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36 Interconnection of Smart Homes and Smart Buildings as a Building Block of Smart Cities

Summary: An increasing digital interconnection of commercial and residential buildings is an important element to achieve a more and more energy efficient control by communication and automation. It provides a significant approach to fight climate change and increasing energy prices in a cost-effective manner with low initial investment. Besides potential energy saving for inherent amortization, automation solutions and resulting communication infrastructures allow us to establish innovative digital services and new points of intersection. Another aspect of smart buildings is the matter of fact, that systems are getting more and more complicated, error-prone and challenging during planning, implementation, maintenance and more general the entire management and lifecycle process. During the last years we have developed an automation platform with standard and open-source components including configuration generating processes to efficiently build up infrastructure for a digital heating community in apartment houses. The resulting information and communication infrastructure between smart homes and smart buildings opens up a nearly undiscovered field of interconnection beyond individual internet access of the inhabitants and an important opportunity to provide innovative digital services based on this. Therefore, we are going to provide an additional insight for example into our latest implemented services that go hand in hand like an emergency call service and automatic analysis of heartbeats as well as a rental system for micro mobiles.

36.1 Introduction

Nowadays, the achievement of energy savings and simultaneously increasing comfort and security in buildings by implementingcommunication and automation systems is a matter of fact. (e.g., Wisser 2018, Naumann/Christian/Göttert et al. 2016, Teich/Hoffmann/Igel 2015, Aschendorf 2014) Because of a significant demand and hence the highest consumption part of heating energy in living areas, we find an enormous energy saving potential when addressing thermal room energy as well es the energy supply and delivery of heating systems within multi-family houses. In long term, any energy savings

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effect will play an import role to refinancing the required technical investment in smart automation components. Any motivation about energy savings and carbon dioxide reduction as fundamental elements against climate change are laudable but it is also a matter of fact that priority questions from real estate companies and landlords are about accruing costs and financing of innovative solutions. Especially when confronted with heating costs accounting, those questions are anything but trivial to answer because resulting costs are allocated directly to the final consumer. Hence consumers will become the only profiting party, but without paying any direct contribution to refinancing on invested technology. (Pachowsky 2018) Consequently, in future we need more and more creative and innovative operator models, like accounting a more stable thermal energy price but keep cost savings for refinancing. Beside this financial aspect, a systematic and comprehensive development of information technology and communication systems provided and required by automation solutions and interconnection play an important role. Implemented smart homes and their internal connection to smart buildings provide a new solid foundation for developing and creating smart city districts independent from the public internet connection of residents. (Magnaghi/Flambard/Mancini et al. 2021) In the long term it provides an additional opportunity to connect regional and trans-regional service providers or suppliers in urban and rural areas to strengthen local economy and giving easier access to their services.

Especially providing an existing communication infrastructure allows the creation and establishment of innovative value-added services to smart city inhabitants in a comfortable way. Consequently, it may support refinancing of implemented smart components and network infrastructure by third parties and hence achieving additional benefits for any involved actor. Important requirements are decentralized structures, clearly defined communication services and data structures as well as interfaces with defined processing workflows to guarantee privacy, data protection and reliability.

36.2 Smart Heating Community

Initial energy saving effects of a single flat in an apartment building result from preventing unwanted leaks of energy and circumventing temperatures in beyond higher comfort areas. By defining reasonable temperature ranges and appropriate setback values as well as adapted heating time periods we already achieve basic savings in a very scalable solution. Regular events like scheduled absence periods and the daily user behavior can be adapted either directly or indirectly (e. g. smart locking system) by user defined, comfortable heating periods and adequate setback periods. Random but energetic relevant events like spontaneous long-term absence or leaks of energy, like open windows and other energy sinks, may be communicated or recognized and finally processed by the automation system. Studies show that about 15 percent of the events with very high energy transfer are responsible for about 55 percent of total energy output.

Consequently, it is crucial to evaluate the energetic situation continuously to avoid ineffective or wasteful energy output situations. Allowing for a prevention of defined excessive temperature areas an energy savings potential of between 20 and 25 percent can already be demonstrated by the systematic implementation of smart home automation heating systems. (Schröder/Papert/Teich et al. 2018) Furthermore, it is necessary to collect and summarize information about real thermal energy demand over all flats. Nowadays it is most commonly state of the art to operate heating systems using a weather-driven control. (Hesse 2020) That means, a heating system uses a measured outside temperature value to calculate the required flow temperature for the heating circuit. Therefore, the outside temperature is used as a parameter for a heating curve function. Additional parameters that may be configured by the operator are either steepness (S) or parallel shift (K) of the curve to adapt a heating system on the building conditions (Figure 36.1: Heating curve). In fact, there is not any evaluation whether those parameters and the resulting heating curve fit a real thermal energy demand for any outside temperature value on any time because there is no feedback loop included in the heating system. Normally those parameters include plenty security headroom to ensure a sufficient supply and necessary flow temperature at the furthest heater within a circuit. Hydraulic balancing may be another important aspect to consider for efficient thermal energy transfer, that shall be mentioned only for the sake of completeness.

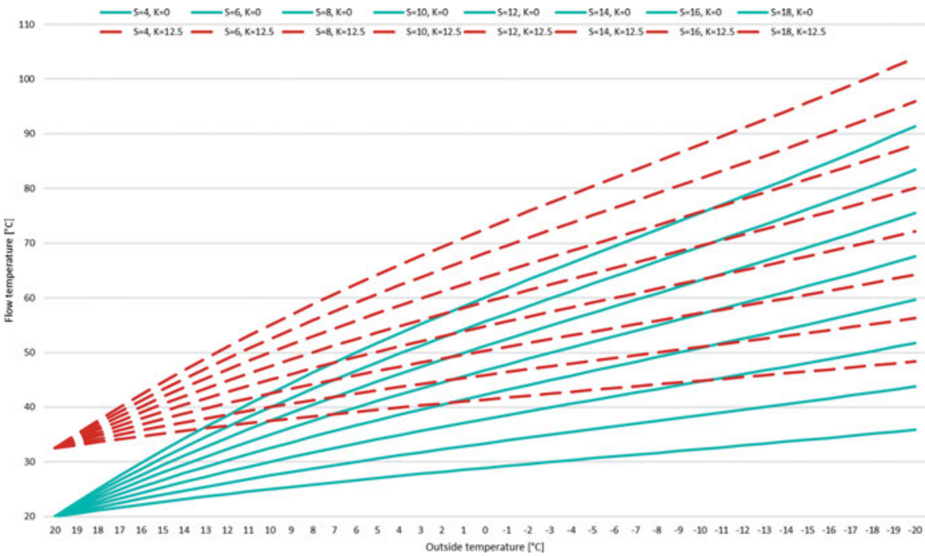

Figure 36.1: Heating curve.

Objectively, the significant benefit of high flow temperatures is a faster modification speed of room temperature and subjectively a sensible radiant heat next to the radiator. Otherwise, there are obvious multiple disadvantages of higher flow temperatures like thermostats blocking the flow most of the time especially during seasonal transition time and there are higher transmission losses in the piping system. Additionally, the efficiency of a heating system is getting increasingly worse with higher flow temperature so that regenerative approaches like installing geothermal heat pumps are getting increasingly unattractive. Strictly speaking, touching a radiator with e. g. 30° C suggests a “cold” feeling because of a normal body temperature above 36° C. Relative to a given room temperature of 21° C, over a defined period, we have a continuous thermal energy output. An approach to determine the real demand has already been described by (Baumgarth 1991). He describes a basic algorithm to calculate the current thermal heating flow temperature demand evaluating the current valve positions as a demand indicator. Thus, a heating system’s weather-based control can be replaced by an efficient demand-driven regulation. Put simply, the objective of this approach is to force valve positions of demanding rooms between a positioning of 70 to 90 percent. A heating system may decrease the current flow temperature if valve position values are below the lower border. Otherwise, if we pass the upper boarder, a heating system’s flow temperature may be increased. Additionally, this approach may be combined with a classic weather-based control heating curve to decrease or increase a calculated delta value e. g. within given bounds. For this approach it is essential to implement automation solutions and create a complete heating information network to regulate and control valves within each room and collect these position values within the building to adapt the heating system parameters driven by demand automatically.

36.3 Multi-Service-Platform

Resulting from various research projects executed by the University of Applied Sciences in Zwickau, especially “Low Energy Living (LEL)” and “Ambient Assisted Living in Controlled Environments” (A^2LICE) we initiated the development of a more flexible and scalable hardware and software platform with the objective to create fundamental communication and automation nodes for smart buildings and smart districts in the future. (Leonhardt/Neumann/Kretz et al. 2018) Development has been focused especially on simplifying and minimizing configuration and initial operation process for field implementation and to maximize automation in this stage for a highly scalable serial product. The initial scope of functions has been limited on the heating control system scenario to focus the initially mentioned high potential for energy savings with regard to an efficient way for refinancing required hardware components. Another important aspect in this context is resulting from the corporative development with Metrona Union GmbH as a research and development company of several BRUNATA houses because they already provide measuring services and a very huge sensor network in Germany. Their heat cost allocators, which are installed on many heaters, have the primary task to measure the energy output of heaters for further accounting. Within a patented procedure (EP 3009908 and EP 3035144) those devices have been enlarged and got advanced functionality to enable room heating control and advanced algorithms for efficient calculation of room- and heater temperatures or to detect open windows without additional sensor installation. (Schröder/Papert/Teich et al. 2016, Teich/Kretz/Scharf et al. 2016)

Our developed hardware platform consists of a system on module developed by Toradex (NXP i.MX6) as a full-featured dual- or quadcore computer with a 32-bit ARM architecture. To provide necessary field bus access as well as input and output interfaces we have developed a custom carrier board to connect bus systems for communication, control, and regulation in the field of smart automation (Figure 36.2). These include e. g. ethernet network, USB (Universal Serial Bus) and CAN (Controller Area Network) interface, RS485 and UART (Universal Asynchronous Receiver Transmitter) for serial communication and 1-Wire e. g. for various sensors and actuators of heating systems and circuits. Additionally, our carrier board provides extension sockets to plug in extension boards e. g. with EnOcean radio transceiver. Depending on operational scenarios we can develop various carrier boards providing task specific interfaces. Currently, we designed a compound solution for smart home applications as well as for smart building applications and services. During several hundred installations in laboratory and field areas we had to recognize that a lot of interfaces remain unused. Therefore, we are going to separate and develop specialized boards for smart home and smart buildings with different assembly configurations in future versions.

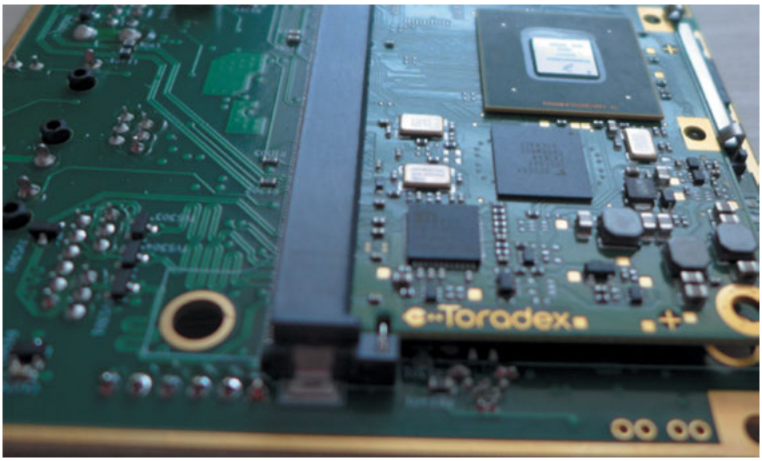

Figure 36.2: SOM with carrier board.

For this hardware platform we have created an individual operating system based on Linux using Open Embedded components with Yocto project to create a tiny system with low memory consumption and small processor usage. (Vaduva/Gonzalez/

Simmonds 2016) Especially for networking we have included necessary services for secured connection in context of smart home, smart building, and smart city districts. Therefore, we utilize services like firewall and packet filtering, virtual private network and secure shell host for encrypted and secured communication and maintenance. Additionally, we support flexible connection scenarios using either the provided ethernet interfaces or plug in additional wireless adapters using the USB interface. Our operating system and configuration tools support parallel utilization as wireless station or access points using a suitable adapter. Thus, we have achieved reduced hardware costs and port allocation. Especially for the digital coverage of inhabited properties, wireless solutions are essentially required for a minimal invasive retrofitting. Our primary paradigm is to provide certificate-based VPN channels to create secure connection internally as well as externally of smart homes and smart building to avoid publicly accessible services under any circumstances. Furthermore, we have developed a specialized configuration toolkit that supports a completely automated set up and configuration. Required configuration files are generated from custom workflow definitions that contain a required project description. With this approach we can set up hundreds of devices, flats and buildings, within a common infrastructure in shortest time. Precondition for efficient implementation are projects with template-based configurations and parameterization abilities based on dynamic workflow descriptions as we find in multi-family houses with identical or comparable technical equipment and functional scenarios (Figure 36.3). Workflows may be designed with parameters to customize project specifics artefacts or they may be bundled in separate generator workflows to create reusable project workflow templates. An important source of information to run through the generation process is a description file containing a digital twin of the building, flats, equipment to install and scenario specific parameters. Necessary information can be extracted directly from enhanced 3D models developed with building information modeling (BIM) standards with specified information requirements as well as using defined BIM objects. Using this approach, we generate not only the configuration files for our automation platform, but also the configuration for various administrative tools for support and maintenance of the resulting infrastructure as well as associated services. These include configuration of a domain name service (DNS), security policies, connection and authentication certificates for VPN communication, remote management tools or the generation of dashboards and required databases to analyze and monitor infrastructure and system interaction.

Based on this foundation, we can develop and design value-adding services and automation solutions in a highly modular manner. Required services like databases, web proxies, monitoring dashboards etc. are deployed as microservices via a separately generated maintenance infrastructure and service providers like update repositories and additional packet management tools or e.g., Docker container registries. (Grubor 2017) Furthermore, individual software components to implement a heating system network including individual room and heating system control, has been realized as a JAVA based OSGi (Open Services Gateway initiative) application that it can be deployed and installed either via packet management or Docker container. Using

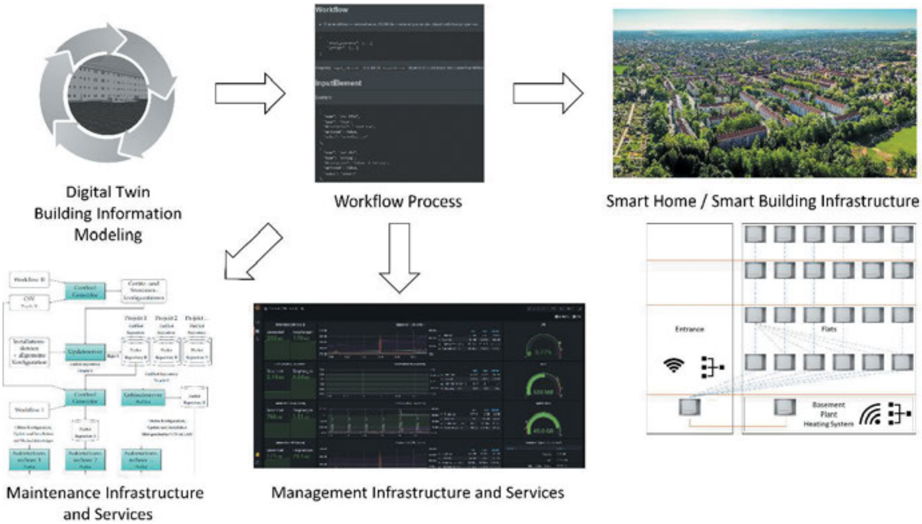

Figure 36.3: Generated infrastructure.

the OSGi standard specification, enables further service orientation because individual product definitions support a dynamic composition of application modules (bundles and features). Available interfaces, services, layouts, and applications can be customized for each project and delivered by the given service and maintenance infrastructure. Finally, we have developed a web-based dynamic and responsive user interface application that represents the result of application services and dynamic application of generated configuration files (Figure 36.4).

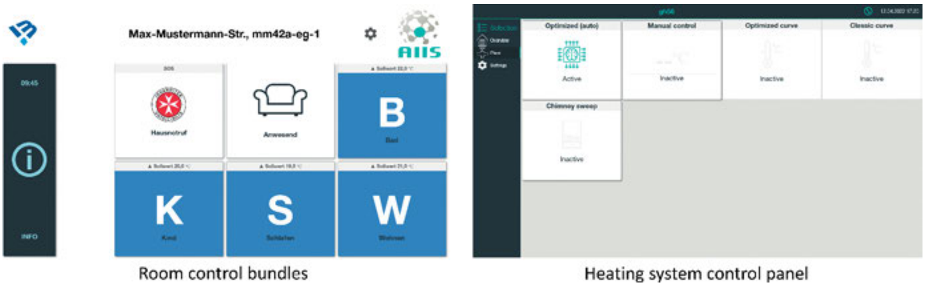

Figure 36.4: Variable product composition (UI).

If we want the interaction of different communication nodes within our network, we can include bundles for REST communcation (Representational State Transfer) or provide services to permanently store meta and logging data e. g. in a common database. Independent of the final product configuration, a decisive factor is to avoid configuration efforts of individual devices in the field whenever possible. Required customizing parameters need to be extracted from a digital twin or project specific description and shall be enriched by specific generator modules. In this way, we could massively reduce initial efforts during set up and configuration phase and hence minimize manual error rate to an absolute minimum. Errors in the workflow or template design ensure that all nodes in the network have the same problems in a reproducible manner. These can be fixed easily by generating updates that are automatically distributed and hence can easily be eliminated in bulk. Using this approach, we have implemented several living labs, distributed within the entire federal republic e. g. in cities like Borna, Jena, Hamburg, Cologne, Munich and Zwickau with round about 500 flats or offices and many thousands of peripheral devices and finally prepared the ground and added fundamental pieces for smart city districts. Especially in Zwickau we implement advanced infrastructure services for smart thermal grids in the research project ZED – "Zwickauer Energiewende Demonstrieren". (Leonhardt/Höhne/Neumann et al. 2018, Werner/Leonhardt/Höhne 2020) Additionally, in Jena the research project JenErgieReal is building on resulting infrastructures and the presented MSP. (Leonhardt/Teich/Bodach et al. 2020)

36.4 Application Module – Emergency Call Service

Because of the increasing number of elderly people (UN 2017a), as well as the lack of people working in the health care sector (UN 2017b), non-residential nursing care is becoming increasingly important. To enable non-residential nursing, it is beneficial to submit emergency calls (ER) from within the apartment. This is currently done by installing a physical button somewhere within the apartment which requires direct action of the inhabitant. Additionally, the developed automation platform offers a software button (Figure 36.5), as well as automated detection of unusual, potentially harmful behavior.

Figure 36.5: Emergency call process (UI stages).

Figures 36.5 and 36.6 show a simplified version of the submission of an ER based on the real-world process of our MSP submitting an ER to the Emergency Operations Center of the Johanniter-Unfall-Hilfe e.V. (JUH) where the ER will be processed by an operator at any time, optionally receiving your current location if not at home.

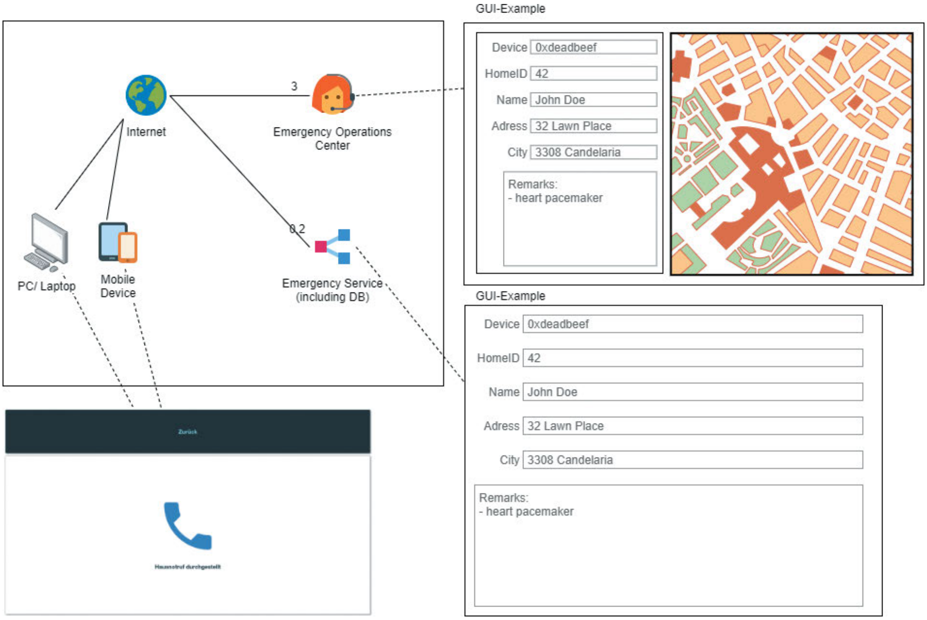

Figure 36.6: Emergency call service.

Prior projects like A²LICE (Ambient Assisted Living in Controlled Environments, Teich/Hoffmann/Igel (2015)) showed that there are concepts from the health care sector, like activities of daily living, that are detectable by a digitalized environment and therefore may be used to detect unusual, possibly harming situations and conditions. For example, if an elderly inhabitant is detected to be present in the apartment but did not change rooms or at least go to the bathroom within the last 24 hours. It therefore is possible to automatically detect (potentially) life-threatening situations and run an escalation routine accordingly. This includes calling for emergency, but also, for example, informing/calling for family members or neighbors.

Furthermore, the platform can analyze locally available data about the living behavior of the inhabitant and inform or alarm him about certain conditions and, if desirable, make an appointment with the family doctor or next medical doctor. In a next step this local information could be made available to the nursing as well as ambulance service or medical doctors to gain more insights on the current health state of the habitant and therefore increase the quality of provided medical services.

In conclusion, the emergency call feature is just a first step towards the enablement of health care services that will decrease the workload of employees working in the non-residential nursing care as well as enabling inhabitants to live longer in their accustomed, desired living environment.

36.5 Application Module – Electrocardiogram

Until now, analysis of electrocardiogram recordings could be applied in clinical or ambulant environments with trained persons and required expert staff in this medical sector. Since the availability of smart watches, the recording port and basic automatic analysis of electrocardiograms (ECGs), parts of this check-up could be integrated into home environment. In fact, the current ECG evaluation functionality of smart watches is very limited. Further application modules of our MSP supply artificial intelligence (AI) algorithms to enhance existing ECG evaluation of smart watches with advanced diagnoses. Additionally, we could improve the accuracy of sinus rhythm detection against the smart watch algorithms and our solution includes the interpretation of pediatric smart watch ECGs of children. We have developed a visualization module to support ECG in our dynamic front-end application with the precision of printed ECGs in clinical application areas. This supports verification and view of results by medical personal. Furthermore, there is also interactive functionality implemented, e. g. measurement of distances inside the electrocardiogram view. AI detected results are recorded into the ECG to check and evaluate these as well as resulting diagnoses. Therefore, AI diagnoses are printed directly into the ECG view within the diagnosis relevant position. Our ECG evaluation is implemented using Convolutional Neural Networks (CNN) (Jun/Nguyen/Kang et al. 2018, Moody/Mark 2001). CNNs are used for image processing and recognition as well as image classification. For an automated evaluation of ECGs our AI modules extract singular pulses and classify them. To teach a CNN AI model we need a huge amount of training data. Training data has been provided in comma-separated value (CSV) files from an apple watch. These CSV files contain digitized measurements of an analogous ECG signal. For further processing, we had to translate those unidimensional EGC signals into multiple single frames using an image segmenter. Therefore, a segmenter receives digital sensor values of ECG export values and a digitization rate. The output provides indices of our measurement values with R-R peaks (heartbeat – maximum amplitude, Figure 36.7). Using these indices values we can divide ECG values automatically into single frames to group given training data into classes and finally train our AI model. Each class defines a possible heartbeat that may be found within ECGs. Classes define e.g., pulse or beats on normal level, right or left bundle branch block as well as a pacemaker stroke. More complex training and detailed classification data improves the resulting diagnosis quality. Within our developed MSP we can integrate AI models and provide custom application programming interfaces or user interaction modules with appropriate visualization and diagnostic views. Recorded user data can be exported easily for further processing and AI diagnosis. Additional parameters like ECG diagnoses and age of recorded person support further analysis using the implemented domain specific medical knowledge of these MSP application bundles.

The integration of an AI based ECG evaluation and diagnosis module provides an easy integration into daily living and future ability to implement event driven care services within connected smart buildings. Secondary prevention by early disease detection may also reduce costs in the healthcare sector. To treat a disease by early recognition is usually easier than after their manifestation. Required diagnostic process e.g., recognition of cardiac arrhythmia using electrocardiogram is usually done in medical facilities because of required infrastructure, devices, and staff and consequently this process becomes expensive and cost intensive. Integrating this service provides a basis for innovative health services for elderly but also younger people beyond the medical area. Especially diagnostic algorithms for children providing acceptable results were missing. Especially in younger age there is a demand because cardiac arrhythmia is not uncommon in childhood, but a diagnosis is usually difficult because of paroxysmal events. This disease may also suspend during a year and hence repeated recording is required. Using smart watches this process can be established and integrated in the home area with smart connections and evaluation services. Existing smart home technology supports this process and the advanced AI algorithms support pre-diagnosis and may be combined e.g., with the emergency call service in future releases.

Figure 36.7: ECG visualization module and AI diagnosis results.

36.6 Application Module – Mobility Service

The mobility station in Zwickau was created as part of the ZED project and offers residents in the district, a lending service for electric scooters and cargo bikes. The offer is intended particularly for people who are often dependent on help in everyday life, for example to go shopping or to the doctor. The project enjoys solid support and regular use. The mobility station has an office, which is supervised with fixed opening hours from Monday to Friday. Next to it, we provide an additional autonomous lending station that is always accessible via RFID cards. This gives users a way of independently lending vehicles after office hours and weekends. This so-called mobile box is currently in its first prototype phase. It offers space for one e-scooter, charger, and the electronic lending system. The lending process is controlled by an embedded computer. The software for the system was further developed based on the multi-service platform (MSP). It uses its core components and is expanded with an adapted user interface which enables users to start and end lending processes via touch display (Figure 36.8).

Figure 36.8: User interface scooter checkout.

The current prototype phase is intended to collect initial user feedback for future developments. Right now, it is limited to a single e-scooter and a reduced group of users but targeted expand to more stations and a larger user group in the next phase. The current feedback shows that, an important feature for further development should be a reservation option. This offers further opportunities to utilize the MSP. In apartments, a mobility service could be offered as a supplement to heating control. The status of the mobile box can be called up to see whether and how many e-scooters are available nearby and to reserve them if necessary. The mobility concept in its entirety and the accompanying services present new perspectives, to bind their residents to the smart city district in the long term and to keep the facilities livable and lively into old age (Figure 36.9).

Figure 36.9: MOBIL BOX – autonomous rental station.

36.7 Conclusion

In this chapter we provided a small insight into our development efforts of our Multi-Service-Platform. The initial motivation was triggered by the objective to create a highly scalable product that is also suitable for mass configuration and installation. Therefore, we gave a broader technical overview about the created system to get an idea about its potential expandability. Our development basically started with an automation solution for heating control and demand driven heating system adjustment. As we have already shown in Zwickau-Marienthal, using the valve position algorithm of Baumgarth, we can save up to 25 percent primary energy input that scales up in our example to a saving value round about 10.000 € yearly for four connected multi-family houses. (Teich/Hoffmann/Igel 2015) This amount could be initially used for amortization of required technical investments but this requires sophisticated cash flows. In fact, we could develop a cost-minimized solution because of reusing existing sensor networks like heat cost allocators for temperature measurement in each room. Our developed hard- and software solution provides much more power and this scenario is technically seen very lightweight. Because of resulting networks for inhabitant interaction, it is possible to develop and install new services that bring together local suppliers, service providers and inhabitants. This in mind, we can achieve a long-term win-win situation for all participants in this restricted local service network. Our currently developed application scenarios like emergency call service, electrocardiogram and a rental station service for micro mobiles provided a tiny example, how our platform currently grows and interconnects to various digital services in the neighborhood of our near future.

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