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SMART PLATFORM-BASED IOT-MODULES FOR APPLICATIONS IN HEALTH CARE AND REHABILITATION

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ABSTRACT

Embedded systems and the Internet of Things (IoT) enable new procedures, measurement and analysis methods in the field of biomedical systems. The measurement of data, based on electrocardiogram (ECG)-, electromyogram (EMG)- or electroneurogram (ENG)-signals, allows a multitude of new approaches in diagnosis, prevention or rehabilitation. As part of a project for ENG-based control of prostheses, a platform has been designed, called smart modular biosignal acquisition, identification and control system (SMoBAICS), that also uses IoT-devices.

In this paper, different IoT-devices are presented and described. In the context of an analysis of use cases, it becomes clear that the platform represents a toolbox, which provides appropriate modules and module configurations for different requirements. The designed IoT-devices use standard interfaces in order to integrate a specific additional function into the system. In the focus are two microcontroller (mC)-devices with different characteristics and a front-end system that enables the connection of a variety of Force Sensing Resistor (FSR)-sensors. Based on this platform architecture, many applications were presented, and examples were given of how the required functionality for the corresponding application can be achieved with the help of these IoT-systems.

This platform enables a fusion of the various sensor data with the objective of motion identification and prosthesis control based on this by reading out various data (forces, acceleration, ENG-data, etc.) and integrating identification algorithms.

Keywords: Hardware-/Software-Platform, Data-Driven Methods, Modelling, Simulation, Sensor Fusion

1. INTRODUCTION

Embedded systems open new approaches in biotechnology and medical therapy. Based on modelling and simulation methods, biological, physical and technical relationships can be described and verified (Kandel et al., 2000), (Law and Kelton, 2000), (Zeigler et al., 2000), (Klinger, 2014). The integration of hardware and software components offers an smart and application-specific system. The integration of sensors and actuators into an adaptive hardware/software system platform extends the functionality to include the recording of states, events or the execution of actions. In diagnosis, therapy and rehabilitation there are many applications that can support conservative forms of treatment. Continuous data acquisition as well as online- and offline-data processing and, in particular, identification on the basis of correlated sensor information are at the center of interest and represent the essential challenge.

The platform paradigm describes the project-specific adaptation possibilities of a system through a modular and layer-oriented architecture. Changes and adaptations of an existing system are always necessary, for example by changing the interfaces, modifications of the graphical user interface, the number of channels, changes of sensor and actuator types, scaling of sensor and actuator systems and the project-specific processing of data in the broadest sense, which can also manifest itself in a corresponding scaling of the processing power and memory resources. If a system does not satisfy the platform paradigm, the system can in most cases only be used in another application area or the required system parameters can only be adapted by developing a new system. Here, the platform paradigm is to be used both, in the area of hardware domain and in the area of software domain, if the entire system is to satisfy the requirements of a platform. A hardware-focused view of a typical data acquisition platform is shown in Figure 1 in principle.

The SMoBAICS-platform is such a hardware and software platform based on this paradigm, which contains the following functional blocks:

- Identification,
- Data acquisition and stimulation,
- Data processing,
- Data Conditioning,
- Data archiving,
- Data exchange/Connectivity,
- User interface,
- Configuration,

as described in (Klinger, 2016). Using the platform paradigm, the partitioning between hardware- and soft-

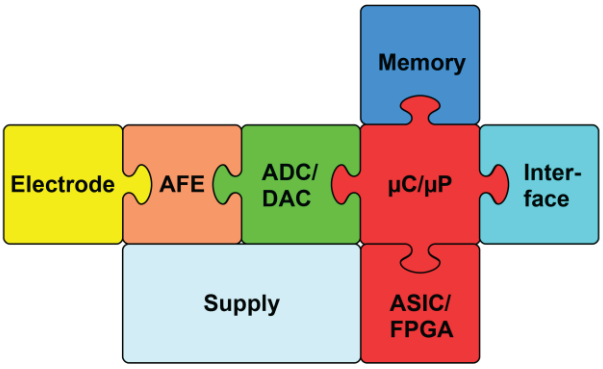


Figure 1: Illustration of the modular strucutre of a platform system

ware-components is adaptable concerning project-specific requirements. Furthermore, the platform characteristic enables a modular architecture with high-level flexibility. The integration of sensors and actors in this adaptive hardware/software-platform increases flexibility and provides a measurement and identification platform for lots of applications. Furthermore, the integration of IoT-devices, based on standard interfaces creates a toolbox that can be used in various projects. In (Klinger and Klauke, 2013), (Klinger, 2014) and (Klinger, 2015) we have presented a first modular platform focused on the acquisition of electromyogram (EMG) and electroneurogram (ENG)-signals and a data-based identification approach. The identification, basis for prosthesis control, requires specific motion data acquired by micro-electro-mechanical systems (MEMS) and mobile control skills which require mobile, smart and intelligent devices. The entire platform is presented schematically in Figure 2. This architecture covers the whole SMoBAICS-platform, including the IoT-module, providing the signal acquisition and the first-level signal processing. The current IoT-extension, designed for SMoBAICS (SMoBAICS-IoT- Device.1 (SID1)) integrates additional sensors, like pedobarographic and MEMS for specific applications. The recording and evaluation of EMG-data, for example, are also currently used in other projects (Ryser et al., 2017), (Wu et al., 2018), (Yang et al., 2018). Here, too, IoT systems represent a central architectural component or could replace parts of the existing architecture. A corresponding platform architecture, which enables better integration of components and reusability of systems, creates a modular character that allows for much more efficient prototyping. We will introduce different types of applications in section 3.

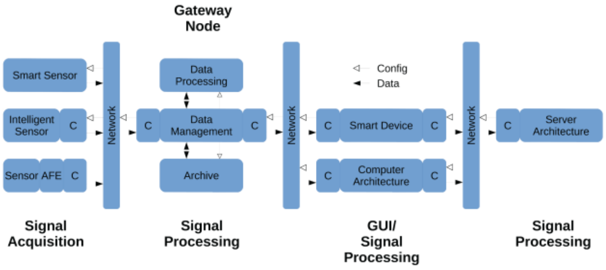


Figure 2: Hardware platform, presenting the modular und service-oriented Architecture (AFE: Analog Front-End, C: Connectivity)

2. IOT-PLATFORM

As described in (Klinger and Klauke, 2013) and (Klinger, 2014), SMoBAICS is a modular system with the objective of ENG-based motion identification and prosthesis control. Based on the acquisition of action potentials via ENG, the information of the peripheral nervous system is used to identify movement patterns. A MEMS used during the mobile operation of the prosthesis control (mobile phase (Klinger and Klauke, 2013)) and/or camera system (learning phase (Klinger and Klauke, 2013)) is necessary to get information about the movement trajectories and about plausibility. To integrate the MEMS, an IoT-module was designed to improve flexibility and to simplify the integration of different sensors using wireless connection. In this paragraph, a general concept of the SID1 is presented. The hardware platform is a system which can be used for multiple applications, is modular and can be used with different types of software. As hardware is less flexible than software and the effort and costs are much higher in terms of redesigning the hardware, the priority of the project was set on the design of a universal hardware platform, which can be used for multiple applications. Each specific application field of the device will require a dedicated software, while the hardware part will stay the same. Moreover, designing, manufacturing and storing only one type of hardware system is much more time, place and cost efficient than preparing and executing the whole process for application specific systems. In order to increase the field of applications, it was decided to split the platform (SID1) into data processing (SID1_UC) and signal acquisition (SID1_FE) parts and to develop an embedded platform with an interchangeable application specific front-end. The platform itself is an autonomous device, equipped with a microcontroller for data processing.

2.1. Machine Learning: Operation Modes

The hardware part of the project includes the partitioning between the different printed circuit board (PCB)s. The architecture of the IoT-device is realized according the platform paradigm, too. The mC-board is designed as a standalone board that can be run independently from the presence of an application specific front-end. Such an assumption forced the designer to include several components on the board. The key constraints for the design are defined by the four basic characteristics of an IoT-system (Klinger, 2016): Connectivity, processing, memory, sensor/actor integration.

1) Microcontroller-Board (SID UC CC2650): The main tasks of this component are data processing, archiving and connectivity, based on Bluetooth Low Energy (BLE). As the system's main task is data acquisition, one of the main requirements was sufficient number of analog inputs and integrated analog-digital converter. Another required feature were an integrated Bluetooth 4.1 transceiver and SPI interface. The microcontroller CC2650 (CC2650F128RGZ) of (Instruments, 2015) was chosen. On this PCB several sensors are integrated,

like a motion sensor with "wake-on-motion"-capability, MPU-9250 (InvenSense, 2014), a microphone, temperature sensor, light sensor and buzzer. Additionally, a SD-card slot is integrated for logging and archiving, and the whole infrastructure for communication (e.g. antenna) is integrated.

2) Microcontroller-board (SID_UC_ESP32): The CC2650 component, selected for the first microprocessor board offers a high level of functionality for the IoT-area and also provides a good combination of sensors in the environment used here. This module is ideal for additional scenarios (see section III) and offers both, the required connectivity and sufficient processor power for processing events and linking multiple sensor values. If the identification functionality, already described in (Klinger, 2015) is to be used in operation mode, greater processor power is required. In order to perform the necessary tests, a second mC-module with a more powerful architecture was designed, the ESP32. This offers additional interfaces for the sensor/actuator connection, e.g. a DAC is integrated. The processor performance is considerably higher, and 2 cores are available for for algorithms that require higher computational power. In addition, this module also provides WLAN functionality, extending the range of applications. Depending on the application, the uC-module SID_UC_CC2650 or the new microprocessor module SID_UC_ESP32 can be used. Figure 3 shows a qualitative comparison of the two microprocessors, related to the key parameters of IoT-systems, introduced in (Klinger, 2016).

3) FrontEnd-Board (SID FE P): The Front End (FE)-board provides the application specific sensor/actor interface, integrating filtering and signal conditioning. It delivers the measurement signal to the mC-board. Due to the platform paradigm, the IoT-system is partitioned into different boards, providing flexibility according the functional characteristics. In the current application, the front-end is used to measure the changes in resistance of the FSR sensors, described in the next paragraph. In Figures 8(a) to 8(d) (see last page), the two PCB designs, the mC-board (SID1_UC_CC2650) and the FrontEnd-board (SID1_FE_P), are shown.

4) Force Sensors: The FSR-sensors are the interface between mechanical pressure and electrical representation. They convert the change of the pressure of the foot into the change of electrical quantities.

FSR show the following advantages: Higher sensitivity than tensometric sensors, possibility of static measurements in contrary to piezoelectric sensors and finally, higher operation frequency than capacitive sensors. Moreover, a relatively low price and the small construction space are additional advantages of resistive sensors. One of the disadvantages of this type of sensors is time drift of resistance, therefore calibration functionality should be available. Using the mC-board, a zero-point calibration can be performed automatically before each use.

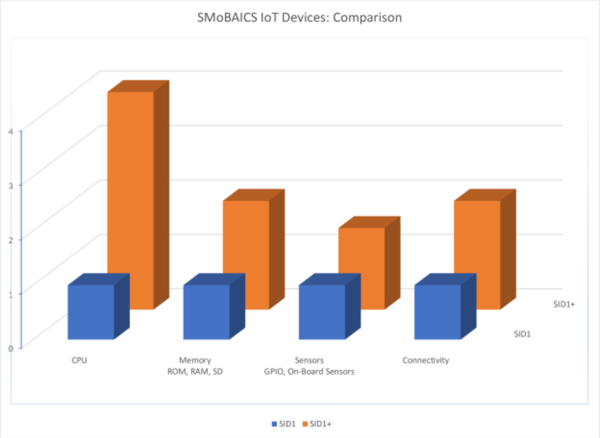


Figure 3: Qualitative comparison of SID_UC

In Figure 4 a typical FSR-sensor is shown, Figure 5 presents the positioning of the three FSR-sensors and of the SID1 sensor inside the sole.

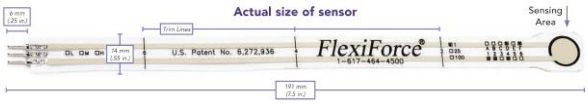


Figure 4: FSR-sensor

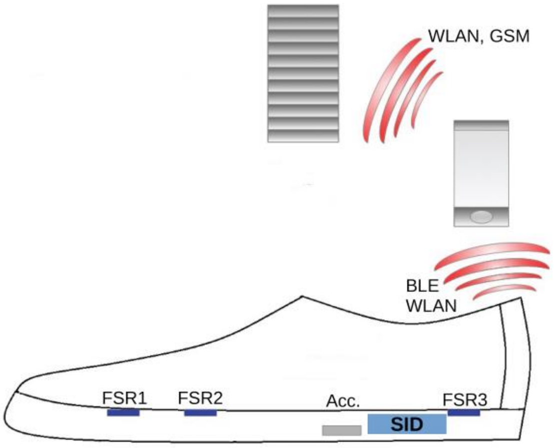


Figure 5: Learning and Operating Mode

2.2. Software

The software platform provides an operating environment, or an operating system under which other smaller applications can be executed. Regarding the platform paradigm, different types of software have to be implemented, embedded software for the mC and software for an Android smartphone to control the device.

Microcontroller-based: Embedded software is necessary for microcontroller operation, e.g. read-out from the sensors, setting the gain, DAC levels and BLE stack. Microcontroller software can be subdivided in three groups: Application software, stack software, both composed with help of an integrated development environment (IDE). CC2650 consists of two different processor cores, an Advanced RISC Machines (ARM)-

M3 (Application) and an ARM-M0, responsible for low level communication. Texas Instruments provides a framework for a double-image architecture software, to be able to update application software independently from the stack software development. The stack software provides basic host roles, like

- Broadcaster: Only advertising, no connection possible
- Observer: Cannot initiate connections
- Peripheral: Connectable advertiser, slave single-link operation
- Central: Master operation, multiple connections

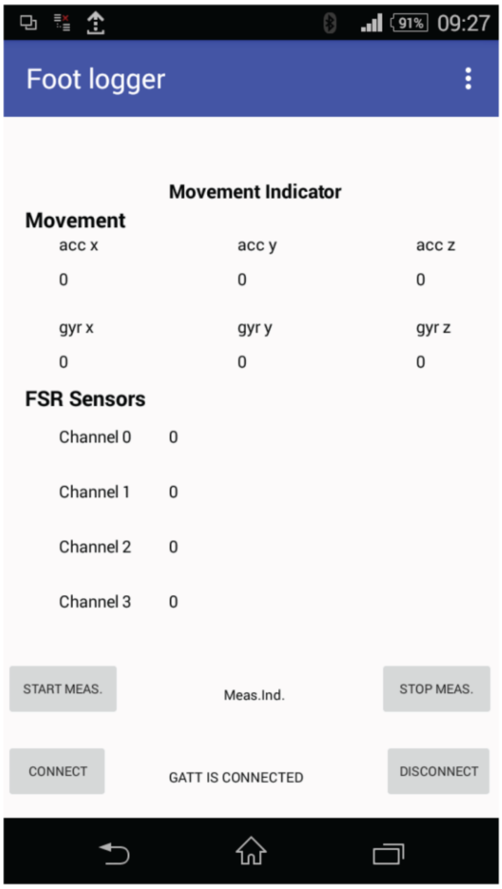
In current project, peripheral role was selected. In order to assure appropriate communication between stack and application, a special ICall framework is provided by the vendor and is a part of the application project. This framework handles the communication between both, the M3 and the M0.

The application software is running on a real time operating system (RTOS) providing services and handling of the different tasks, like BLE communication, sensor data acquisition, data processing and other ser-vices. According to the Bluetooth specification, the de-vice acts as a GATT (Generic Attribute Profile) server.

2) Android-based: A basic Android application for monitoring and configuration of SID1s was developed. The main task is to read-out the motion values from the motion sensor and the force data, provided by the FSR-sensors. Additionally, the mobile phone takes the role of a global system for mobile communications (GSM)-based emergency call device (e.g. fall detection, see Table 1). Currently the application consists of different pages, e.g. for configuration, event display and raw data terminal for debugging. The debugging page shows after initiating the connection, the current FSR values to the user. The user should enter calibration values and confirm by pressing a button. Pressing of the button results in sending updated values to the DAC and amplifiers. When the circuit is calibrated, the measurement can be switched on by enabling notifications and measurement indicator. To stop measurements, measurement indicator, as well as notification handle, switches to zero. In Figure 6 the debugging page is presented.

3. APPLICATION SCENARIOS

There are a variety of possible scenarios, based on standalone SID-IoT-modules and based on a network of these modules. Therefore, to somehow visualize the range of application, some use cases are presented in Table 1 (see last page) and in Figure 7 the positions of the IoT-modules with regard to the scenarios are shown (see column “position”).



Movement Indicator

Movement

acc x	acc y	acc z
0	0	0
gyr x	gyr y	gyr z
0	0	0

FSR Sensors

Channel 0	0
Channel 1	0
Channel 2	0
Channel 3	0

Meas.Ind.

GATT IS CONNECTED

Figure 6: Debuggung page of the Android application

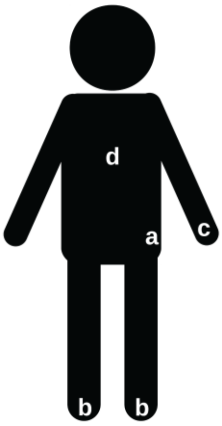


Figure 7: Learning and Operating Mode

Fall detection, (FD): According to (CDC, 2016), in USA more than 700 000 people a year are hospitalized as a result of fall injury. The motion sensor, integrated on the SID1_UC_CC2650-board, is able to detect ab-normal acceleration values in the ground direction and inform emergency department using Bluetooth and mobile phone connectivity. In addition, GPS coordinates from the smartphone can be included in the emergency message. The time of the event can be saved on the SD Card. The system operates in a low power mode until an interrupt from the motion (MPU-9250, see subsection 2.1) is triggered. When no user reaction is detected, a smartphone notification and alarm are generated.

Pedobarographic front-end (P1): After the smartphone application and platform are initialized, an automatic BLE connection is established. After it is formed, it is possible to manually input configuration data for the platform, e.g. the measurement period for foot sensors and accelerometer. Moreover, it is possible to calibrate the signal path of the force sensors: Offset, gain, filter parameters and filename. When “Initialize”-button in configuration screen is pressed, the calibration values are sent to the platform. Pressing of “Start”-button in the main screen starts acquisition of the data. Pressing “Pause” suspends the acquisition, however, does not close the file. Being in the suspend state and pressing “Pause” again leads to the data acquisition. “Stop”-button pressed any time ends the measurement procedure. Another application scenario might be a stand-alone use of the platform. The measurement results can be saved on the SD Card. The motion sensor is used to switch the system into a low power mode in case of not being used for a certain period of time. The sensor can also switch the system on in case of any movement is detected, it generates a wake-on-motion interrupt. If the values are out of range, in case of need for new calibration values, the buzzer is switched on for 5 seconds. Then, the system needs to be calibrated via Bluetooth, or one of the buttons has to be pressed for 15 seconds to download default calibration coefficients. If the calibration is successful, both LEDs are blinking. Emergency notification functionality seems to be the most promising and could be useful among all use cases. Appropriate frontends and Android software would help to improve the overall functionality.

Gait Evaluation (GE): This scenario focuses on the measurement, archiving and evaluation of pressure, shear and torsion loads on the foot. The gait evaluation helps for precaution and rehabilitation after a fracture, luxation, etc. of the lower extremities. Using this system, a static therapy plan is not necessary. It is rather possible, based on the individual circumstances of the patient, to determine the type and intensity of the phases of stress and the frequency of the resting phases at the progress of the healing process. This also makes it possible, for example, to make a detailed assessment of the rehabilitation progress in relation to the static and dynamic loads and the corresponding accumulated load. This local system enables, in contrast to the fixed system base plate or to alternative camera-supported measuring systems, a mobile application of the system.

The sensors can be used to measure the load data and the local intelligence can also be used for online evaluation and archiving. The feedback about the load case or an achieved limit load can be displayed in the Android App. The simplest case can be an acoustic or optical alarm. In addition, the connection of the embedded system via BLE with a so-called Smart Device, is possible. This connection can be used for data exchange, system configuration and display of current or historical data. Since this is a standard interface, almost any systems can be used as Smart Devices. This also means that the communication path to the attending physician, who can adapt the therapy in knowledge of the data or specific events.

4. SUMMARY AND FURTHER WORK

The implementation of prosthesis control based on ENG-signals, requires the integration of sensors into the overall system. It is helpful to define a hardware-/software-platform that is not only flexible, but also has great expansion potential and good integration capabilities for additional systems and devices, such as sensors and actuators.

In this paper, such additional devices were presented that use standard interfaces based on the IoT-concept in order to integrate a specific additional function into the system. These are already two mC-modules with different characteristics and a front-end system that enables the connection a variety of FSR sensors. On the basis of this IoT-platform architecture, a large number of applications were presented, and examples were given of how the required functionality for the corresponding application can be achieved with the help of these IoT-devices. The paradigm of platform-based architecture that underlies the approach presented here, provides great flexibility in the acquisition and data-based identification of measured values. The focus on biotechnological applications, especially the focus on EMG- and ENG-signals, enables a multitude of applications in research, therapy and rehabilitation. The design of a second microprocessor module was necessary in order to implement new experiments that will enable identification during mobile operation of the prosthesis control. The new mC-IoT-device can be used to replace the CC2650-based variant.

The further work has the following key aspects:

- The peer-to-peer Bluetooth communication has to be replaced by the new mesh functionality of BLE. It allows an even better integration of additional IoT-systems into a so-called body area network (BAN), corresponding to wireless personal area network (WPAN), a wireless LAN protocol.
- Ongoing tests to improve the sensor fusion and to verify additional use cases based on the platform architecture.
- Comparison of different implementations of a local identification method, running on the SMoBAICS-IoTDevice.1 with enhanced performance (SID1+). Analyzation of the power consumption and optimization characteristics, compared to a hardware-based optimization algorithm (Klinger, 2018), should help to pro-vide a better analyzation in the ENG-based motion detection using mobile identification.

(a) SID1_UC_CC2650 (Front)

(b) μC-modul (SID1_UC_CC2650, Back)

(c) FronEnd-modul (SID1_FE_P, Front)

(d) FrontEnd-modul (SID1_FE_P, Back)

Figure 8: SMoBAICS-IoT-Device.1

Table 1: APPLICATION SCENARIOS

Use Case	ID	Sensor	#Systems	Position in Fig. 7	Android Support	#IO Analog (A) Digital (D)	Description
Fall detection	FD	Motion	1	a	+	-	System detects fall (motion sensor) and sends a notification to a smartphone to trigger an emergency call.
Pedobarography	P1	Pedobarographic	2	b	+	A: 4, D: 8	Acquisition of values of pressures in 3 or 4 points on the feet. Controlled by an Android application.
Pedobarography	P2	Pedobarographic	2	b	-	A: 4, D: 8	As above, but no Android control – results saved on SD Card
Gait Evaluation	GE	Pedobarographic	3	b, a	+	A: 4, D: 8	Acquisition of values of pressures in 3 or 4 points on the feet. Additional motion sensor attached to the belt, providing sensor fusion and gait evaluation. Controlled by an Android application
Interval running	IR	Heart-rate (HR), Pedobarography	3	b, c	+	A: 5, D: 10	System monitors heart-rate of the runner and the time of intervals
Sleep monitoring	SM	Microphone	1	c	+	A: 2, D: 1	For patients with sleep disorders – snoring, bruxism monitoring
Life activity monitoring	LAM	HR + ECG + Blood Pressure + Glucose + Breath	4	a, b, c, d	+	A: 8, D: 10	Live monitoring of life activities and emergency notifications
Prosthesis Control System	PCS	MEMS + Pedobarographic	4	b, c, d	+	A: NN, D: NN	Movement identification and prosthesis control

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