets for the Digitalization of the System Design", his research focuses on innovative methods for the development and operation of wireless sensors.